U.S. Department of
Transportation

**Federal Railroad
Administration**

A Comparative Risk Assessment of Remote Control Locomotive Operations versus Conventional Yard Switching Operations

Office of Research
and Development
Washington, DC 20590

DOT/FRA/ORD-06/09

Final Report
May 2006

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE May 2006	3. REPORT TYPE AND DATES COVERED Final Report January 2002–February 2005

4. TITLE AND SUBTITLE
A Comparative Risk Assessment of Remote Control Locomotive Operations versus Conventional Yard Switching Operations

5. FUNDING NUMBERS

6. AUTHOR(S)
Stephen Reinach, Steven Fadden[1], Frederick Gamst[2], Sarah Acton, and Simon Bartlett[1]

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Foster-Miller, Inc.
350 Second Avenue
Waltham, MA 02451-1196

8. PERFORMING ORGANIZATION REPORT NUMBER
DFRA.020175.007

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-06/09

11. SUPPLEMENTARY NOTES 1 Booz Allen Hamilton 2 Consultant to Foster-Miller, Inc.

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 a comparative risk assessment of U.S. remote control locomotive (RCL) and conventional yard switching operations. First, a hierarchical task analysis (HTA) was conducted to provide a detailed description of yard switching tasks. Based on the HTA results, a preliminary hazard analysis (PHA) and human reliability assessment (HRA) were performed. For each method of switching operation, the PHA identified a worst credible scenario for 19 potential outcomes. Each scenario was assigned a risk score based on an assessment of the likelihood of occurrence and potential severity. The HRA consisted of two complementary techniques: the Human Error Assessment and Reduction Technique (HEART) and Absolute Probability Judgment (APJ). A set of yard operating scenarios was developed to provide the basis for the HEART and APJ assessments. Analysis of PHA variables indicated that the 19 RCL worst credible scenarios yielded higher risk scores compared to similar conventional worst credible scenarios. The HEART assessment did not reveal any differences between the two methods of operation in terms of human error probabilities (HEP). Substantial variability existed in HEP assignments between HEART assessors, suggesting that HEART may be inappropriate as an HRA technique for the railroad yard switching environment. Fourteen railroad operating employees participated in four APJ assessments. While individual HEP values varied across a large range, the patterns in the data show a trend toward greater HEP for RCL scenarios. The HEART and APJ data, however, should be considered preliminary and interpreted with caution, due to the study's subjective nature, numerous study limitations, and methodological challenges. These limitations and challenges are discussed.

14. SUBJECT TERMS
Remote control locomotive operations, portable locomotive control, railroad safety, remote control device, risk assessment, human reliability

15. NUMBER OF PAGES
201

16. PRICE CODE

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

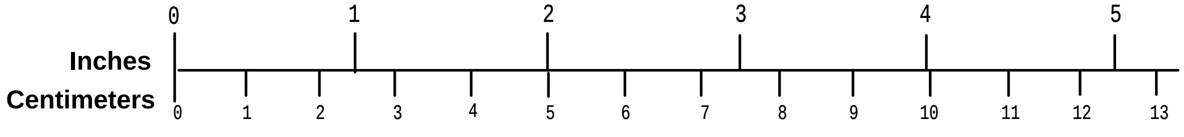
NSN 7540-01-280-5500

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

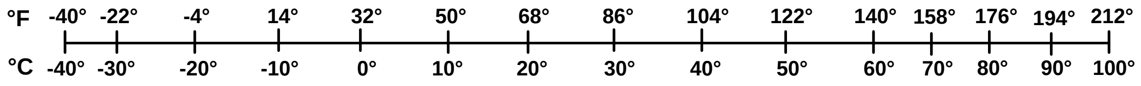
METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC	METRIC TO ENGLISH
LENGTH (APPROXIMATE)	**LENGTH** (APPROXIMATE)
1 inch (in) = 2.5 centimeters (cm)	1 millimeter (mm) = 0.04 inch (in)
1 foot (ft) = 30 centimeters (cm)	1 centimeter (cm) = 0.4 inch (in)
1 yard (yd) = 0.9 meter (m)	1 meter (m) = 3.3 feet (ft)
1 mile (mi) = 1.6 kilometers (km)	1 meter (m) = 1.1 yards (yd)
	1 kilometer (km) = 0.6 mile (mi)
AREA (APPROXIMATE)	**AREA** (APPROXIMATE)
1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)	1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)	1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)	1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)	10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres
1 acre = 0.4 hectare (he) = 4,000 square meters (m^2)	
MASS - WEIGHT (APPROXIMATE)	**MASS - WEIGHT** (APPROXIMATE)
1 ounce (oz) = 28 grams (gm)	1 gram (gm) = 0.036 ounce (oz)
1 pound (lb) = 0.45 kilogram (kg)	1 kilogram (kg) = 2.2 pounds (lb)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)	1 tonne (t) = 1,000 kilograms (kg)
	= 1.1 short tons
VOLUME (APPROXIMATE)	**VOLUME** (APPROXIMATE)
1 teaspoon (tsp) = 5 milliliters (ml)	1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 tablespoon (tbsp) = 15 milliliters (ml)	1 liter (l) = 2.1 pints (pt)
1 fluid ounce (fl oz) = 30 milliliters (ml)	1 liter (l) = 1.06 quarts (qt)
1 cup (c) = 0.24 liter (l)	1 liter (l) = 0.26 gallon (gal)
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 meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)	1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)
TEMPERATURE (EXACT)	**TEMPERATURE** (EXACT)
[(x-32)(5/9)] °F = y °C	[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION



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

Contents

Illustrations

Tables

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 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 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 Federal Railroad Administration (FRA)-certified RCOs, although a small minority of RCOs are also FRA-certified locomotive engineers who have experience operating a locomotive. Switchmen were never traditionally trained to operate a locomotive.

FRA's Office of Research and Development Human Factors Program and FRA's Office of Safety initiated a multi-study RCL operations research program in early 2002, just as RCL operations began on a large scale in the United States, to ensure RCL operations were as safe as possible. FRA sponsored three separate studies: a comparative risk assessment of RCL and conventional yard switching operations, a root cause analysis (RCA) of RCL-involved train accidents/incidents, and focus groups with RCOs. This report presents the results from the comparative risk assessment of RCL and conventional yard switching operations. FRA's Office of Research and Development Human Factors Program and FRA's Office of Safety sponsored this research under Contract DTFR53-01-D-00029.

The risk assessment was unable to address all types of risks associated with RCL and conventional yard switching operations. This limitation is due to the following: (1) tremendous diversity exists in railroad yard switching operations across the United States; (2) RCL operations were relatively new when the study was conducted, and operating practices, procedures, and rules are continually being updated; and (3) only a fraction of all yard switching scenarios and tasks could be assessed. Furthermore, given the inherent limitations in the risk assessment methodologies available (for instance the lack of existing railroad operator reliability data to draw from), results of the risk assessment should be interpreted with caution. This study addresses a particular subset of RCL operations, and its findings are only applicable to these operations and their conventional counterparts. Results from this study, therefore, should not be generalized to all RCL applications.

The study originally focused on conducting a full probabilistic risk assessment (PRA) that was to include estimates of human reliability, as well as estimates of mechanical and electrical reliabilities associated with each method of operation. However, the study team was unable to obtain RCL equipment reliability data from RCL suppliers. Due to the lack of access to RCL equipment reliability data and since locomotive and track reliability was expected to be both very high and the same between the two methods of switching operation, the study team changed the focus from a full probabilistic risk assessment to a more specific human reliability assessment (HRA) of each method of operation.

Risk was assessed in terms of potential harm to either railroad operating employees and/or railroad property and equipment. This study does not address potential harm to the general public (for example, to motorists at public grade-crossings) and operational delays. Furthermore, RCO exposure to electromagnetic radiation as a result of RCL operations was not examined. This study did not include distributed power, although it is a form of remotely controlled locomotive operation, since this is considered a separate type of operation from RCL operations, even though both share some of the same mechanical and electrical components and principles of operation.

Generally, risk assessment, including HRA and PRA, should be part of a larger organizational safety assessment to evaluate active and latent system risk factors and conditions. Active risk factors are those conditions, decisions, or other aspects in a system that are closest in time and physical space to a known failure or accident/incident. These may include a poor decision by an RCO or a broken rail. On the other hand, latent risk factors or conditions exist at higher levels of an organization, including front-line supervision, upper management, and the senior executive level, and may exist for years before a failure or accident/incident occurs. These may include senior management decisions regarding deferment of resources or hiring freezes that result in reduced staffing levels years later. Typically, some combination of active and latent risk factors contributes to a system failure and subsequent accident/incident. Put another way, accidents/incidents do not result from one risk factor or are caused solely by one event; rather, multiple risk factors, including active and latent risk factors, play a role in every mishap or accident/incident. Traditional risk assessments generally focus on active risk factors, however, and only implicitly address the latent risk factors and conditions. In this vein, since this study is based on traditional risk assessment approaches, it focuses on potential errors and conditions immediately preceding yard switching accidents/incidents (i.e., active risk factors). The study does not explicitly address the supervisory or organizationally-based policies, procedures, oversight, and activities (latent risk factors) that permit or contribute to these errors nor the preconditions for the unsafe operator acts, other than as performance shaping factors. These latent risk factors are equally important to study to better understand the risks of each method of operation.

Ideally a variety of approaches is used in an organizational safety assessment to address active and latent risk factors across a system and throughout the entire lifecycle of the system. These may include proactive risk assessment methods to identify active risk factors before a system goes online, ongoing risk assessment methods to study possible negative effects of upgrades and changes to a system, as well as RCAs of accidents/incidents that occur to identify and eliminate active and latent risk factors that contributed to the accident/incident. In fact, risk assessment and RCA may be viewed as two sides of the same coin. Whereas risk assessment tries to identify risk factors before an accident/incident occurs, RCA identifies risk factors after an accident/incident occurs. Given their different methodologies and advantages, each is valuable as part of an overall organizational safety assessment.

Acknowledgments

This report summarizes a comparative risk assessment of RCL and conventional yard switching operations. FRA Office of Research and Development Human Factors Program and FRA Office of Safety sponsored this research under Contract DTFR53-01-D-00029.

The authors would like to express thanks to a number of people who made this study possible. First, thanks to Dr. Thomas Raslear, FRA Office of Research and Development, and Mr. John Conklin, FRA Office of Safety, for sponsoring and supporting this research and answering a myriad of technical questions throughout the project.

The authors would also like to thank Mr. Tom Griego, Dr. Peter Katsumata, and Ms. Mandy Cohen, Booz Allen Hamilton, for assisting in the early stages of the study.

Given that RCL operations were new when the study began, little was publicly known or published about RCL operations. Consequently, stakeholders were identified to help the research team learn more about RCL operations and facilitate data collection during the study. Stakeholders included FRA, RCL equipment suppliers, labor unions and railroads. Representatives from these stakeholder groups were called on at various times during the project to provide information, facilitate site visits, and recruit research participants. In particular, the study team would like to thank the following individuals and their organizations:

- Mr. Larry Breeden, Union Pacific Railroad, Mr. John Drake, CSX Transportation, Mr. Charles Lynch, Florida East Coast Railroad, and Mr. Brent Brewer, Vermont Railway, for providing the study team opportunities to visit their railroad yards to talk with RCOs and observe RCL and conventional switching operations under a range of conditions and scenarios.
- Mr. Rick Marceau, United Transportation Union (UTU), and Mr. Robert Harvey, Brotherhood of Locomotive Engineers and Trainmen (BLET), for helping to identify candidate locations for the pilot and main (HRA) studies and for facilitating the recruitment of research participants.
- Mr. Bob Aiken, Cattron-Theimeg, Inc., and Mr. Bernie Maskerine, Beltpack Corporation (formerly CANAC), for hosting study team members at their facilities and providing the study team an opportunity to learn more about their RCL technologies.

In addition, the team would like to acknowledge and thank each of the aforementioned individuals and organizations for providing the team with instructional manuals, rule books, and other RCL-related materials.

Lastly, thanks to each of the BLET and UTU members who participated in the HRA study by lending their experiences to the assessment of RCL and conventional methods of yard switching operations.

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 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 (RCL), (2) an onboard control computer (OCC) that interfaces with the locomotive's controls (and is 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, and controls the RCL through inputs to the RCD.

Although the technology has been around for decades, largely in industrial plants and mines, 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. However, 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 for railroads to report the involvement of RCLs and RCOs in train accidents/incidents (effective May 01, 2003), this data collection process will require several years before ample 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 RCL operations research program 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, a root cause analysis (RCA) of RCL-involved train accidents/incidents, and focus groups with RCOs. This report presents the results from the comparative risk assessment of RCL and conventional yard switching operations.

The objectives of this research study were to select one or more operationally relevant and suitable risk assessment technique(s), apply these technique(s) to both RCL operations and conventional yard switching operations, and evaluate the relative safety of RCL operations compared to conventional yard switching operations. These objectives were designed to provide FRA with a better understanding of RCL operations in general and of the relative safety of RCL operations compared to conventional yard switching operations which RCL operations are beginning to replace.

Risk may be defined as the product of the likelihood of a system failure multiplied by the consequence of the failure. System failure and its consequences depend on a number of factors, some of which are mechanical and electrical, and others of which are human-centered. The study originally focused on conducting a system-level probabilistic risk assessment (PRA) that was to include estimates of human reliability, as well as mechanical and electrical reliabilities associated with both methods of yard switching operation. However, the study team was unable to obtain RCL equipment reliability data from RCL suppliers, making estimates of hardware reliability associated with the RCL equipment unfeasible. Consequently, the study's focus changed from a system-level probabilistic risk assessment to a human reliability assessment (HRA) of potential operator errors and reliability associated with each method of operation. It was assumed that any failures associated with the RCL equipment, locomotive equipment, or track structures would be built into operator reliability estimates since the operators—RCOs and conventional yard switching crews—interact with the equipment and track to carry out their tasks. Furthermore, it was expected that locomotive equipment and track structure reliability would be high to begin with and would be the same between the two methods of operation.

Given the myriad tasks and dynamic environment of railroad yard switching, it became apparent that no one approach to HRA would adequately identify the potential risks of railroad yard switching operations. Furthermore, since RCL operations were new, insufficient quantitative accident/incident data were available to support certain HRA techniques. Human error rate data tables have been created for other complex engineering systems, such as nuclear power plants, but these process-oriented systems do not have much overlap with the tasks involved in RCL operations.

Consequently, a multi-pronged strategy was developed that employed several complementary methods and HRA techniques. The multi-pronged approach included the following.

1. Conduct of a hierarchical task analysis (HTA) to delineate the specific tasks involved in RCL and conventional yard switching operations.
2. Conduct of a preliminary hazard analysis (PHA) to assess the overall risk of each method of yard switching operation.
3. Conduct of an HRA to generate operator reliability estimates associated with each method of operation.

The HTA provided a common reference and task-based framework to assess RCL and conventional yard switching operations, while the PHA and HRA provided quantitative and complementary approaches to compare the risks of each method of operation. Operator reliability is also referred to as human error probability (HEP) since human error is quantified as a probability (likelihood of an error). Operator reliability, thus, refers to the likelihood of an error occurring.

Since RCL operations were new when this study began in early 2002, very little was publicly known about RCL operations at the time. Consequently, two ancillary activities were carried out to obtain a better understanding of some of the potential safety issues that may be encountered in RCL operations. The first activity was an analysis on Mine Safety and Health Administration (MSHA) mine fatalities involving remotely controlled equipment (RCE) from January 1995 through March 2002. The analysis provided an analogous reference point for the more general study of remote controlled operations and aided the study team in better understanding some of the potential risks associated with RCL operations. The second activity was the generation of a catalog of potential hazards and sources of operator error associated with RCL operations. The catalog was based on self-reported narratives from RCOs and other railroad yard operating employees. These two activities provided some early insights into, and background information on, some of the potential safety issues and hazards associated with RCL operations. These data were used to inform the study team and were not explicitly used in the risk assessment.

To provide a foundation for the PHA and HRA, an HTA was conducted to provide a systematic description of yard switching tasks. The HTA enabled both methods of yard switching operations to be captured in an efficient manner. First, applicable yard switching tasks involving classifying inbound trains and building new outbound trains were identified. Next, an HTA was produced. The HTA consists of a set of hierarchical tasks and a plan that describes the relationships among tasks. The HTA was also modified by the addition of a third component—a breakdown of task activity by crewmember according to each method of operation. The breakdown of activities according to crewmember was required due to the team-based nature of yard switching. This breakdown of tasks into their subtasks allowed the study team to capture some of the communication and coordination activities among crewmembers and allowed for the capture of specific crewmember activities in carrying out a particular task.

Study Assumptions and Limitations

Assessment of every aspect of RCL and conventional yard operations was not feasible, so the following set of assumptions and study limitations was developed to help bound the study:

- Failures associated with the RCL, locomotive equipment, or track structure were assumed in operator reliability estimates.
- The study did not address exposure to electromagnetic radiation associated with wearing an RCD.
- The study did not address risks associated with distributed power. Distributed power, although it is technically a form of remote control (the locomotive engineer controls locomotives placed in the middle and/or rear of the train from his/her console at the head end of the train), is separate from, and bears few similarities to, RCL operations.
- The study did not address ergonomic issues related to wearing the RCD except as they affect RCO operational performance.
- The study addressed only outcomes that result in injury (including fatality) and property damage (e.g., train accident).
- The study did not address risks to the public (e.g., at public grade-crossings or trespassers) nor risks associated with operational delays.
- The study addressed only errors and conditions immediately preceding an accident/incident. The study did not address latent supervisory or organizationally based policies, procedures, oversight, conditions, and activities that permit or contribute to risk nor the preconditions that may contribute to risk and accidents/incidents.
- The study addressed only yard switching operations; it did not address RCL or conventional operations on main tracks, spur/industrial tracks, or sidings.
- Each method of operation was associated with only one crew configuration—a two-person RCO crew and a three-person conventional yard switching crew. The study did not address other crew configurations and their potential for different risks.
- The study addressed only initiating events that are considered human error in nature. The study did not address initiating events that are mechanical failures and acts of nature.

PHA Methods

A PHA was conducted to assess the overall risk of each method of operation. The PHA identified different outcome types (e.g., collision) and generated an assessment of risk for two types of scenarios: a worst credible scenario and most likely scenario. Risk was based on evaluating the likelihood of occurrence and the potential severity for each scenario. The PHA was used to assess the global risks of RCL and conventional yard operations, and it was intended to be a first-pass tool to prioritize which RCL and conventional operating scenarios or moves should be further investigated using HRA techniques.

The PHA involved all research team members. First, 19 general outcome types that were applicable to both RCL and conventional yard switching operations were identified. Outcome types included collisions, derailments, excessive slack, hard coupling, unexpected movements, and slips/trips/falls. To assess the relative risks associated with the 19 outcomes for each method of operation, the team generated two sets of scenarios to represent or illustrate each outcome type, including a worst credible scenario and a most likely scenario. Each scenario consisted of an initiating event (e.g., failure to protect the point), a sequence of events, and the specified outcome (e.g., RCL hits own crewmember). After scenarios were generated, the team assessed the risk of each scenario for each method of operation by evaluating and assigning a numeric rating of the likelihood of occurrence and the anticipated severity of the outcome. Severity ratings ranged from 1 (negligible) to 4 (catastrophic), and likelihood of occurrence ratings ranged from 1 (nearly impossible) to 6 (frequent). If the severity was expected to be less than negligible, it was assigned a value of 0. A score was then computed for each scenario by multiplying the values associated with the severity and likelihood of occurrence ratings. Thus scores could range from 0-24.

HRA Methods

After evaluating the applicability of several HRA methods, the research team selected the Human Error Assessment and Reduction Technique (HEART). Originally developed as a less complex and research-intensive technique for the process control industry, HEART is an economical and flexible technique that can be adopted for use in domains that involve human operators performing tasks under different kinds of conditions. HEART was also developed for use by practitioners who do not have extensive training and experience in the technique. A significant benefit of HEART is that the HEP values are already provided in the methodology so the subject matter expert (SME) assessor (e.g., an RCO or other yard operating employee) does not have to generate reliability estimates on his/her own.

The HEART process consists of an iterative procedure where an SME assessor examines a railroad yard scenario to identify the general type of task being performed, along with the conditions that may influence performance in the specific scenario. The HEART process consists of the following steps:

1. Review description of the scenario to be evaluated.
2. Identify one predefined Generic Task Type (GTT) that best approximates the task described in the scenario.
3. Identify error producing conditions (EPCs) (also referred to as performance shaping factors) (PSFs) that influence task performance in the scenario.

4. Assign an assessed proportion of affect (APOA) associated with each EPC to indicate if the EPC has a small or large influence on task performance in the scenario.
5. Calculate the final HEP. After the GTT, EPCs, and APOA have been identified, an HEP can be readily calculated using a straightforward calculation.

Applying HEART to the assessment of railroad yard operations enabled the study team to produce HEPs for conventional and RCL operations based on established human performance data without requiring a significant amount of time, resources, or training. However, HEART does not represent an infallible technique for arriving at HEPs. The criticisms and limitations of the technique warranted the adoption of an additional, complementary approach to estimate HEPs. The assessment team selected Absolute Probability Judgment (APJ) as a second assessment method.

Unlike HEART, APJ does not require the selection of predefined task types (GTTs) and the identification of EPCs that are mathematically combined to arrive at an HEP. Instead, APJ relies on SMEs to generate HEP estimates based on their personal experiences and expertise in the domain. The premise behind APJ is that, absent an objective human reliability (i.e., HEP) database, the next best database is the one contained within the minds of SMEs.

The APJ process consists of a series of steps that are iteratively performed to elicit HEPs from SME assessors. Because APJ relies on subjective recollections and assessments, APJ sessions were performed with multiple SMEs who could compare their experiences and discuss their decisionmaking processes in a group setting. The specific steps for the APJ include the following:

1. Review description of the scenario to be evaluated.
2. Consult a probability chart to help determine the most likely frequency of occurrence of a human error (i.e., HEP) in the scenario.
3. Record the HEP on a data response sheet.
4. Moderate the discussion of participants' decisionmaking processes and factors that were considered in developing their estimates.
5. Conduct a Delphi discussion group, anonymously revealing the HEPs that participants selected so each participant can see the range in the data.
6. Give participants an opportunity to revise their HEP estimates based on the discussion.

PHA scenarios associated with the greatest risk provided the basis for the development of the HEART and APJ operating scenarios to be assessed. Based on the results of the PHA, 11 sets of scenarios were developed to capture moves that could be performed under either conventional or RCL operations. Scenarios include a variety of PSFs that could contribute to, or degrade, the reliability associated with the system being assessed. For each set, one scenario was developed to be evaluated in the context of a conventional yard switching operation, and a second, almost identical, scenario was developed to be evaluated in the context of an RCL operation. Differences between the two scenarios in each set were due only to operational differences (e.g., the presence of a locomotive engineer for a conventional crew and the absence of one in an RCL crew). Otherwise, the PSFs that were included in each scenario were the same within each set.

Following a pilot study to evaluate the feasibility of each HRA method and to provide an opportunity to modify and streamline both methods, the HEART and APJ exercises were conducted at two locations—a large city in the southern United States (location A) and a large city in the midwestern United States (location B)—to include multiple SME participants with experience in different yard environments under a variety of operating procedures and environmental characteristics.

The HEART assessments comprised a within-subjects design, with one individual participating in the HEART evaluation at each location (for a total of two participants). Each participant evaluated the RCL and the conventional scenarios. The APJ assessments comprised a between-subjects design, with two groups of participants (one conventional, one RCL) participating at each location (for a total of four groups). A total of 14 individuals participated in the APJ assessment, with seven participants assessing RCL operations and another seven participants assessing conventional yard switching operations.

PHA Findings

The PHA provided a simple means of evaluating the relative risk of RCL and conventional yard operations by comparing the sum of the risk ratings for the worst credible scenarios for the 19 outcomes that were identified for each method of operation. The 19 RCL worst credible scenarios yielded a total risk score of 197 compared to 143 for the 19 worst credible conventional scenarios. This difference was statistically significant. Examination of the average and median values for each method of operation for the worst credible scenarios also revealed greater relative risk for RCL operations. The average rating for worst credible scenario for RCL operations was 10.4 compared to 7.5 for conventional worst credible scenario. The median value for RCL worst credible scenarios was 12 compared to 6 for conventional worst credible scenarios. Lastly, pair-wise comparisons for each of the 19 worst credible scenarios indicate that RCL scenarios had greater risk for 6 worst credible scenarios, conventional scenarios had greater risk for 1 scenario, and risk ratings were equal for each method of operation for 6 scenarios.

These findings suggest that, at least in terms of risk associated with worst credible scenarios, RCL operations are associated with greater risk compared to conventional operations. Given the subjectivity of the assessment and the inherent subject matter knowledge limitations of the assessors (the study team), however, additional interpretations of the PHA data are not recommended.

HRA Findings: HEART

Order of magnitude (OOM) was used as a practical measure of agreement or difference in the HEART and APJ assessments. If two HEPs fell within 1 OOM, they were considered roughly equal or in agreement, while HEPs that were more than 1 OOM apart suggest a difference. The HEART assessment revealed no overall difference in HEPs between the two methods of operation. Analysis of the first HEART participant's data (location A) indicated that four conventional scenarios were associated with a HEP that was at least 1 OOM greater than the RCL counterpart, three RCL scenarios were associated with greater HEP than their conventional counterpart, and three scenarios where no difference existed (i.e., the HEPs for each scenario set were within 1 OOM of each other). Data were missing for one scenario for the participant from location A; thus only 10 of the 11 scenarios could be formally assessed using HEART.

Analysis of the second HEART participant's data (location B) show a similar trend: four conventional scenarios were associated with HEPs that are at least 1 OOM greater than their

RCL counterpart, three RCL scenarios are associated with HEPs that are greater than their conventional counterpart, and four scenarios where no difference existed (see Table 1). Thus, HEPs generated by both HEART participants resulted in a nearly equal number of cases where RCL was seen to be worse than conventional, conventional was worse than RCL, and where the two types of operation yielded no difference.

Table 1. HEART results

	HEART participant	
	A	B
Number of RCL scenarios associated with an HEP 1 OOM or more than equivalent conventional scenario	3	4
Number of conventional scenarios associated with an HEP 1 OOM or more than equivalent RCL scenario	4	3
Number of RCL and conventional scenarios with HEPs within 1 OOM of each other (i.e., no difference)	3	4

It is possible that RCL and conventional operations are both associated with some risks resulting in greater HEP for one type of operation over the other, depending on the scenario. However, the more likely explanation for the HEART results is that the HEART method is insufficient, insensitive, or invalid as a technique for comparing human reliability in railroad yard operations as deployed in this study. Additional analyses of the HEART data suggest significant variability between the two participants regarding the selection of GTT and EPC for the different scenarios. The substantial number of differences between participants' data suggests that the participants' understanding of the scenarios—and how the GTTs and EPCs applied to them—was inconsistent, leading to inconsistent HEPs. Due to the amount and degree of variability in HEPs across many of the scenarios, therefore, it is prudent to interpret the HEART results with caution. Participants appeared to be poorly calibrated to one another, either as a result of insufficient training on HEART, poor understanding of the scenarios, or a lack of fit between the HEART method and railroad yard operations. It is also possible that two assessors are simply too few to yield consistent results, and with a greater number of HEART participants, greater consistency may emerge among scenario assessments. Typically, HEART is used with only one assessor. Regardless, at best, HEART results appear inconclusive, and at worst, HEART results suggest that the method may be insensitive or otherwise inappropriate for the assessment of railroad yard operations.

HRA Findings: APJ

The time required to brief APJ participants and conduct the initial scenarios was greater than expected; consequently, participants were able to complete assessments of only 7 of the 11 scenarios that were developed for the study. Analysis of individual APJ HEP values within each location reveals that, while individual HEP values vary across a large range, the patterns in the data are consistent with a trend toward greater HEP for RCL scenarios than conventional scenarios. Using the 1 OOM criterion for location A data, six RCL scenarios were associated with higher HEPs than their conventional counterparts, while only one conventional scenario was rated as higher than its RCL counterpart. For location B data, all seven RCL scenarios had higher HEPs associated with them than their conventional counterparts.

A second analysis compared location A conventional operations scenario HEPs to location B RCL operations scenario HEPs. The analysis revealed a similar pattern as above, with six RCL scenarios associated with greater HEPs than their conventional counterparts and one scenario where no difference existed between methods of operation. However, when comparing HEPs between location B conventional operations scenario HEPs and location A RCL operations scenario HEPs, four scenarios showed no difference in HEP ratings (see Table 2).

Table 2. APJ results

	Comparison			
	A RCL–A CONV	**B RCL–B CONV**	**A CONV–B RCL**	**A RCL–B CONV**
Number of RCL scenarios associated with an HEP 1 OOM or more than equivalent conventional scenario	6	7	6	2
Number of conventional scenarios associated with a HEP 1 OOM or more than equivalent RCL scenario	1	0	0	1
Number of RCL and conventional scenarios with HEPs within 1 OOM of each other (i.e., no difference)	0	0	1	4

Though the data support a potential trend toward higher HEPs for RCL scenarios, additional analysis of the HEPs generated for each scenario within each method of operation showed considerable variability. For a given scenario within a particular method of operation, participants often assigned a range of HEPs, suggesting a considerable degree of variability among participants.

Despite the variability and disagreement in the HEP values, overall the APJ data indicate a trend toward greater HEP, and thus risk, for the RCL scenarios compared to the same conventional scenarios.

Overall Conclusions

RCL operations were associated with somewhat greater risk ratings and HEPs based on the PHA and APJ assessments, compared to conventional yard switching operations. However, these data should be considered preliminary due to their subjective and comparative nature, as well as the numerous methodological challenges and limitations associated with the methods used and the recent implementation of the technology and operations assessed. More research is needed to understand and quantify the risks associated with each method of yard switching operation.

Some of the methodological challenges that were experienced in the conduct of this study included the following:

- Specific human reliability data for either method of yard switching operations did not exist at the time of the study to support an HRA of yard switching operations.
- RCL operations (historical) accident/incident data did not exist at the time of the study to support generation of HEP data.

- Due to the recent implementation of RCL operations, RCOs had minimal RCL operations experience to help in assessing human reliability.
- HRA techniques have been designed and developed for other-than-railroad industries, and many of these have little similarity to the railroad operating environment.
- At the time the study was conducted and data collected, no HRA technique had been developed *explicitly* for the railroad operating environment. The United Kingdom is currently validating an HRA method that was recently developed for some U.K. railroad operating environments, though yard switching operations is not explicitly covered by the method.
- The railroad yard is a highly dynamic, highly variable, complex, open-loop operating environment. Tremendous variation exists across all railroad yard switching methods in terms of yard layout, grade, equipment used, operating rules, the number of crewmembers, and number of jobs working at one time. Since railroad yard switching operations are so highly dynamic with many variables in play at any one time, the risk assessment covered only a small subset of all possible yard operating scenarios.

Lastly, to address this need for additional research, a number of research studies were identified to improve future HRA studies of the railroad industry. Research studies focus on two primary areas: production of railroad-specific HEP data and development of railroad-relevant HRA techniques. Specific suggested studies include the following:

- Conduct failure modes, effects, and criticality analysis (FMECA) of RCL operations.
- Develop an HEP database for yard switching operations.
- Modify HEART for railroad yard switching operations.
- Refine the APJ approach for railroad yard switching operations.
- Develop nonpunitive incident reporting system.

1. Introduction

This report describes the results of the comparative risk assessment that examined conventional yard switching operations relative to RCL operations. Section 1 provides an introduction to the study. Section 1.1 provides a background to the study; in particular, it describes railroad yard switching, RCL operations, and risk assessment. Section 1.2 presents the study's objectives. Section 1.3 discusses the study's scope and limitations. Section 1.4 describes the overall approach used in the risk assessment. Section 1.5 explains the report's organization.

1.1 Background

Section 1 is divided into three sections. Section 1.1.1 describes railroad yard switching operations and activities, Section 1.1.2 provides the background to the introduction and implementation of RCL operations in the United States, and Section 1.1.3 presents an overview of risk assessment to provide a methodological context for the study.

1.1.1 Railroad Yard Switching

Reinach and Gertler (2001) provide a thorough discussion of the function of and activities within railroad yards in the United States:

> A railroad yard is a system of railroad tracks with defined limits that is used for classifying strings of cars into blocks going to common destinations, assembling blocks of cars into trains, and storing cars for later use. Trains arrive and are inspected, disassembled, and reassembled. Newly assembled trains are then inspected before departing for another destination. Many yards also have facilities to inspect and service locomotives and some yards have facilities to conduct major car repairs. Yards come in all sizes and shapes; no two yards are identical, since each is generally built to fit a particular geographical area or a particular logistical need. Many yards have areas for transferring intermodal freight to and from the rail system. Some yards handle primarily through freight while others service local industries (11).

Conventional yard crews typically consist of an FRA-certified locomotive engineer and one or two switchmen. Switchmen include all train service employees and 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, on many railroads, a switchman responsible for a road train is called a conductor, while the same switchman in charge of a job in a yard is called a yard foreman.

In conventional yard switching operations, the locomotive engineer is responsible for, and operates, the locomotive. He controls the locomotive via inputs to the throttle and brake and generally monitors its activity and health. A yard foreman (or other category of switchman) is responsible for the overall crew and its activities within the yard, including the overall switching moves. A third crewmember, a switchman often referred to as a helper, may also assist the crew. Occasionally a utility man may also be temporarily assigned to a crew to assist with specific moves within the yard environment.

Yard switching crews carry out a myriad of switching activities in yards. Moorhouse (2001, p.1) recently conducted a job demands analysis for a yard foreman or helper (i.e., switchman). This analysis identified the following duties and tasks which describe the activities of the other yard crewmembers:

- Operate track switches.
- Uncouple freight cars using the operating lever.
- Apply and remove handbrakes using the handbrake wheel or lever.
- Adjust coupling drawbar and knuckle.
- Couple air hoses.
- Climb on and ride on moving equipment.
- Radio (or hand) communication.
- Standing/walking for up to 5 hours (h) at a time
- Read and interpret switch lists of cars to be moved to a particular location.

Switching is also highly variable because of differences in yard and track configurations, length and weight of different cuts of cars to be switched, and the environment. Yard switching occurs in an open, mostly uncontrolled environment 24 h a day, 365 days (d) a year, in hot and cold weather, dry and wet conditions, and in varying degrees of noise and illumination. These and other variables make yard switching a unique industrial activity and help to distinguish yard switching from other industrial processes, many of which are closed-loop systems, such as petrol-chemical processing or a nuclear power plant, that have been studied using risk assessment methods.

Figure 1 provides a simple diagram to describe the process by which inbound cars are switched to become outbound cars for their next destination. The shaded boxes in the diagram in Figure 1 show yard switching operations; the tasks and duties that make up yard switching, described by Moorhouse, center on these activities.

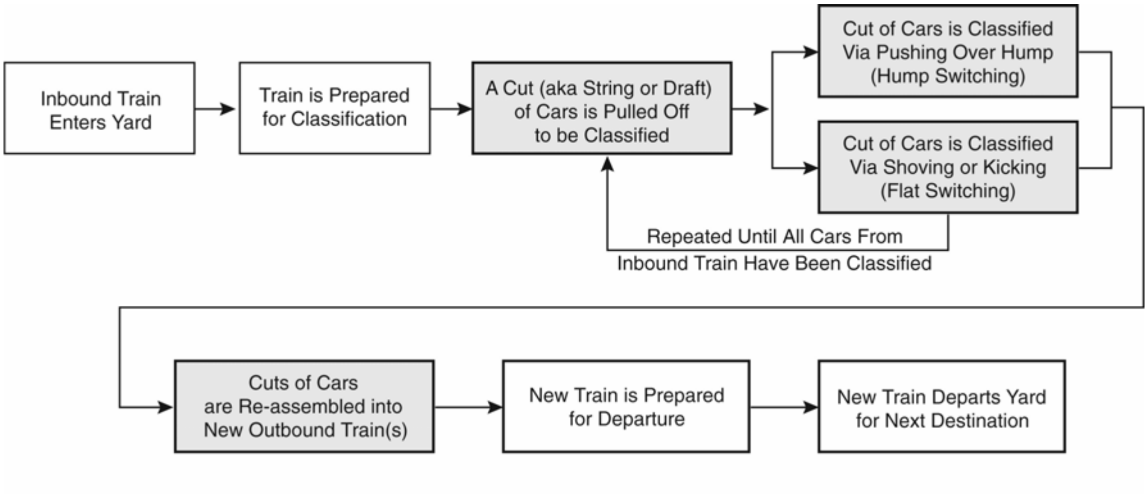


Figure 1. Basic flow diagram of railroad yard switching

Railroad yard switching occurs in a complex and dynamic environment; multiple yard crews may work and interact in a switching yard at any one time, day or night. Carmen, maintenance-of-way, signalmen and others periodically work among these yard crews to install, repair, or maintain equipment and infrastructure. Furthermore, railroad yard switching is highly variable. Railroad yard switching activities are heavily governed by operating rules, but the precise method of switching cars is not prescribed. Typically no one right way of switching cars or making a move exists; rather, usually a number of acceptable ways exist to carry out a particular move. The methods and practices used to switch cars may vary from railroad to railroad, crewmember to crewmember, from one move to the next. This variation depends on a host of factors. For example, tremendous variation exists across railroads in terms of yard layout, grade, equipment used, operating rules and practices (e.g., what is permitted and what is prohibited), and the number of crewmembers working together as a team. Variation also exists within any one railroad and even within one yard. Some factors that affect this additional variability in yard switching include crewmember training and experience (i.e., how a crewmember was trained to switch cars) and current yard conditions (e.g., certain tracks are occupied and thus cannot be used) and activities (e.g., another crew may occupy the route typically used to make the needed move).

1.1.2 RCL Operations in the United States

In an effort to reduce operating costs and increase safety and efficiency, Class I freight railroads in the United States have begun to implement RCL operations in railroad switching yards. RCL operations consist of three components: (1) the locomotive (the RCL), (2) an OCC (see Figure 2) that interfaces with the RCL's controls (and usually mounted somewhere inside or on the RCL), and (3) a portable RCD, also frequently referred to as a belt pack, operator control unit (OCU), or box. See examples in Figure 3 and Figure 4. An RCO wears the RCD harnessed to a vest (Figure 5). In RCL operations, typically only one or two crewmembers (one or both are RCOs) switch cars, commanding the locomotive to move through inputs to the RCD rather than radio or hand signals to the locomotive engineer onboard the locomotive. The RCO in control of the move is often referred to as the A operator or primary RCO, while the second RCO is referred to as the B operator 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 through radio frequency to the OCC. The OCC then actuates locomotive commands by interfacing with the RCL and sending instructions to the RCL. Figure 6 illustrates the basic concept of RCL operation. An RCO on the ground can now directly control the locomotive rather than communicating movement directions to a locomotive engineer stationed onboard the locomotive. Consequently, RCL operations have led to reduced crew size—typically one to two crewmembers are in an RCO crew compared, generally, 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 locomotive operator the best vantage point (see Figure 7). 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-related concerns, including inadequately trained operators, the added mental and physical stress of wearing and operating the RCD, and electromagnetic radiation emissions.

Figure 2. OCC

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

Figure 4. Top view of an RCD
(Courtesy of Cattron-Theimeg, Inc. 2004. Reprinted with permission.)


[redacted]

Figure 5. RCO

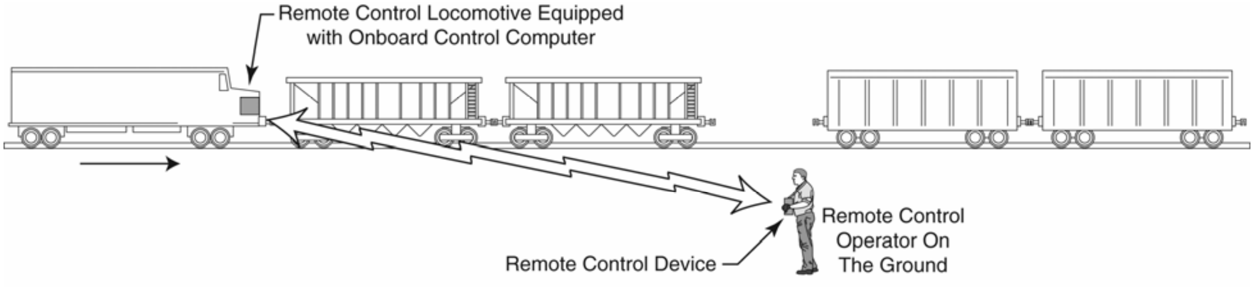


Figure 6. Basic illustration of RCL operation

Figure 7. RCO making coupling

Canadian National Railway, 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 U.S. Class I freight railroads had implemented RCL operations as of 2000.

In an effort to provide guidance and assist the 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. Subsequently, on February 14, 2001, FRA published an FRA Safety Advisory that contained RCL operation guidelines (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 specifically pertain to RCL operations, including qualification and certification of RCOs (49 CFR § 240), and daily and periodic inspection of the RCL equipment (49 CFR § 229).

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 beginning 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 vicinity of the RCOs. A majority of RCOs on U.S. Class I railroads are switchmen who receive 80 h of additional training on the RCD and RCL operations to qualify as RCOs, though a small number of RCOs on U.S. Class I and some regional railroads are also FRA-certified locomotive engineers who have experience operating a locomotive. Traditionally, switchmen were not trained to operate a locomotive.

Although the technology has been around for decades, largely in industrial plants and mines, the particular safety implications of using these devices in the U.S. railroad industry and of reducing crew size in switching operations remain unknown. Although FRA collects accident/incident data, including those involving RCL operations, it will take several years before adequate RCL-related data are available to analyze since RCL operations began on a large scale in the United States only beginning in early 2002 and 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's Office of Research and Development Human Factors Program and FRA's Office of Safety initiated a multi-study RCL operations research program in early 2002, just as RCL operations began on a large scale in the United States. FRA sponsored three separate studies including a comparative risk assessment of RCL and conventional yard switching operations, focus groups with RCOs to identify safety issues and best practices, and an RCA study of RCL-involved accidents/incidents. This report describes the results of the comparative risk assessment of RCL and conventional yard switching operations. This research was aimed at comparing some of the operational risks between the two methods of yard operation and complements the other FRA-sponsored RCL operations research.

1.1.3 Risk Assessment Overview

Risk may be defined as the product of the likelihood of a system failure multiplied by the consequence of the failure. System failure and its consequences depend on a number of factors, some of which are mechanical and electrical, and others of which are human-centered. The primary purposes of assessing risks associated with a system are to support decisions about acceptable risks of the system, to identify effective means to mitigate the risks, and to eliminate the risks by removing the associated hazards. Risk is not an empirical reality, however, so it cannot be directly measured. Instead, the risk associated with a system can be assessed through the use of logic and models that characterize or approximate the system. The quantification of the logic and models allows analysts to measure system risks.

Risk assessment fundamentally consists of answering the following questions (Kaplan and Garrick, 1981):

- What can happen? (i.e., What can go wrong?)
- How likely is it that it will happen?
- What are the consequences if it does happen?

By projecting how the future will turn out as a result of undertaking a certain course of action (or inaction), risk can be assessed. Risk assessment utilizes a variety of sophisticated modeling, analysis, and evaluation approaches. In spite of the sophisticated methods, though, risk assessment also contains uncertainty. For example, some risk assessments focus on natural processes and phenomena that are inherently random, and the states of such phenomena are naturally indeterminate. Consequently, these states cannot be described definitively (Ang and Tang, 1975) and thus contain some uncertainty. Uncertainties may be attributable to a number of factors, such as the following:

- The statistical nature of the event
- Insufficient understanding of physical/biological phenomena
- Unpredictable events (e.g., natural, biological, and human behavior) (Kastenberg and Solomon, 1985)

The most common and accepted method of addressing uncertainty in risk assessment is through the use of probabilistic methods. PRA techniques have evolved over the last 30 years (yr). Their purpose is to produce quantitative estimates of the risks associated with complex engineering systems (Apostolakis, 1990), such as nuclear plants, chemical process facilities, waste repositories, space systems, and transportation systems. Complex systems inherently contain uncertainty in their processes.

PRAs can provide the following:

- A method of quantifying uncertainty surrounding a system event
- A structured view of system dependencies and interactions
- A rational integrated view of system response in terms of consequences, their likelihood, and the responsible contributing factors
- A flexible tool for managing system safety

Major strides have been made in PRA methods, the most significant of which has been the assessment of human reliability. Traditional risk assessment methods did not explicitly account for operator behavior; rather, they focused on failures of machine parts and components, including mechanical and electrical failures. HRA techniques identify different types of operator errors that are possible within a complex system, and/or they provide numeric estimates of the likelihood of operator errors occurring. These data can then be evaluated on their own when examining human factors issues. HRA data can also be used as part of a larger, system-level risk assessment that might include evaluation of operator errors, as well as failures associated with hardware and electrical components of a system.

Depending on the specific technique, HRAs can accomplish the following:

- Provide quantitative estimates of human error potential.
- Identify weaknesses in operator interfaces with the system.
- Demonstrate quantitative improvements in human interfaces.
- Demonstrate quantitative predictions of human behavior.
- Improve system evaluations by including human elements.

In fact, risk assessment, including HRA and PRA, should be part of a larger organizational safety assessment to evaluate active and latent system risk factors and conditions. Active risk factors are those conditions, decisions, or other aspects in a system that are closest in time and physical space to a known failure or accident/incident. An example is an RCO who commands his/her RCL to move in the opposite direction as intended. On the other hand, latent risk factors or conditions exist at higher levels of an organization, including front-line supervision, upper management, and the senior executive level, and may exist for years before a failure or accident/incident occurs. These may include senior management decisions regarding deferment of resources or hiring freezes that result in reduced staffing levels years later.

Some combination of active and latent risk factors typically contributes to a system failure and subsequent accident/incident. In other words, accidents/incidents do not result from one risk factor or are caused not solely by one event; rather, multiple risk factors, including both active and latent risk factors, play a role in every mishap or accident/incident. However, traditional risk assessments generally focus on active risk factors and only implicitly focus on the latent risk factors and conditions. To conduct a comprehensive organizational safety assessment, ideally a variety of approaches is used to address active and latent risk factors across a system and throughout the entire lifecycle of the system. These may include proactive risk assessment methods to identify active risk factors before a system goes online and ongoing risk assessment methods to study possible negative effects of upgrades and changes to a system, as well RCAs of accidents/incidents that have already occurred to identify and eliminate active and latent risk factors that contributed to the accident/incident. In fact, risk assessment and RCA may be viewed as two sides of the same coin. Whereas risk assessment tries to identify risk factors before an accident/incident occurs, RCA identifies risk factors after an accident/incident has already occurred. Given their different methodologies and advantages, each is valuable as part of an overall organizational safety assessment.

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 basic objectives of the study included the following:

1. Select one or more operationally relevant and suitable risk assessment techniques.
2. Apply the risk assessment technique(s) to RCL operations and conventional yard switching operations.
3. Evaluate the relative safety of RCL operations compared to conventional yard switching operations.

These objectives were designed to provide FRA with a better understanding of RCL operations and the relative safety of RCL operations compared to conventional yard switching operations which RCL operations are supplanting.

1.3 Scope and Limitations

The study originally focused on conducting a PRA that was to include an assessment of human reliability, as well as mechanical and electrical failures associated with both methods of yard switching operation. However, the study team was unable to obtain RCL equipment reliability data from RCL suppliers, making estimates of hardware reliability associated with the RCL equipment unfeasible. Consequently, the study team changed the focus from a system-level PRA to a more focused HRA of potential operator errors and reliability associated with each method of operation. To change the focus to an HRA, the study team made the assumption that failures associated with the RCL equipment, locomotive equipment, or track structures would be built into operator reliability estimates since the operators, RCOs and conventional yard switching crews, interact with the RCL and locomotive equipment and track to carry out their tasks.

The study team assessed risk in terms of potential harm to either railroad operating employees and/or railroad property and equipment. Potential harm to the general public, for example to motorists at public grade-crossings, and operational delays were not assessed. Furthermore, this study does not examine RCO exposure to electromagnetic radiation as a result of RCL operations. Distributed power, although it is a form of RCO operation, was not included in this study since that is considered a separate type of operation from RCL operations, even though both share some of the same mechanical and electrical components and principles of operation.

Lastly, the study was unable to address all types of operator-related risks associated with RCL and conventional yard switching operations. This limitation is due to the fact that: (1) tremendous diversity exists in railroad yard switching operations across the United States; (2) RCL operations were relatively new when the study was conducted, and operating practices, procedures, and rules are continually being updated; and (3) only a fraction of all yard switching scenarios and tasks could be assessed. Consequently, the study is limited to a particular subset of RCL and conventional yard switching operations.

1.4 Overall Approach

Early on, it became apparent that no single approach to HRA would adequately identify the potential risks of railroad yard switching operations, given the myriad tasks and dynamic environment. Furthermore, since RCL operations were new, insufficient quantitative accident/incident data were available to support certain HRA techniques. Human error rate data tables have been created for other complex engineering systems, such as nuclear power plants, but these process-oriented systems do not have much overlap with the tasks involved in RCL operations. Quantified expert judgment can be used to provide operator reliability estimates, however, and is considered a practical and statistically sound method to acquire quantitative human reliability data (Embrey, 1981). Consequently, a multi-pronged strategy was developed that employed several complementary methods and techniques. The multi-pronged approach included the following:

1. Conduct an HTA to delineate the specific tasks involved in RCL and conventional yard switching operations.
2. Conduct an PHA to assess the overall risk of each method of yard switching operation.
3. Conduct an HRA to generate operator reliability estimates associated with each method of operation.

The HTA provided a platform to assess RCL and conventional yard switching operations, while the PHA and HRA provided a quantitative approach to assessing the overall risk of each method. Taken together, the results of the PHA and HRA provide a more complete or holistic picture comparing RCL operations to conventional yard switching operations than if one or the other approach was employed. For any statistical tests that were performed, significance was set to $p \leq 0.05$.

Since RCL operations were new when this study began in early 2002 and consequently very little was publicly known about RCL operations on which to draw for the study, the study team carried out two additional, distinct activities to obtain a better understanding of some of the potential safety issues. First, the study team conducted a preliminary analysis on Mine Safety and Health Administration (MSHA) mine fatalities involving RCE from January 1995 through March 2002. The study team conducted the mine fatality analysis to provide some early insights on some of the potential safety issues that may be present in RCL operations in railroad yards. Although the results of the mine RCE analysis were not directly incorporated with the other methods used in the risk assessment study, the analysis provides an analogous reference point in the more general study of remote controlled operations and aided study teams in better understanding some of the potential risks associated with RCL operations. Appendix A presents the MSHA data analysis. Briefly, the MSHA RCE analysis identified the following broad issues associated with RCE-involved fatalities that may also be potential risk factors in RCL operations: staffing and training, position of the RCO and other personnel relative to the RCE, RCE operation and maintenance, and the RCE. Appendix A further discusses these issues.

A second ancillary activity that was conducted in parallel with the HRA study design, data collection, and analysis was the generation of a catalog of potential hazards and sources of operator error associated with RCL operations. Over the course of 2 ½ yr, from July 2002 through November 2004, a member of the study team collected, through the Internet, a myriad of written SME narratives pertaining to RCL operations. Data came from RCO and conventional yard crewmembers and other railroad operating employees from U.S. Class I freight railroads, a number of short-line and regional railroads across the country, and a few Canadian railroads. Data included self-reported written information mainly through the Internet but also included some paper comments and enclosures. The information railroad operating employees provided consists largely of self-reported problems they have experienced, and reports of close calls and accidents/incidents with which they are familiar. Based on the narratives from RCOs and other railroad operating employees, the study team classified and produced a catalog of ways in which RCL tasks could be a potential problem (difficult to deal with to the point of creating a hazard) in U.S. RCL operations in railroad yards. In the absence of published reports and data on RCL operations and numerous years of RCL accident/incident data, the catalog of potential hazards and sources of operator error provided the team with a qualitative look at some of the potential risks of RCL operations. The catalog was used to enhance the study team's basic knowledge and understanding of RCL operations. Appendix B presents the catalog.

1.5 Organization of the Report

This report is organized into several sections. Section 2 describes the HTA that was conducted to understand and formally structure yard switching activity. Section 3 presents the PHA of RCL and conventional yard operations while Section 4 describes the methods and results of the comparative HRA. Section 5 presents some key findings and recommendations. Section 6 lists references used in the study. In addition, a number of appendices is included. Appendix A presents the analysis of the MSHA RCE-involved fatality data. Appendix B presents the catalog of potential hazards and sources of error associated with RCL operations. Appendix C presents the HTA. Appendix D contains the results of the PHA. Appendix E describes the HEART and APJ pilot study. Appendix F through Appendix M present the materials used in the pilot and main HEART and APJ studies. Lastly, this report includes a list of abbreviations and acronyms and a brief glossary of terms.

2. Railroad Yard Switching HTA

To provide a common reference and task-based framework to assess RCL and conventional yard switching operations, a systematic description of yard switching tasks was needed. Kirwan and Ainsworth (1992) provide an excellent discussion and description of numerous task analytic techniques and approaches that are available to study and characterize work in a systematic, objective manner. Task analytic techniques include task data collection methods, task description methods, task simulation methods, task behavior assessment methods, and task requirement and evaluation methods. See Kirwan and Ainsworth (1992) for further descriptions. Kirwan (1994) notes that HTA is ideally suited for HRA. HTA is a task description method that was selected for use due to its ability to facilitate decomposition of yard switching tasks at a number of different levels. This layered approach supports risk assessment at any number of detailed levels. The hierarchical structure also allowed for both methods of yard switching operations to be captured in an efficient manner. As such, HTA provided a logical, flexible, and valid approach to describing and characterizing conventional and RCL yard switching activities.

Section 2 describes the approach used to identify a set of yard switching tasks of interest (Section 2.1), selection and application of HTA to the yard switching environment (Section 2.2), and the results (Section 2.3). Appendix C presents the complete HTA for reference.

The HTA consists of two components:

1. A set of hierarchical tasks and subordinate tasks
2. A plan that describes the relationships among subordinate tasks in completion of a higher-level task

The HTA was also modified by the addition of a third component:

3. A breakdown of subtask activity by crewmember according to specific method of operation (conventional or RCL) for the lowest level tasks

The HTA starts at the highest level and identifies a set of top-level tasks to achieve a particular goal, such as switch cars. Each task can be further broken down into a set of subordinate tasks. Next, a plan is generated that conveys, for a particular task, how the task is carried out based on subordinate tasks. That is, the plan describes how subordinate tasks are performed—in parallel or in sequence, for example—to complete a higher-level task. Where differences exist between methods of operation in completing the subordinate tasks—for instance, if a subordinate task pertains to one method of operation but not the other—the plan differentiates between conventional and RCL crews. The last part of the HTA is a breakdown of the lowest level of tasks, such as maintain locomotive movement, into constituent subtasks. It is at this subtask level where many of the differences exist between the two different methods of operation. At higher levels of the HTA, the tasks are the same (e.g., switch cars) for each method of operation. Each of the lowest level tasks is associated with a letter and thus is referred to as a lettered task. For each lettered task, crewmember activity is described for each method of operation as a set of subtasks.

The breakdown of tasks according to crewmember actions is not ordinarily a part of an HTA; however, it was required due to the team-based nature of railroad yard switching. A challenge in applying task analysis methods to railroad yard switching is that, typically, task analysis methods address one operator carrying out one task. Railroad operations in general, and most yard switching operations, involve two or more individuals working together as a team toward a common goal or task, such as switching a cut of cars. This study used a three-person conventional crew (an engineer, a yard foreman, and a switchman) and a two-person RCL crew configuration (two RCOs). This third component, the subtask breakdown, allowed the study team to capture some of the communication and coordination activities among crewmembers, as well as the capture of different crewmembers carrying out different activities as part of a particular task.

2.1 Task Identification

To identify which yard switching tasks and activities should be included in the risk assessment, the study team initially identified a preliminary taxonomy of yard switching operations (see Table 3) based on an understanding of railroad operations, SME input, and conversations with FRA. These RCL tasks represented railroad conventional and RCL methods of operation at the time the study was conducted.

Table 3. Taxonomy of railroad yard switching operations

General yard switching taxonomy	Supporting activities involved in yard switching operations
• Running light engine (without cars) from place to place • Pulling cars • Shoving cars (flat switching) • Shoving cars (hump switching) • Doubling and tripling over cars (pulling and shoving cars) • Kicking cars • Spotting cars at carrier's car-repair facilities and customers' industrial facilities (car loading/unloading)	• Aligning manual switches and derails • Applying/releasing handbrakes on a car or cut of cars • Coupling an engine to a car and then reversing to test the coupling • Coupling a cut of cars to standing cars and then reversing to test the coupling • Coupling air brake hoses between an engine and the lead car of a cut of cars • Coupling air brake hoses between many cars in a cut of cars • Bleeding off air in a car or cut of cars • Inter- and intra-crew communications

The taxonomy of yard switching operations was then re-categorized into six yard switching tasks. Tasks were then prioritized, with the help of labor, management, and supplier representatives, in terms of their frequency in yard operations—the more frequent the task, the higher the priority. The results, starting with the most frequent yard task, include the following:

1. Switch cars (flat yard).
2. Operate locomotive/light engines.
3. Switch cars (hump yard).
4. Trim cars.
5. Pick-up/set-out cars from industry.
6. Spot cars/engines at a railroad repair facility.

The task analysis addressed the top four tasks, since these are the tasks that make up the bulk of yard switching activity. These top four tasks make up classifying inbound trains and building new outbound trains in yards. Industry work and spotting cars at repair facilities, though very important, were considered secondary activities to yard switching.

For each method of operation, a number of different crew configurations can exist, depending on a number of factors. For example, a conventional crew may consist of 2-4 individuals, while RCL operations typically involve 1-2 crewmembers. To simplify all analyses and assessments, the study team selected the one crew configuration that was most typical of each method of operation. These were the three-person conventional crew (one locomotive engineer and two switchmen) and a two-person RCL crew (both FRA-certified RCOs, and each with an RCD).

2.2 HTA Methodology

To perform the HTA, this report/study team used four separate methods to collect data on switching operations and to organize this information into the HTA. The tasks that were studied included flat switching, hump switching, trimming, and running light engines, all within the yard environment. The following sections briefly describe each of the four data collection methods. Before data collection, visits were made to two RCL suppliers to get an overview of RCL equipment. Operating manuals were also obtained.

2.2.1 Step 1: Documentation Analysis

Documentation analysis was the first step of the HTA and involved the review of RCL-related documentation provided by several railroads and two RCL suppliers. The documentation analysis provided an opportunity to gain an initial understanding of RCL operations as they were being implemented.

2.2.2 Step 2: Talk-Throughs

Next, site visits were conducted at several RCL-equipped yards. An FRA-certified RCO crewmember or other individual familiar with RCL operations was asked to describe the tasks involved by verbally talking through the job, step-by-step. The crewmember was asked to describe in detail the task activities, any cognitive demands that were required or imposed, and communications with other crewmembers and others within the yard. Talk-throughs provided an overview of each task; this overview was used to structure the naturalistic observation in Step 3. Talk-throughs also enabled the cognitive and other hidden aspects of the operation, which cannot be otherwise observed, to be captured. Talk-throughs were typically conducted in an office or room that afforded a view of the operation under study to enable a visual aid during the talk-though.

2.2.3 Step 3: Naturalistic Observation

Next, naturalistic observations of yard switching activities were conducted for each task at participating railroad yards. During naturalistic observation, researchers observed the operation on the ground and occasionally from the locomotive and/or yardmaster’s office. Researchers would shadow the RCOs, as well as watch them from a short distance. Radios were also provided to the researcher where possible. Task-related information was collected using a special data collection form specifically designed for this task.

2.2.4 Step 4: Structured Interviews

A structured interview was administered with one or more RCOs following the naturalistic observation. The structured interview provided an opportunity to ask RCOs specific questions pertaining to the operation that were not otherwise addressed during the talk-through and naturalistic observation. Questions addressed, among other aspects, cognitive demands and communication requirements related to the tasks under study. Other questions addressed PSFs, such as how crew size, crew experience, training, and activity volume affected task performance. Data from the structured interviews were used to fortify the HTA.

2.3 HTA Results

This HTA was conducted over several iterations, with verification and correction provided by an SME. Section 2.3 presents, at a top level, the results of the HTA, which covers RCL and conventional operations. Appendix C includes the complete HTA.

The HTA is made up of three primary components: the tasks, the plan, and a subtask matrix. The tasks are presented in an outline format and are written in a generic fashion to be as broadly applicable as possible. Many, though not all, of the tasks also have a plan associated with them. The plan explains how a particular task is carried out. Whereas the tasks are written in a generic fashion, the plan begins to account for differences in procedures between RCL and conventional operations by informing which tasks should be carried out by RCOs and which tasks should be carried out by conventional crewmembers.

Each lowest-level task is assigned a letter. Each lettered task is further broken down depending on the method of operation. A subtask matrix (i.e., a table) contains the breakdown of each lettered task to reveal further differences between the two methods of operation, in particular by characterizing specific crew activities to accomplish a particular lettered task.

Figure 8 presents the first-order level of tasks (tasks 1-6) in graphical form. It conveys the overall scope of the HTA by identifying the top-level task (task 0) and the set of subordinate tasks (tasks 1-6) that make up this task. Associated with task 0 is a plan that describes how the subordinate tasks 1-6 are to be carried out in accomplishing the top-level task 0. This hierarchical structure then continues at lower and lower (more subordinate) levels of detail.

Figure 9 presents Task 3 and its subordinate tasks (3.1 and 3.2) along with its associated plan.[1] Figure 10 presents Task 4 and its subordinate tasks (4.1-4.5) along with its associated plan. Figure 11 presents Task 5 and its subordinate tasks (5.1-5.5) along with its associated plan. Figure 12 presents Task 6 and its subordinate tasks (6.1-6.6) along with its associated plan. Appendix C presents the complete HTA, including the tasks, plans, and subtask matrix.

---

[1] For brevity, Tasks 1 and 2 are not presented here.

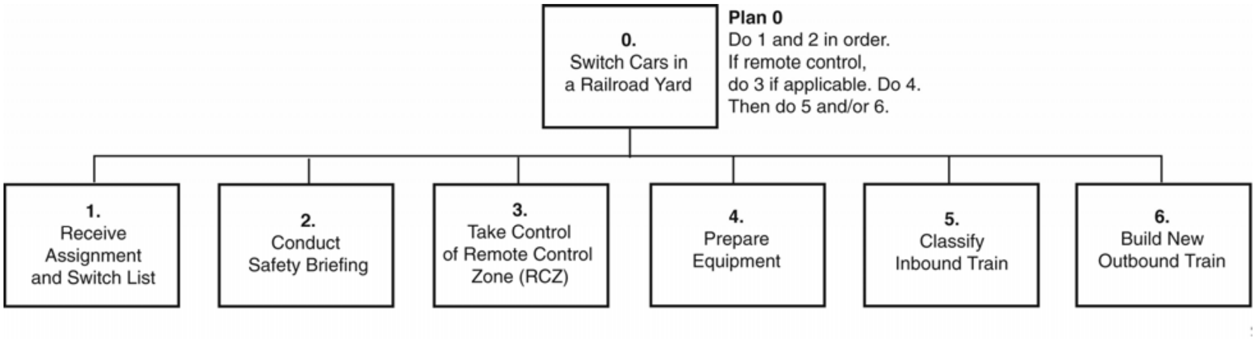


Figure 8. Task 0, Switch cars in a railroad yard, with subordinate tasks and plan

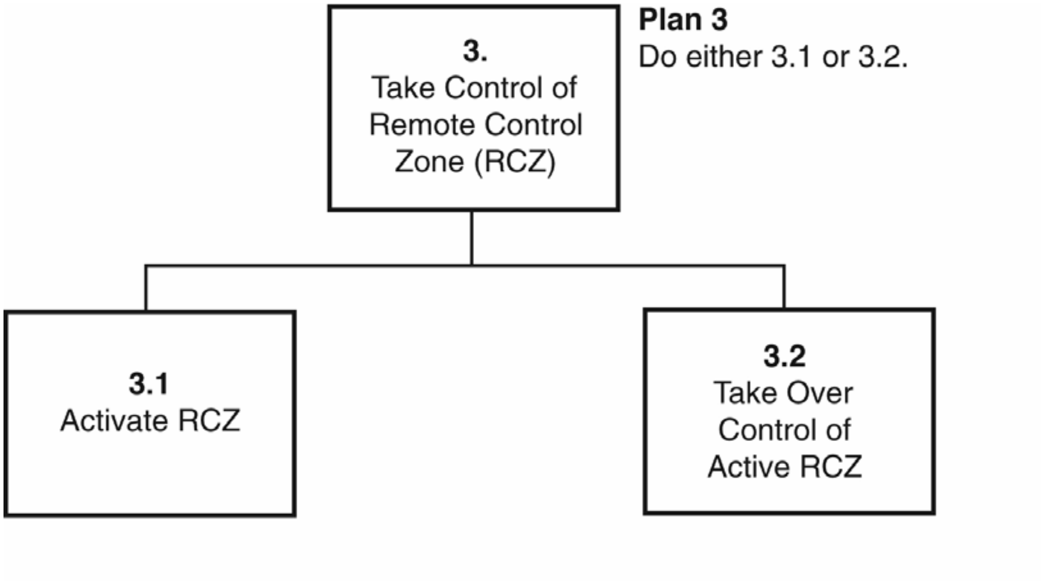


Figure 9. Task 3, Take control of remote control zone, with subordinate tasks and plan

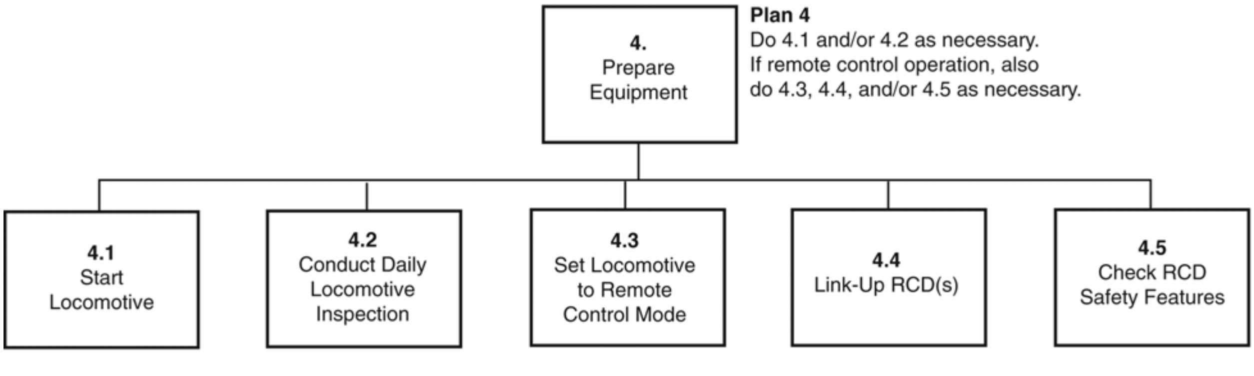


Figure 10. Task 4, Prepare equipment, with subordinate tasks and plan

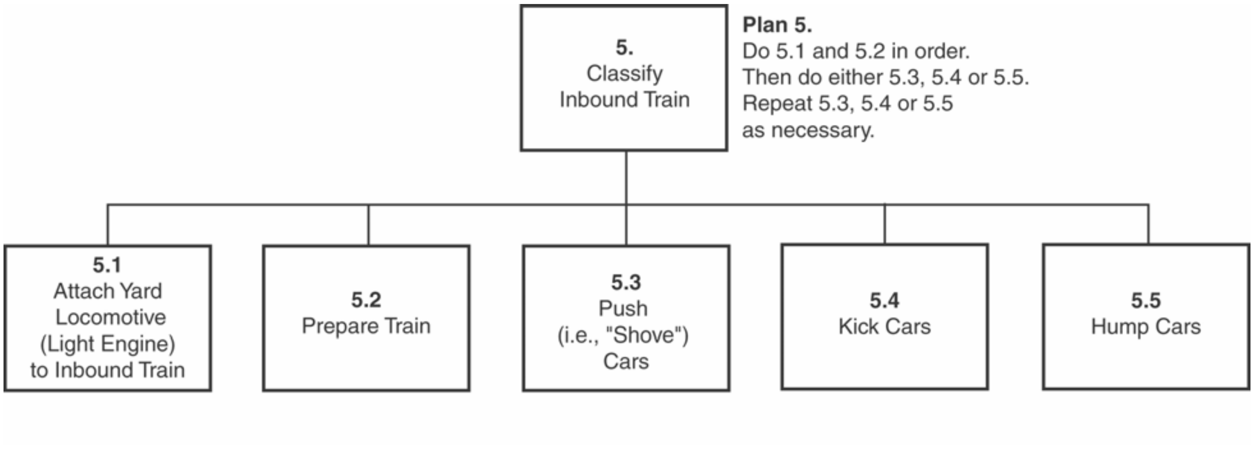


Figure 11. Task 5, Classify inbound train, with subordinate tasks and plan

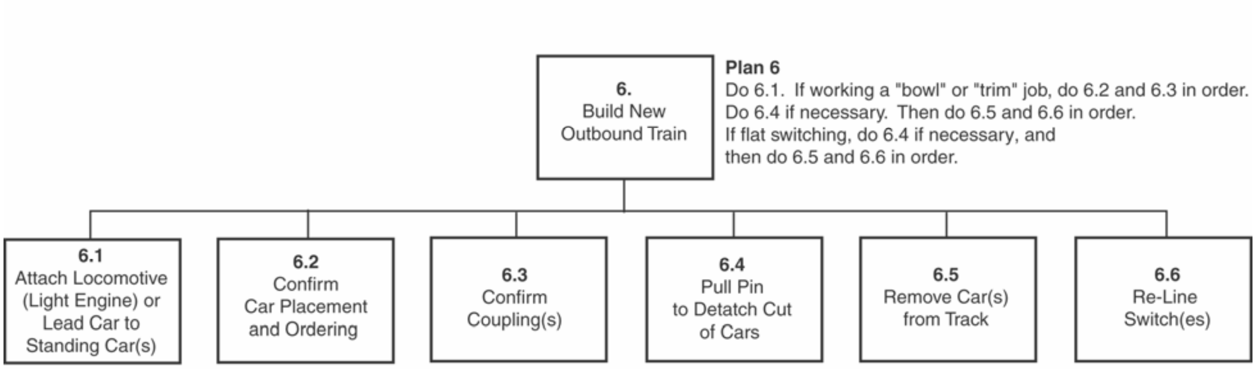


Figure 12. Task 6, Build new outbound train, with subordinate tasks and plan

3. PHA

A PHA was conducted to assess the overall risk of each method of operation. PHA, as applied in this study, is an early evaluation of the risk associated with certain yard scenarios. The PHA identified different outcome types (e.g., collision) and generated an assessment of risk for two types of scenarios: a worst credible scenario and most likely scenario. Risk was based on evaluating the likelihood of occurrence and the potential worst credible severity for each operational scenario. The PHA was used to assess the global risks of RCL and conventional yard operations, as represented in the scenarios that are identified, and was intended to be a first-pass tool to prioritize which RCL and conventional operating scenarios, or moves, should be further investigated using HRA techniques.

3.1 PHA Methodology

All research team members participated in the PHA over a 3 d period. Subject matter expertise was provided by the team's consultant, as well as Foster-Miller staff, who have spoken with over 80 RCOs and visited numerous RCL-implemented yards over the previous 3 yr. A study team member familiar with PHA and other risk assessment methods served as the group's facilitator.

A number of defining or delineating factors were identified first to bound and specify the contents of the PHA. Specifically, these included the following:

- The PHA was limited to outcomes that were either an acute[2] injury (including fatal injury) and/or property damage (as an outcome). Operating inefficiencies (i.e., delays) were not addressed.
- Outcomes must, at a top level, be applicable to RCL and conventional operations, even though the initiating event and sequence of actions may be different.
- The PHA did not address exposure to electromagnetic radiation (e.g., contact burn)[3] nor electromagnetic interference (e.g., communication malfunction).
- The PHA did not address ergonomic considerations, such as weight of the equipment and harness design.
- The PHA did not address risks to the public, such as vehicle users at public grade-crossings and trespassers.
- The PHA did not address the use of wayside or locomotive-mounted cameras in support of RCL operations.

---

[2] Acute injuries refer to injuries, regardless of severity, that specifically occur during a shift of up to 12 h. Acute injuries are in contrast to illnesses and injuries that result from prolonged or chronic exposure to hazards. These latter illnesses and injuries are not included in the scope of the PHA or the HRA.

[3] This report considered electromagnetic radiation (EMR) but EMR was not expected to result in an acute, FRA-reportable injury, such as a burn to the skin, during a shift of up to 12 h. Thus, EMR is not further considered. This does not mean, however, that EMR is not a chronic health risk factor. Chronic illnesses and injuries were not included in the scope of the PHA or HRA.

- The PHA did not address distributed power, such as when a locomotive engineer controls locomotives located in the middle and/or rear of the train through remote control technology using the lead locomotive cab, even though distributed power is functionally similar to a person-mounted RCD.
- The PHA included flat and hump yard switching operations.
- The PHA did not address any RCL operations on main tracks, spur/industrial tracks, or sidings (e.g., setting off/picking up cars or spotting).
- The PHA did not address vandalism or acts of terrorism.
- The PHA examined only one crew configuration for each method of operation—a two-person RCO crew and a three-person conventional yard switching crew. These two crew configurations have been selected for the risk assessment because they reflect the most common configuration of each method of operation. Other crew configurations (e.g., one-person RCO crew) are sufficiently different from the two selected (e.g., comparing a one-person RCO operation to a two or even three-person RCO operation in terms of recovery mechanisms) to warrant their own separate study.
- The PHA included only the newest generation of RCDs (speed selector) available as of early 2002.
- The PHA addressed RCL equipment design and functionality at a level that was common across manufacturers.

Top-level outcome types were then identified for each method of operation, which included the following:

- collisions
- derailments
- excessive slack
- hard couplings
- unexpected movements
- slips/trips/falls

Then, for each method of operation, a number of second-order (i.e., more specific) outcomes were specified, and finally, third-order outcomes were identified when appropriate and meaningful. For example, for collision as a top-level outcome, five second-level outcomes were identified (e.g., an RCL or conventional locomotive collides with other equipment versus an employee), and for four of these five second-level outcomes, third-level outcomes were specified to distinguish unique outcome types (e.g., RCL or conventional locomotive hits own crewmember versus another employee). Second and third-level outcomes were specified when the team felt that different circumstances existed that could lead to different outcomes. A total of 19 outcomes was identified.

Next, the team generated two sets of scenarios to represent or illustrate each outcome type: a worst credible scenario and a most likely scenario. Worst credible scenarios are scenarios that may be expected to occur in the railroad yard, though not frequently. Worst credible scenarios are distinct from worst-possible scenarios, which focus on the most egregious scenario that the analyst can imagine as occurring, regardless of the likelihood. Scenarios that were most likely to occur include those that may be considered somewhat common. Most risk assessment methodologies, such as PHA, focus on the worst credible scenarios, but the team felt that the analysis should also shed light on more common scenarios that may be expected to occur.

Each scenario is based on some initiating event. Based on this study's focus on human reliability and its focus on only injury and property damage outcomes, an initiating event was defined as a human error that began a sequence of events that had the potential to lead to an injury (including death) or property damage. The PHA did not address other types of initiating events, such as physical (e.g., mechanical, electrical) failures or acts of nature. For example, the analysis excluded a communication failure between the RCD and the OCC that might result in an injury. Thus, each scenario consisted of an initiating event (e.g., failure to protect the point), a sequence of operational events, and a specified outcome (e.g., RCL hits own crewmember).

After scenarios were generated, the assessment team used the approach specified in military standard Mil-Std-822C[4] (1993) to assess and prioritize the risk of each scenario for each method of operation. Mil-Std-822C categorizes scenarios or hazards into ordinal severity ratings and likelihood of occurrence ratings. Then, severity ratings and likelihood of occurrence ratings are combined into a risk matrix to help prioritize which combinations of severity and likelihood of occurrence require attention first. In its simplest form, a scenario with a very high severity and very high likelihood of occurrence would be considered more critical than a scenario with low severity and low likelihood of occurrence.

Rather than using Mil-Std-822C's specific definitions for each category, however, the team generated definitions to better suit the railroad operating environment due to the uniqueness of railroad yard switching. Table 4 and Table 5 present definitions of severity and likelihood of occurrence. The number of severity ratings remained the same as Mil-Std-822C. However, whereas Mil-Std-822C identifies five likelihood of occurrence ratings, the team added a sixth level (nearly impossible) to further distinguish very unlikely outcomes.

The team conducted a consensus exercise to assign severity and likelihood of occurrence ratings for each scenario, both worst credible and most likely. As a rule of thumb, if the PHA team could not reach consensus on a particular severity or likelihood of occurrence rating, the most severe rating or most likely to occur rating among those advocated by team members was selected. Thus, in cases where it did not reach consensus agreement, the team selected ratings that led to the greatest potential risk.

The team also assigned each ordinal rating a numeric value depending on the number of candidate ratings. Severity ratings ranged from 1 (negligible) to 4 (catastrophic), and likelihood of occurrence ratings ranged from 1 (nearly impossible) to 6 (frequent). If the severity was expected to be less than negligible (1) (i.e., result in less than an FRA-reportable[5]

---

[4] Mil-Std-882C was referenced and used instead of the more recent Mil-Std-882D because Mil-Std-882C is much more comprehensive with regard to risk assessment guidance and guidelines, and provides guidance for conducting a PHA. Mil-Std-882D, though more recent, is much less detailed (around 30 pages for Mil-Std-882D versus around 150 pages for Mil-Std-882C).

[5] For the PHA, FRA-reportable incidents for the 2004 calendar year included train accidents associated with $6700 or more in damage, or employee casualties that required medical attention beyond first aid treatment. For further definitions of reporting thresholds, see FRA, 2003.

accident/incident), it was assigned a value of 0. This occurred only for most likely scenarios. No outcomes were generated that were less than nearly impossible. A score was then computed for each scenario by multiplying together the values associated with the severity and likelihood of occurrence ratings. Scores could range from 0-24.

Table 4. PHA severity definitions[6]

Label	Category	Value	Result	
			Injury	Property damage ($)
Catastrophic	I	4	Fatality or permanent total disability	$1 million or more in damage
Critical	II	3	Fracture, amputation, dislocation, loss of eye, electric shock/burn, or other burn	$200K–$999,999 in damage
Marginal	III	2	Lost workday (LWD) injury other than those listed above	$50K–$199,999K in damage
Negligible	IV	1	Non-LWD FRA-reportable injury	$6700 (FRA reportable threshold)–$49,999K

Table 5. PHA likelihood of occurrence definitions

Label	Category	Value	Definition[7]
Frequent	A	6	Once per week
Probable	B	5	Once per month (mo)
Occasional	C	4	Once per yr
Remote	D	3	Once in 10 yr
Improbable	E	2	Once in 40 yr[8]
Nearly Impossible	F	1	Less than once in 40 yr

3.2 PHA Results

Once numeric values were assigned to all scenarios for each method of operation, comparisons could be made between the two methods of operation. Based on the operating scenarios, outcome types could be prioritized: the higher the assigned score, the greater the risk for a particular outcome. It is important to keep in mind that three SMEs assigned consensus scores,

---

[6] Severity definitions are based on Mil-Std-882C suggestions, Switching Operations Fatality Analysis (SOFA) Working Group definition of a severe injury (SOFA Working Group, 1999), and engineering judgment with respect to the yard switching operational environment. No non-FRA reportable injury or accident thresholds are used. Critical injury is based on the SOFA Working Group definition of severe injury.

[7] Exposure is for all U.S. railroad yards.

[8] 40 yr was identified as a realistic length of service for many train, yard, and engine (TY&E) service operating employees (i.e., the duration of an entire career for an individual).

and as such, these should be viewed as subjective and not absolute. In fact, scores are best interpreted in a relative fashion—that is, to enable comparisons between the two methods of operation only. Results primarily focus on the worst credible scenarios, as is common practice among risk assessments, because ultimately risk assessment tries to eliminate or mitigate the worst-case scenarios. Most likely scenarios are also briefly examined since they are the scenarios that will be encountered most often.

Table 6 presents an example of the results from the PHA. In this example, worst credible scenarios are developed that result in the outcome specified—a collision between a conventional locomotive or RCL, and a crewmember. An assessment is made on the likelihood of occurrence and the expected severity for the conventional and RCL worst credible scenarios. Table 6 shows that, for this particular outcome and associated worst credible scenario, RCL operation is associated with a greater risk (likelihood of occurrence rating multiplied by the severity rating) than conventional switching.

Table 6. PHA example: RCL versus conventional worst credible scenario

Method of operation	First order outcome	Second order outcome	Third order outcome	Worst credible scenario	Likelihood of occurrence	Severity	Total
Conventional	Collision	Conventionally operated cut of cars pulls into employee	Locomotive hits own crewmember	Locomotive engineer fails to provide point protection and runs over and kills own crewmember	F 1	I 4	1X4=**4**
RCL	Collision	Remotely controlled cut of cars pulls into employee	RCL hits own crewmember	RCO fails to provide point protection and runs over and kills own crewmember	C 4	I 4	4X4=**16**

Appendix D includes the detailed results of the entire PHA. Specifically, Appendix D contains four tables. Table D-1 and Table D-2 present the results of the conventional yard switching operations PHA for worst credible and most likely scenarios, while Table D-3 and Table D-4 present the results of the RCL operations PHA for worst credible and most likely scenarios.

Table 7 presents the numeric severity x likelihood of occurrence risk ratings for each set of operations under worst credible scenarios and most likely scenarios. In addition, Table 7 includes two sets of tabulations for most likely scenario—one where non-reportable severity ratings are assigned a value of 0, and a second where these non-reportable scenarios were excluded from average and median calculations. The purpose of presenting two sets of results for the most likely scenarios is that differences can exist in average and median values when calculating values of 0 versus missing data.

Table 7. PHA risk ratings

Outcome number	Worst credible scenario		Most likely scenario Non-reportable = 0		Most likely scenarios Non-reportable = (.)	
	RCL	Conventional	RCL	Conventional	RCL	Conventional
1	12	4	4	4	4	4
2	12	4	5	6	5	6
3	16	4	10	1	10	1
4	12	4	8	1	8	1
5	12	12	0	0	.	.
6	12	12	5	8	5	8
7	16	16	10	8	10	8
8	12	12	8	6	8	6
9	9	6	8	2	8	2
10	9	6	0	0	.	.
11	4	2	2	0	2	.
12	4	2	0	0	.	.
13	9	6	5	0	5	.
14	6	12	0	0	.	.
15	8	4	5	4	5	4
16	12	9	0	0	.	.
17	12	8	4	4	4	4
18	12	12	0	0	.	.
19	8	8	0	0	.	.
Total	197	143	74	44	74	44
Ave.	10.4	7.5	3.9	2.3	6.2	4.4
Median	12	6	4	1	5	4

At the simplest level, the PHA provides an ordinal means of evaluating the relative risk of RCL and conventional yard operations by comparing the risk rating totals for each method of operation. Scores can be compared within the worst credible scenario situation or the most likely scenario. In both cases, the RCL scenarios yielded a higher score than their conventional counterparts: 197 to 143 for worst credible scenarios and 74 to 44 for most likely scenarios. A simple, paired t-test performed on the ratings for the worst credible scenarios revealed a significant difference ($t_{18} = 3.06$, $p = 0.007$) between the two methods of operation. A similar t-test performed on the most likely scenarios did not reveal a significant difference ($t_{18} = 1.79$, $p = 0.09$) between the two methods of operation. Examination of the average and median values for each method of operation for each scenario (worst credible or most likely) also revealed greater relative risk for RCL operations. The average rating for worst credible scenarios for RCL operations was 10.4 compared to 7.5 for conventional worst credible scenarios. The median value for RCL worst credible scenarios was 12 compared to 6 for conventional worst credible scenarios. Although less variance exists in the most likely scenario ratings, the bottom line result is the same; RCL operations yield slightly higher ratings (and thus risk) than their conventional counterparts. When the ratings for the most likely scenarios with less than FRA-reportable severity are removed from the calculations, the overall findings are the same; RCL operations ratings reveal greater risk although differences are less (see Table 7).

Pair-wise comparisons for the 19 worst credible scenarios indicate that RCL scenarios had higher (and thus, greater risk) ratings 6 times (4 related to collisions, 1 related to unexpected movement, and 1 related to hard coupling), conventional scenarios had higher ratings than RCL scenarios 1 time (related to a derailment), and the ratings were equal for each method of operation among the remaining 6 scenarios.

The highest rating assigned to any one scenario was 16. Two RCL scenarios—an RCO (controlling the move) hits his/her own crewmember (with the RCL or cut of cars) while pulling cars or while shoving or kicking—were associated with a rating of 16, while 1 conventional scenario—a conventional locomotive engineer hits his/her own crewmember while making a shove or kick move—was associated with a rating of 16. A number of scenarios occurred (mostly collisions, but also a derailment, hard coupling, unexpected movement, and even a slip/trip/fall) in one and/or the other methods of operation where the rating was 12.

The PHA provides an assessment of the overall relative risk of each method of operation and begins to shed some light onto the types of scenarios that are most at-risk within each method of operation. This latter aspect of the PHA helped to guide the HRA, which is described in Section 4.

4. HRA

Section 4 is divided into four sections. Section 4.1 provides an overview of HRA, while Section 4.2 discusses the HRA methods selected and applied in this study. Section 4.3 briefly discusses a pilot study that was designed to determine the feasibility and applicability of selected HRA methods to the railroad yard switching environment; Section 4.4 discusses the results of the main study.

4.1 HRA Overview

Since RCL operations are relatively new, a sufficient database does not exist from which one can perform an assessment of the human reliability issues associated with RCL operations. In addition, very little information exists from the research literature regarding human performance and reliability in the railroad yard environment, and no human reliability data currently exist for railroad yard switching operations (conventional or RCL). The U.K. Rail Safety and Standards Board (RSSB) has recently[9] developed an HRA tool for railroad operations, but the tool focuses on the tasks of passenger operations, dispatching, and maintenance, not on yard switching; furthermore, the method has yet to be validated (e.g., see RSSB, 2005). Furthermore, UK CORE-DATA, a computerized database of HEPs from a number of work domains, does not contain railroad yard operations HEP data that could be used (W.H. Gibson, personal communication, January 22, 2004; Gibson and Megaw, 1999). Therefore, the assessment team conducted a survey of established and accepted HRA methods to identify techniques that could provide insight into the human reliability associated with RCL operations versus conventional yard switching operations.

HRA techniques provide the practitioner with numeric estimates of human reliability. These estimates can be used as inputs to system-level analyses of risk, such as a PRA, that provide estimates of reliability at the system level, including the hardware, software, and operator reliability. Human reliability estimates can also be used as a basis for quantitative comparison and contrast. Specifically, these estimates can be used to compare the reliability between conventional and RCL methods of yard switching operation.

The research team evaluated the applicability of several HRA methods, and the results of the survey revealed several classes of techniques available for identifying and assessing system reliability, including techniques for identifying human error opportunities, classifying and describing errors in a system, and calculating the relative level of reliability associated with system performance. Although a detailed evaluation of each method is beyond the scope of this report, several reviews of multiple HRA techniques are available (e.g., Global Aviation Information Network, 2003; Kirwan, 1992, 1994; Strater, 2000; Swain & Guttman, 1983). Kirwan's 1994 publication is particularly noteworthy because it provides detailed coverage of the overall HRA process and philosophy, along with a comprehensive review of specific HRA methods highlighting strengths and limitations of each approach.

Several issues and concerns were identified to help facilitate the selection of an HRA approach appropriate to railroad yard switching operations. These points were grouped as follows:

---

[9] The study team became aware of the details of this tool only after this project had concluded.

Issue: Economy

The HRA approach should be economical, tending toward a conservative expenditure of time and resources. Although input and participation from SMEs, such as railroad operating employees, trainers, and other stakeholders, was deemed important for the success of the study, the team avoided selecting HRA techniques that required substantial amounts of time and resources for execution. Resource-intensive processes, such as collecting observational data over a period of months or years, or interviewing hundreds of SMEs from multiple environments, was beyond the scope of the project. In addition, without a valid and accepted model supporting the use of such an approach, the results from such an activity may be questionable in supporting an exploratory study such as the one conducted here. An economical approach also yields benefits by requiring minimal resources for planning, deployment, collection, and analysis of results. This allowed the team to plan and execute the HRA in a timely manner, evaluating initial results and modifying procedures if necessary to provide more informative results.

Issue: Flexibility

The HRA must be flexible enough to be adapted to the railroad yard environment. While many HRA methods have been used to carry out comprehensive evaluations of human reliability in domains such as process control and nuclear operations, these methods are too rigid and formal to adapt to the railroad yard domain or are too specific to one industry. The HRA technique should be amenable to tailoring to enable it to be applicable to scenarios experienced in railroad yard operations, and it could not require the use of specific databases or the assumption of existing processes and procedures that were not applicable to the railroad yard switching environment. The method, thus, should be able to accommodate multiple operators working in a highly variable and dynamic environment performing physically and cognitively demanding tasks.

Issue: Validity

The method should represent a valid approach to evaluating human reliability. Because HRA techniques have not been developed and validated for the railroad yard environment, it will be difficult to select a method that can be said to be truly valid. However, it is possible to identify a content-valid approach; that is, one that is meaningful and applicable to the railroad yard operating environment. The absence of reliability data and additional studies regarding human reliability in RCL versus conventional yard switching operations in general presents a considerable challenge for establishing the overall validity of a method.

No specific technique currently exists that would be considered completely valid; therefore the team decided to select a technique that was economical and flexible enough to provide it with information regarding the reliability of RCL and conventional operations in the form of a reliability estimate that could be used to compare one method of operation to the other. Without a database of reliability values gathered from objective observations and analyses of railroad yard operations, the utility of the reliability values should be limited to the comparison of values between conventional and RCL operations. Consequently, data will not be treated as absolute values.

4.1.1 Use of HEART

Results of the HRA led to the identification and selection of HEART developed by Williams (1988) to generate reliability estimates. Originally developed as a less complex and research-intensive technique for the process control industry, HEART is an economical and flexible technique that can be adopted for use in domains that involve human operators performing tasks under different kinds of conditions. HEART was also developed for use by practitioners who do not have extensive training and experience in the technique.

In contrast, more conventional HRA methods, such as the Technique for Human Error Rate Prediction (THERP) developed by Swain and Guttman (1983), require substantial training and time to effectively perform the technique for tasks of interest. In addition, THERP is based on data originating from studies of human performance in nuclear power operations and may not generalize well to railroad yard operations. While HEART was originally developed for use in process industries, it does not rely exclusively on data from specialized industry databases. Instead, HEART uses data that originate from over 100 sources of research about human performance in certain operational and laboratory environments. Williams (1988) explains his rationale for using the human performance literature as follows:

> ...the human factors literature now extends back in time some forty years or so. Data collected during the countless studies reported exhibit massive absolute variability but possess very much narrower relative variability. So narrow is the relative variability that it is possible (to a first approximation) to describe major performance modifying effects in very simple, consistent mathematical terms, so that reliable predictions can be made about the probable extent of an error probability change, given that the situation can be modeled with some clarity (p. 436).

Today, HEART is accepted and used in the United Kingdom and elsewhere, and in fact has been used to assess railroad operations reliability in the United Kingdom (e.g., Arthur D. Little, 1997), and several efforts have been made to validate the approach to compare it against more traditional and accepted methods in the process control industry. A comprehensive study conducted by Kirwan (1997) compared the validity of HEART, THERP, and Justification of Human Error Data Information (JHEDI, a proprietary method developed by Kirwan for British Nuclear Fuels, a chemical reprocessing company).

While the results of this research are available in three articles in the *Applied Ergonomics* (Kirwan, 1996; Kirwan, 1997; and Kirwan, Kennedy, Taylor-Adams, & Lambert, 1997), the main finding is that each technique was viable and valid as a method for use in calculating human reliability. While HEART is based on reliability estimates derived from data in the psychology and human factors literature, the reliability estimates generated from HEART are comparable to those calculated using THERP and JHEDI. Kirwan (1997) summarizes his findings as follows:

> Since HEART has been demonstrated to have empirical validity in at least one major validation exercise, this empirical and quantitative validity may satisfy those carrying out risk analyses whose over-riding concern (at least initially) is the provision of accurate numerical estimates of failure likelihood (p. 28).

It is important that Kirwan takes a conservative tone because he is not convinced that HEART (in addition to other HRA techniques) is an appropriate method to use when attempting to reduce human error. He takes issue with the notion that HEART may be used as an error reduction technique, as claimed in the technique's name. Despite this reservation, Kirwan agrees that HEART is an equally viable and valid option for conducting a HRA when compared to THERP and JHEDI.

From a practical standpoint, HEART is the most appealing choice among current HRA methods for the current assessment exercise. It is more expedient than other, more conventional HRA methods, as it does not require the use of an extensive database to assign error probabilities and PSFs that influence every aspect of a person's behavior. HEART also does not require the involvement of numerous SMEs to carry out the evaluation. In its simplest form, the only person required to carry out a HEART assessment is an analyst who is familiar with the technique and understands the operational domain under investigation. The analyst then examines the scenario under evaluations and selects the appropriate type of task and EPCs for the scenario.

HEART calculations are straightforward, and HRA estimates can be produced quickly once GTTs and EPCs have been identified. HEART can be applied to tasks at multiple levels of granularity. If reliability differences are not identified using high-level tasks, lower-level task elements can be used as a basis for HEART. In other words, HEART is scalable to researcher needs and methodological limitations and is well-suited to use with results from a HTA, which itself is a scalable method of characterizing tasks.

Several criticisms can be directed toward the HEART method, including that the probability estimates that form the basis of each task and condition are based on data predominantly from the laboratory human performance literature. These data may not be applicable (or meaningful) in the context of the operational railroad yard environment. Therefore, the assessment team selected an additional HRA technique to use to augment the findings derived from the HEART study. Another criticism is that HEART may not be sufficient to capture the complexity of the interactions and communications that occur between multiple team members. HEART also does not allow for consideration of recoveries in task performance; if an operator commits an error, some systems afford more opportunity to recover from that error than others, and HEART does not explicitly address these types of situations. Though HEART's GTT and reliability values associated with GTTs may not perfectly match railroad yard switching tasks, GTT and reliability values can serve as a practical approximation. In fact, a limitation of HEART is that its reliability ranges are conservative; the selection of one GTT and multiple EPCs with high APOAs can quickly drive an HEP to unity.

4.1.2 Use of APJ

Despite the criticisms and limitations associated with HEART, it is important to note the dearth of viable HRA alternatives available for the assessment of railroad yard operations. To date, an accessible collection of human reliability data for railroad yard operations does not exist, and most HRA applications continue to focus on highly procedural, single-operator tasks for process control environments. The United Kingdom is in the process of generating railroad-specific reliability data for its Safety Risk Model, but the model (and thus, reliability data) exclude yard switching activities. Applying HEART to the assessment of railroad yard operations will enable the assessment team to develop reliability estimates for conventional and RCL operations, based on established human performance data, without requiring a significant amount of time, resources, or training. However, HEART does not represent an infallible technique to arriving at human reliability estimates. The criticisms and limitations of the technique warranted the adoption of an additional approach to estimate human reliability, allowing for comparison of reliability estimates between the two methods.

The assessment team selected APJ as the second assessment method (discussed in more detail in Kirwan, 1994, and Comer, Seaver, Stillwell, & Gaddy, 1984). Unlike other HRA techniques, APJ does not require the selection of task types or the identification of PSFs that are mathematically combined to arrive at a reliability estimate. Instead, APJ relies on SME participants to generate estimates of human reliability based on their personal experiences and expertise in the domain. The premise behind APJ is that, absent an objective human reliability database, the next best database is the one contained within the minds of SMEs. Operational experts in the domain have the ability to recall personal experiences and compare them with other experiences to arrive at an estimate of the base rate for human reliability associated with various conditions and circumstances. SMEs can also compare their personal experiences with scenarios and circumstances presented in an APJ session and extrapolate estimates based on personal experience.

While SMEs are subject to biases and inaccuracies in their recollections of events and determination of reliability estimates, the estimates they develop provide an informative gauge of the perceived base rates associated with different events and scenarios. In addition, biases and misperceptions can be countered through the use of a group APJ approach. With this type of approach, multiple SMEs participate in the session and are encouraged to discuss their observations and perspectives to arrive at an estimate. A mediator facilitates the discussion to reduce peer influences and avoid domination by one particular person or perspective. Peer influences can also be countered by adopting a Delphi approach, in which participants record reliability estimates before discussion with the larger group. In the Delphi approach, a facilitator shares each of the reliability estimates with the group, and then participants have an opportunity to discuss their estimates and their rationale and basis for the estimates. Each participant is then given an opportunity to update his/her own reliability estimate based on the new information, or he or she may maintain his/her original estimate. A single estimate is then generated based on the latest estimates provided by participants (for example, by selecting the median or mean estimate value); this value approximates a consensus estimate.

4.1.3 Assumptions

Once it had selected the two HRA methods (HEART, APJ) to guide the assessment process, the study team outlined the assumptions and scope that the HRA would cover. Assumptions and scope criteria were established to help constrain the HRA to a feasible set of goals and activities while ensuring that the coverage of the assessment would provide for an informative comparison between RCL and conventional operations.

Each HRA method required the identification of scenarios and operational characteristics to ground the assessment and provide study participants with some context for evaluation. While an assessment of all possible RCL and conventional operations with all possible crew complements under all possible conditions would be ideal, the number of scenarios required to ensure sufficient coverage would be enormous. Therefore, the following constraints and assumptions were made for the operating scenarios that would be included in the assessment process:

Assumptions: Operational Scenarios

- Scenarios will be limited to a small sample of all possible railroad yard switching operating scenarios. These scenarios include different environmental conditions, yard locations (e.g., classification track versus a lead track), times-of-day, and operator characteristics.
- Scenarios are limited to initiating events that are considered operator error in nature. Other types of initiating events, such as physical failures or acts of nature, are not addressed.
- Scenarios will be developed to potentially result in the highest-risk outcomes identified in the PHA.
- A scenario will be defined as a yard move and specified as if it were a directive made by a yardmaster to a yard crew. Each scenario will consist of the equipment to move, a starting location and an end location. Additional information regarding how the move should be made may also be included. Thus, HRA scenarios may be thought of as yard moves. They will be designed with certain EPCs or PSFs so that certain types of outcomes may be more likely; however, actual outcome is not specified as it is in the PHA.
- Scenario outcomes may include employee injury, including fatal injury, and/or property damage, including accidents/derailments. Scenarios that result exclusively in delays or loss of productivity are not addressed.

Assumptions: Hazards

- Hazards will not address exposure to EMR and ergonomic considerations, such as the weight and harness design, except as they affect an RCO's performance in operating the RCD.
- The assessment will not consider risks to the public, such as at public grade-crossings or trespassers.
- The assessment will address only the active errors and conditions immediately preceding an accident/incident. The HRA will not address latent supervisory or organizationally-based policies, procedures, oversight, conditions, and activities that permit or contribute to risk, nor the preconditions that may contribute to risk.

Assumptions: System and Procedures

- RCL technology is limited to the newest generation of RCDs available as of 2002 (i.e., the speed control RCDs, not the previous generation of throttle-and-brake RCDs).
- The assessment will not consider differences in equipment design or functionality of different remote control manufacturers. Similarly, differences in locomotive equipment and specific railroad operating practices will not be addressed. The risk assessment will address these elements at a level where functionality and operating practices, are common across equipment or railroads.

- The assessment will not address distributed power, such as when a locomotive engineer controls locomotives located in the middle and/or rear of the train through remote control technology using the lead locomotive cab, even though distributed power is a form of RCL operation.
- The assessment will consider only independent brake maneuvers. Switching with the automatic train air will not be included. Although some RCOs and conventional yard crews switch cars with automatic air cut-in, it is less frequent than switching solely with the locomotive's independent brake(s).
- Only yard switching operations will be included. The assessment will not address operations on main tracks, spur/industrial tracks, or sidings.
- Each method of operation will consider only one crew configuration, a two-person RCO crew and a three-person conventional yard switching crew. These two crew configurations were selected because they currently reflect the most common configuration of each method of operation.

4.2 HRA Methodology

The HRA was conducted using the HEART method to quantitatively derive the reliability associated with RCL and conventional operations using pre-established reliability values, while the APJ method was used to elicit reliability estimates directly from railroad yard operations SMEs. For each method, study participants evaluated scenarios developed by the assessment team and derived from the results of the PHA. Whereas the PHA identified outcome types and the potential likelihood and severity of certain scenarios that result in these outcomes, HEART and APJ examined the likelihood of making errors that might lead to some of the outcomes identified in the PHA. Outcome types associated with the worst credible scenarios in the PHA were used in developing new scenarios that were examined using HEART and APJ.

The HEART process consists of an iterative procedure where an SME participant examines a scenario to identify the general type of task being performed along with the conditions that may influence performance in the specific scenario. The process consists of the following steps:

1. Review description of the scenario to be evaluated.
2. Identify the GTT that best approximates the task covered in the scenario.
3. Identify the EPCs that influence task performance in the scenario.
4. Assign an APOA associated with each EPC to indicate if the EPC has a small or large influence on task performance in the scenario.
5. Calculate the final HEP.

Most of the HEART process relies on examining a GTT and EPC list for each scenario being evaluated. The analyst must also determine the APOA associated with each EPC, based on the degree to which the EPC is believed to be in effect. Unfortunately, the author of the procedure provides no guidance on how to determine the APOA, so the assessment team established guidelines to facilitate this process. Kirwan (1994) advises that a large APOA should be used to represent the worst possible manifestation of a condition. To facilitate APOA selection for the current HRA, the team used a simple forced-choice of small or large for the APOA, informing participants that large should be used only when the scenario depicted conditions that were especially detrimental for crewmembers. After each GTT, EPC, and APOA has been selected and identified, a human reliability estimate can be readily calculated by performing a straightforward calculation.

Like the HEART method, the APJ process consists of a series of steps that are iteratively performed to elicit reliability estimates from operational experts. Because APJ relies on subjective recollections and assessments, it is best to perform APJ sessions with multiple SMEs who can compare their experiences and discuss their decisionmaking processes. The specific steps for the APJ are as follows:

1. Review description of the scenario to be evaluated.
2. Consult a probability chart to help determine the most likely frequency of occurrence of a human error in the scenario.
3. Record the HEP on a data response sheet.
4. Moderate the discussion of participants' decisionmaking processes and factors that were considered in developing their estimates.
5. Conduct a Delphi discussion group, anonymously revealing the HEPs that participants selected so each participant can see the range in the data.
6. Give participants an opportunity to revise their HEP estimates based on the discussion.

4.3 HRA Pilot Study

Due to the novelty of applying HEART and APJ to railroad yard operations, the assessment team conducted a pilot study to evaluate the feasibility of each method, determine the applicability of HEART and APJ for evaluating reliability in the railroad yard switching environment, and provide an opportunity to modify and streamline both methods for use in a formal HRA evaluation. From a procedural standpoint, both methods are straightforward and require minimal resources to deploy.

With the assistance of the United Transportation Union (UTU), the team recruited 13 RCOs to help evaluate HEART and APJ. While the team was ultimately interested in comparing similar operating scenarios under RCL operations and conventional yard operations, the pilot study concentrated solely on RCL operations to assess the feasibility and applicability of the selected HRA methods for railroad yard operations. To this end, the team was interested in the range of responses received from pilot study participants, looking for convergence across responses in terms of EPC and GTT identified for each task within each scenario, as well as APJ HEP estimates, as this convergence would help indicate some sensitivity and reliability in the method. Participants were encouraged to provide any comments, positive or negative, regarding the use and understanding of the HRA methods.

Appendix E contains a more complete description of the pilot study data collection methods and results. Despite the difficulties associated with interpreting the HEART data and the biases that likely influence the APJ approach, these approaches are believed to hold promise because they enable the assessment process to be conducted in a reliable and consistent manner that taps into participants' existing knowledge of yard switching operations and experiences. Furthermore, because both HRA methods can be used to evaluate different kinds of scenarios and different levels of task granularity, it is possible to present participants with tasks and scenarios at a level of detail that is compatible with their understanding and awareness of yard operations, that is, at the move level. The HRA methods have content validity by enabling scenarios to be described in terms that participants readily understand; that is, specific moves performed in the context of the operational railroad yard environment. Lastly, drawing on one method that contains built-in HEP values and relying on participants to generate HEPs in a second technique provides a balanced approach to assessing the relative risks of RCL and conventional yard switching operations.

4.4 HRA Main Study

The assessment team modified the HEART and APJ procedures in accordance with the feedback received from the pilot study, to improve the acceptability and usability of the procedures for the SMEs who participated in the main study. First, scenarios were developed to present tasks at the whole task (move) level instead of the smaller lettered task level used in the pilot study. This modification was made to enable participants to evaluate tasks at a level with which they were most familiar. Another modification included the provision of a laminated railroad yard map with dry-erase markers. Although pilot participants were given a yard map (Figure E-1 in Appendix E) to help them visualize and understand the moves and tasks being described, the assessment team believed that providing participants with laminated maps that could be marked up would help participants better visualize the moves and crew configurations involved.

Participants were also asked to review all of the lettered tasks (Table C-1) identified in the HTA. The assessment team gave each participant a copy of the lettered tasks and encouraged him or her to read each task so that he or she would be aware of the specific subtasks included in the risk assessment. A final change to both the HEART and APJ procedures included the facilitators reviewing all of the scenarios with participants before the assessment, allowing participants to mark up their yard maps to help them visualize and understand each move in detail before concentrating on the assessment of each scenario.

The purpose of reviewing the HTA lettered tasks and the scenarios before the assessment was to ensure that participants developed a common understanding of the particular subtasks involved in each move and the scenario details that would be involved in the assessment. Since many of the lettered tasks and their associated subtasks were viewed as automatic, the HTA review helped study participants to explicitly recall the specific steps required for the successful execution of various moves. By reviewing all of the scenarios included in the assessment, participants were able to understand the range of environments, operating conditions, and move details under investigation before they actually made their assessments. Reviewing the scenarios also provided participants the opportunity to consider the range of different conditions and reliability-related issues associated with the scenarios. This approach was designed as a pre-processing step to normalize participant thinking in terms of what would be involved in each scenario that he or she would be assessing.

Several modifications were also made to facilitate the HEART procedure. In the HEART pilot study, participants identified terminology in the GTT and EPC lists that they felt was confusing. Although facilitators clarified terminology during the HEART pilot study, these clarifications were formally added to the GTT and EPC lists to make the information available for all main study participants. After completing the pilot study, HEART participants were asked to identify the GTTs and EPCs they felt were most applicable to railroad yard operations. Based on the pilot study feedback, the GTT and EPC lists were re-ordered for presentation in the main study, based on frequency of response, to reflect the most applicable GTTs and EPCs. Although the lists used in the main study contained the same information provided to the pilot participants, the re-ordering of information was hoped to help expedite the location and identification of GTTs and EPCs that were expected to be most relevant for railroad yard scenarios.

4.4.1 Scenario Design

To inform the development of the scenarios to be used in the assessment, the results of the PHA were used to identify scenarios with the greatest potential to lead to high-consequence and/or high-frequency accidents/incidents. Generic PHA scenarios with high scores (i.e., the greatest risk) provided the basis for the development of operating scenarios to be assessed.

The assessment team developed 11 sets of scenarios to capture moves that could be performed under either conventional or RCL operations with 10 flat switching scenarios and 1 hump scenario. Scenarios were designed to include a variety of PSFs that could contribute to, or degrade, the reliability associated with the system being assessed. For each set, a scenario was developed to be evaluated in the context of a conventional yard switching operation, and an almost identical scenario was developed to be evaluated in the context of an RCL operation. Differences between the two scenarios in each set were based on operational differences (e.g., the presence of a locomotive engineer for a conventional crew and the absence of one in an RCL crew). Otherwise, the PSFs that were included in each scenario were the same within each set. For example, for a particular set of scenarios, one conventional scenario and one RCL scenario, the move to be made was the same, including the time of day, the number of other crews in the vicinity, and weather; all were matched between scenarios within each scenario set.

In addition to the 11 scenario sets, a 12th conventional scenario was developed for use in the RCL and conventional groups to serve as a common baseline scenario. The purpose of having a common scenario was to verify that each group's assessments were at least somewhat in-line with each other and not completely divergent. Divergent assessments of the same scenario might suggest the potentially confounding effect of group differences rather than differences based on the different methods of operation.

Table 8 presents a brief listing of the scenario sets and their potential outcomes. Scenarios were developed to potentially address the most risky of the outcomes as determined in the PHA. Outcomes[10] whose worst credible scenarios were associated with severity x likelihood of occurrence ratings greater than or equal to 12 were the focus of the HRA. These outcomes were identified in the PHA as having the greatest risk, for either RCL and/or conventional operations.

---

[10] One PHA outcome, slip/trip/fall, with a risk value of 12 was not included in the HRA since this outcome is typically associated with working on or around stationary equipment rather than operating the equipment, such as during a shove or kick. Slips, trips, and falls that are caused by operating equipment are covered under other outcomes, such as a fall resulting from a hard coupling. In this case, the potential outcome of interest would be the hard coupling.

Table 8. HRA main study scenario sets and potential outcomes

Scenario set	Potential outcome	PHA outcome number (see Table 7)
1	Potential to kick into side of a moving cut	6
2	Potential to shove into end of a moving cut	5
3	Potential to pull into end of a standing cut	1
4	Potential to pull into side of a moving cut	2
5	Potential to pull into own crewmember	3
6	Potential to pull into other employee	4
7	Potential to shove into own crewmember	7
8	Potential to kick into other employee	8
9	Potential for hard coupling-perfect day scenario	16
10	Potential for unexpected movement	17
11	Potential to pull into side of standing cut	2
12	Potential to shove over a derail (common scenario)	14

Similar to the pilot study, a number of fixed variables were identified and called out to participants. These were the assumptions that existed for each set of scenarios. Fixed operator characteristics included the following:

- Crewmembers were generally motivated to work by the rules (i.e., positive attitude) but understood that not all rules can be followed all the time and that sometimes rules are bent to get the job done.
- Crewmembers had a satisfactory relationship with local management and fellow employees.
- Crewmembers were current on all rules and other qualifications.
- Crewmembers had no work-impairing distractions at home.
- Crewmembers had no previously reported railroad infractions or rule violations.
- Crewmembers had a 30 minute (min) commute each way to and from work.
- Crewmembers wore the appropriate personal protective equipment (PPE).
- RCL-only operator characteristic: RCOs were initially a bit reluctant to use the RCD.

System characteristics included the following:

- 25 yr old road engines (locomotives) were used for switching.
- Locomotives were minimally maintained.

- Operations used the independent brakes only; automatic train air was not cut in.
- All crewmembers have two-way voice radios.
- Three radio channels are in use in the yard: one for crews in the west yard, one for crews operating in the middle yard, and one for east yard crews (see Figure 13).
- Night work was performed with flashlights, lanterns, or clip-on lights provided and approved by the railroad.
- The yardmaster on duty is overworked and does not know anything about RCL operations.
- All switches are two-way hand thrown switches.
- If a crewmember is riding a piece of equipment other than the locomotive, assume he or she is riding a 50 ft boxcar, unless otherwise noted.
- Crewmembers are not permitted by rule to mount and dismount moving equipment.
- RCL-only system characteristics:
    - The newest generation of RCD was being used.
    - The maximum speed selector setting is 10 mph.
    - Remote control safety features include tilt protection, vigilance alarm, and use of the independent brake.
    - Both RCOs have an RCD, though only one operates the RCL at a time.
    - RCOs are permitted to operate the RCD while riding equipment.
    - No RCZ unless otherwise specified.
    - No automatic pullback (stop) protection exists on the lead tracks.

A number of PSFs existed that the study team was interested in examining, including the following:

- crewmember age
- crewmember experience
- crewmember familiarity with each other
- type of assignment and work schedule
- training
- time-of-day
- weather
- PPE
- condition of yard
- yard lighting

- size of cut
- urgency of move
- presence and location of other crews

Different sets of scenarios incorporated different facets of these PSFs. For example, in some scenarios, crewmembers are in their 20s, and in other scenarios, they are in their 50s. Table 9 presents a breakdown of the different PSFs for the RCL scenarios, and Table 10 presents a breakdown of the different PSFs for the conventional scenarios. Since the 12th scenario is a conventional scenario (used as a baseline), it is included in Table 10 with the other conventional scenarios. To ensure that most participants would be able to understand and relate to the scenarios, PSFs were identified that were widely relevant. For example, rainy conditions were selected for inclement weather instead of winter snow, since most yard employees have worked in the rain, but a number of employees may not have experience switching in snow.

Figure 13 presents a diagram of the yard on which the scenarios are based. Although fictitious, the yard was designed to be a prototypical yard with elements that represent a number of different classification yards around the United States, both flat and hump switching, small and large. Copies of this diagram were given to each participant to use as an aid when conducting the assessments. Job numbers were assigned for each scenario to help distinguish the crew/job of interest from other crews in the vicinity. Crews working in the east yard were assigned numbers in the 200s. Crews working in the middle yard, including the hump, were assigned numbers in the 300s. Crews working in the west yard were assigned numbers in the 400s. The job of interest always ended in 01. Thus, if the scenario occurred in the east yard, the job of interest was 201; in the middle yard it was 301, and in the west yard it was 401.

A draft set of the RCL and conventional scenarios and a copy of the yard diagram was sent to two super-SMEs—railroad operating employees with over 25 yr of yard switchman experience (one had 29 yr experience, the other had 30 yr experience), including 2 yr each with RCL operations—to ensure scenarios were logical and would make sense to participants. Most of the feedback focused on the need for clarification when describing the scenarios relative to the yard diagram and additional editing of the scenarios. Feedback was incorporated into the final set of scenarios. The super-SME evaluation also provided some degree of face validity to the operating scenarios.

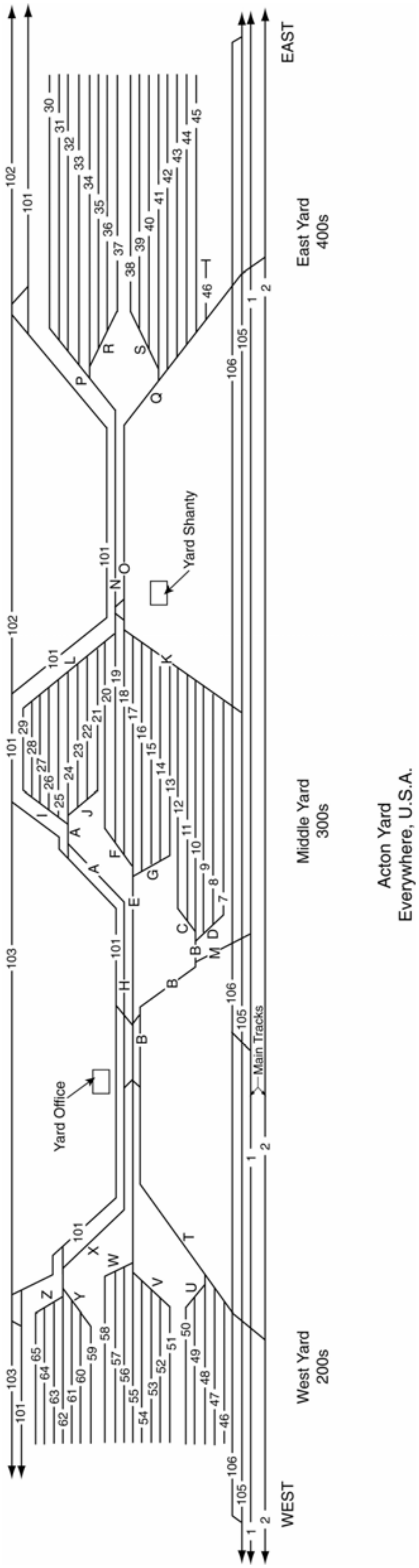


Figure 13. Yard diagram used in HRA main study

Table 9. PSFs for RCL scenarios

	Scenario					
	1-2	**3-4**	**5-6, and 11**	**7-8**	**9**	**10**
Crew age	20s	40s	50s	20s	30s	30s
Crew experience	2 mo as switchman 2 mo as RCO	5 yr as switchman 15 mo as RCO	20 yr as switchman 2 yr as RCO	1.5 yr as switchman 6 mo as RCO	15 yr as switchman 2 yr as RCO	8 yr as switchman 2 wk as RCO
Crewmembers familiar with each other?	Yes	Yes	Yes	No	Yes	No
Regular/extra work assignment	Regular	Extra board	Regular	Extra board	Regular	Regular
Last workday	3 d ago	Yesterday	Yesterday	2 d ago	3 d ago	Yesterday
Number of consecutive days worked	1 (This is the first day back after two days off)	7	5	1 (first day back after 1 day off)	1 (first day back after 1 day off)	6
Training (RCO)	40 h classroom + 40 h hands-on on-the-job training (OJT). OJT was one-on-one instruction so RCOs had full opportunity to practice. Trained at another terminal.	40 h classroom + 40 h OJT. The OJT was shadowing an RCO mentor and got to use the box about 1/3 of the time. Trained at another terminal.	40 h classroom + 40 h training with RCO, 2 d shadowing, and 3 d working with empties on special track. Trained at this terminal.	1 wk classroom (was let go early each day) + 40 h sharing a box with another classmate (approx 15 h actual time). Trained at this terminal.	40 h classroom + 40 h hands-on OJT. OJT was one-on-one instruction so RCOs had full opportunity to practice. Trained at this terminal.	40 h classroom training + 40 h training with RCO, 2 d shadowing, and 3 d working with empties on special track. Trained at another terminal.
Time-of-day	10 p.m.	12 noon	4 a.m.	6:30 a.m.	9 a.m.	3 p.m.
Weather	Rainy, 60s	Sunny, Humid, 93°	Windy, 70°	Mid-40s	65° and sunny	Mid-30s

	Scenario					
	1-2	**3-4**	**5-6, and 11**	**7-8**	**9**	**10**
PPE	Work gloves, safety glasses, safety boots	Work gloves, safety glasses, safety boots	Work gloves, safety glasses, safety boots	Work gloves, safety glasses, safety boots	Work gloves, safety glasses, safety boots	Thick winter gloves, safety glasses, safety boots
Condition of yard	Poorly maintained	Adequate	Adequate	Poorly maintained	Adequate	Poorly maintained
Yard lighting	Poor	N/A	Adequate	Poor	N/A	N/A
Size of cut	20 empties, 5 loads	30 loads	120 loads including 35 Hazmat (6 & 11)	15 empties, 40 loads	45 loads	45 loads
Urgency	None	High	None	None	None	High
Location of other crews	One other crew in vicinity	Three crews in the vicinity	One crew in the vicinity—6 only	Two other crews in the vicinity	One crew in vicinity	Two other crews in the vicinity

Table 10. PSFs for conventional scenarios

	Scenario					
	1-2	**3-4**	**5-6 & 11**	**7-8**	**9**	**10, 12**
Crew age	20s	40s	50s	20s		30s
Crew experience[11]	Loco Engr: 1 yr Foreman: 2 mo Helper: 2 mo	Loco Engr: 2 yr Foreman: 1 yr Helper: 1 yr	Loco Engr: 30 yr Foreman: 15 yr Helper: 6 mo	Loco Engr: 4 yr Foreman: 4 yr Helper: 4 yr	Loco Engr: 20 yr Foreman: 10 yr Helper: 10 yr	Loco Engr: 7 yr Foreman: 1 yr Helper: 2 wk
Crewmembers familiar with each other?	Yes	Yes	Yes	No	Yes	No
Regular/extra work assignment	Regular	Extra board	Regular	Extra board	Regular	Regular
Last workday	3 d ago	3 d ago	Yesterday	Yesterday	3 d ago	Yesterday
Number of consecutive days worked	1 (This is the first day back after 2 d off)	7	5	1 (first day back after 1 d off)	1 (first day back after 1 d off)	6
Training	Regular Loco Engr training. Regular Yd training. Trained at another terminal.	Regular Loco Engr training. Regular Yd training. Trained at another terminal.	Regular Loco Engr training. Regular Yd training. Trained at this terminal.	Regular Loco Engr training. Regular Yd training. Trained at this terminal.	Regular Loco Engr training. Regular Yd training. Trained at this terminal.	Regular Loco Engr training. Regular Yd training. Trained at another terminal.
Time-of-day	10 p.m.	12 noon	4 a.m.	6:30 a.m.	9 a.m.	3 p.m.
Weather	Rainy, 60s	Sunny, Humid, 93°	Windy, 70°	Mid-40s	65° and sunny	Mid-30s

---

[11] Foreman and helper experience are defined in terms of switchman experience. The only reason to distinguish between foreman and helper here is because the amount of their experience will differ between the two crewmembers in some scenarios.

	Scenario					
	1-2	**3-4**	**5-6 & 11**	**7-8**	**9**	**10, 12**
PPE	Work gloves, safety glasses, safety boots	Work gloves, safety glasses, safety boots	Work gloves, safety glasses, safety boots	Work gloves, safety glasses, safety boots	Work gloves, safety glasses, safety boots	Thick winter gloves, safety glasses, safety boots
Condition of yard	Poorly maintained	Adequate	Adequate	Poorly maintained	Adequate	Poorly maintained
Yard lighting	Poor	N/A	Adequate	Poor	N/A	N/A
Size of cut	25 empties	30 loads	120 loads including 35 Hazmat (6 & 11)	15 empties, 40 loads	45 loads	45 loads
Urgency	None	High	None	None	None	High
Location of other crews	One other crew in vicinity	Three crews in the vicinity	One crew in the vicinity—6 only	Two other crews in the vicinity	One crew in vicinity	Two other crews in the vicinity

RCL scenarios

The following presents each of the 12 (11 RCL plus one conventional) scenarios generated for the RCL assessors.

Scenario 1 (potential to kick into side of a moving cut)

It is rainy and 60° F (all temperatures are in Fahrenheit) at 10 p.m. The RCL crew consists of a yard foremen and helper who each have 2 mo experience as a switchman and RCO. Each is in his/her 20s. Their RCO training consisted of 40 h of classroom instruction and 40 h of one-on-one OJT with an instructor. Their OJT took place in another terminal. This is their regular assignment. Both crewmembers are coming off 2 d of rest. The yard is poorly maintained and poorly lit.

Job 304 is the only other crew working in the yard at the moment. This second crew is shoving a cut eastward up leads K and O. One crewmember is hanging on the side of the cut on the point.

Instructions from the yardmaster for Job 301 are to shove 20 empties and 5 loads eastward up the E and F leads and kick 5 loads into track 18, where 40 cars are already tied down on the east end of the track. The F lead switch is currently lined for 17, a clear alley.

Scenario 2 (potential to shove into end of a moving cut)

It is rainy and 60° at 10 p.m. The RCL crew consists of a yard foreman and helper who each have 2 mo of experience as a switchman and RCO. Each is in his/her 20s. Their RCO training consisted of 40 h of classroom instruction and 40 h of one-on-one OJT with an instructor. Their OJT took place in another terminal. This is their regular assignment. Both crewmembers are coming off 2 d of rest. The yard is poorly maintained and poorly lit.

One other crew is working in the yard at the moment, Job 304, which is shoving westward from the L lead into track 26.

Job 301 is shoving 20 empties and five loads eastward up leads H, A, and I into track 26. Track 25 is filled with cars and obstructs the foreman's view of track 26.

Scenario 3 (potential to pull into end of a standing cut)

It is 12 noon, humid, and 93°. The RCL crew consists of a yard foremen and helper, both of whom are in their 40s. Each has 5 yr of experience as a switchman and 15 mo experience as an RCO. RCO training involved 40 h of classroom instruction and OJT that consisted of shadowing a mentor who let them use the box about 1/3 of the time. Their OJT took place in another terminal. This is their seventh straight day on the job. They are working the extra board. The yard is adequately maintained.

While typically only one other crew works in the yard at the same time, because of some delays earlier in the day, two other crews are working in the yard at the moment. All jobs are trying to make up for lost time. Job 312 is currently standing on H, with the rear of the cut just short of A. They are waiting for other jobs to get in the clear before pulling westward, then shoving eastward to track 23 off the J lead. Job 324 is shoving eastward along E and into the F lead.

Job 301 is building a train. The foreman is standing at I and 25 pulling 30 loads out of 25 westward along I, A, and into H. Their next move is to shove eastward into track 29 and couple to more cars. His helper is riding the east end of the pull.

Scenario 4 (potential to pull into side of a moving cut)

It is 12 noon, humid, and 93°. The RCL crew consists of a yard foremen and helper, both of whom are in their 40s. Each has 5 yr of experience as a switchman and 15 mo experience as an RCO. RCO training involved 40 h of classroom instruction and OJT that consisted of shadowing a mentor who let them use the box about 1/3 of the time. Their OJT took place in another terminal. This is their seventh straight day on the job. They are working the extra board. The yard is adequately maintained.

A westbound train, Job 316, is coming off track 9, onto D, to the B and T leads, and onto Main 1.

Job 301, promised an early quit, is pulling 30 loads out of 17 westward along the E lead in order to shove back eastward up the F lead and kick into track 19. The foreman is on the ground on the corner between E and G leads. The helper is riding the side of the cut. The crossover from E to B is currently lined to enter B.

Scenario 5 (potential to pull into own crewmember)

It is 4 a.m., windy, and in the 70s. Each crewmember is in his 50s and has 20 yr of experience as a switchman. They marked up as RCOs 2 yr ago when the first boxes were brought into the yard. Their training included 40 h classroom and then, for their OJT, 2 d observing and 3 d moving 5 empties back and forth along a secluded track. Their OJT took place at this terminal. This is their regular job. Both crewmembers have worked the last 5 d straight. The yard is adequately maintained and adequately lit.

Job 301 is running a light engine eastward along H to enter track 21 off the J lead. It is currently west of the eastward crossover from H-to-E. The helper is already up at J, walking along track 21 making sure all the cars are coupled together. The foreman is walking east along E, expecting the locomotive to be moving eastward on H. The eastward crossover from H-to-E is currently lined for E.

Scenario 6 (potential to pull into other employee)

It is 4 a.m., windy, and in the 70s. Each crewmember is in his 50s and has 20 yr of experience as a switchman. They marked up as RCOs 2 yr ago when the first boxes were brought into the yard. Their training included 40 h classroom and then, for their OJT, 2 d observing and 3 d moving 5 empties back and forth along a secluded track. Their OJT took place at this terminal. This job is their regular job. Both crewmembers have worked the last 5 d straight. The yard is adequately maintained and adequately lit.

One other crew is in the vicinity, Job 216, working westward off leads 101 and Z.

The E, H, and X leads are all part of a RCZ used by this crew, Job 301. Job 301 is tripling over tracks 15, 16, and 17. In order to make a 120 car pull, the movement must enter into the Z lead. The switch is lined for track 62. An employee from another job is on the handbrake platform tying handbrakes on a cut that is standing on the east end of track 62.

Scenario 7 (potential to shove into own crewmember)

It is 6:30 a.m., cool in the mid-40s. Each crewmember has 1 ½ yr of switchman experience and 6 mo of experience as RCOs. Each is in his 20s. The crew received minimal classroom instruction and had to share one box with a second RCO student during their 40 h of OJT. The result was that these RCOs actually practiced with the box about 15 h during their OJT. Their

OJT took place at this terminal. The yard is poorly maintained and poorly lit. This is an extra board assignment. Both crewmembers just returned from 1 d rest.

Two other crews are working in the yard at the moment. Job 413 is pulling eastward on the Q lead to enter track 106. Job 424 is shoving westward along track 102.

Job 401 is shoving 15 empties and 5 loads westward on lead O, to N, up lead L, and into clear track 20. The switch on lead N is currently lined for track 19. The helper is walking westward along the north side of track 19 and is going between cars, adjusting knuckles and drawbars preparing for the next move.

Scenario 8 (potential to kick into other employee)

It is 6:30 a.m., cool in the mid-40s. Each crewmember has 1 ½ yr of switchman experience and 6 mo of experience as RCOs. Each is in his 20s. The crew received minimal classroom instruction (they were let go early each day) and had to share one box with a second RCO student during their 40 h of OJT. The result was that these RCOs actually practiced with the box about 15 h during their OJT. Their OJT took place at this terminal. The yard is poorly maintained and poorly lit. This is an extra board assignment. Both crewmembers just returned from 1 d rest.

Two other crews are working in the yard at the moment. Job 413 is pulling eastward on the Q lead and onto track 106. Job 424 is shoving westward from track 101 onto track 102.

Job 401 is shoving eastward along lead N, into leads P and R, and begins kicking cars into tracks 30-33. As Job 401 kicks 3 tank cars into track 32, a clerk (trackman) is walking across a gap in the cuts from tracks 34 to 31.

Scenario 9 (potential for hard coupling—perfect day scenario)

It is 9 a.m., 65°, and sunny. Each crewmember has 15 yr experience as a switchman and 2 yr as an RCO. They are each in their 30s. Their RCO training included 40 h of classroom instruction and 40 h of OJT, where each student RCO worked one-on-one with an instructor. Their OJT took place at this terminal. The yard is well maintained. This is a regular assignment, and the crewmembers have been working with each other for the past 2 yr. Both crewmembers have also just come off of 2 d of rest.

Job 315 is the only other job in the vicinity. A crewmember on Job 415 is standing up and stretching his legs inside his cab, while the crew is waiting for permission from the yardmaster to leave the yard for an industrial area. The locomotive is on the west end of a cut standing on track 106 on the east of the M lead just south of track 7.

Job 301 is shoving a heavy, 45 car cut eastward through leads B and M and towards track 106.

Scenario 10 (potential for unexpected movement)

It is 3 p.m. and just above freezing. Each crewmember has 8 yr of switchman experience and 2 wk of RCO experience. They are in their 30s. Their training was 40 h classroom and OJT was 2 d observing and 3 d moving 5 empties back and forth along a secluded track. Their OJT took place at another terminal. Job 401 is a regular assignment, but they have only been working with each other for a week. Both crewmembers have also worked the last 6 d straight. The yard is poorly maintained.

Two other crews are working in the east yard.

Job 401, in a bit of a rush to get inside to warm up, moves eastward along leads O and Q, shoving 45 loads eastward into track 42. The OCC suddenly applies the locomotive's brakes and causes heavy slack action. The foreman and helper are both riding the side of the cut.

Scenario 11 (potential to pull into side of standing cut)

For scenario 11 only, assessors are asked to imagine that the yard is now a hump operation (whereas previously it had been a flat yard).

It is 4 a.m., windy, and in the 70s. Each crewmember is in his 50s and has 20 yr of switchman experience and marked up as RCOs 2 yr ago when the first boxes were brought into the yard. Their training included 40 h of classroom instruction followed by OJT which consisted of 2 d observing and 3 d moving 5 empties back and forth along a secluded track. Their OJT took place at this terminal. This job is their regular assignment. Both crewmembers have worked the last 5 d straight. The yard is adequately maintained and adequately lit.

The crest is immediately to the left of the letter E in the yard diagram. The 301 hump job is instructed to hump cars on lead E into tracks 13-20. The crew is pulling westward along 101 to the cross over to H, to E, and then to lead W. Cars are hanging out to foul the east end of track 56.

Scenario 12 (common scenario—potential to shove over a derail)

It is 3 p.m., just above freezing. The locomotive engineer has 7 yr of engineer experience, the foreman has 10 yr of switchman experience, and the helper, new to the railroad, qualified 2 wk ago as a switchman. All are in their 30s. This is a regular assignment. Each crewmember has also worked the last 6 d straight. The yard is poorly maintained.

Two other crews are working in the vicinity. Job 409 is moving westward along track 105. Job 411 is shoving eastward on the P lead into tracks 32 and 33.

Job 401, making its last move of the day and in a hurry to be done, is shoving eastward along lead Q to spot a car on oil spur 46. This spur has a derail located on the west end entrance to protect the tank cars on the spur. The helper is riding the point.

Conventional scenarios

The following presents each of the 12 scenarios generated for the conventional yard switching operations assessors. They are very similar to their RCL counterpart; differences lie mainly in operational differences (e.g., the presence of a locomotive engineer in the conventional scenarios).

Scenario 1 (potential to kick into side of a moving cut)

It is rainy and 60° at 10 p.m. The crew consists of a locomotive engineer with 1 yr of experience and a yard foremen and helper who each have 2 mo experience as switchmen. Their OJT took place in another terminal. All are in their 20s. This is their regular assignment. Each crewmember is coming off of 2 d of rest. The yard is poorly maintained and poorly lit.

Job 304 is the only other crew working in the yard at the moment. This second crew is shoving a cut eastward up leads K and O. One crewmember is hanging on the side of the cut on the point.

Instructions from the yardmaster for Job 301 are to shove 20 empties and 5 loads eastward up the E and F leads and kick 5 loads into track 18, where 40 cars are already tied down on the east end of the track. The F lead switch is currently lined for 17, a clear alley.

Scenario 2 (potential to shove into end of a moving cut)

It is rainy and 60° at 10 p.m. The crew consists of a locomotive engineer with 1 yr experience and a yard foreman and helper who each have 2 mo of switchman experience. Their OJT took place in another terminal. All are in their 20s. This is their regular assignment. Each crewmember is coming off of 2 d of rest. The yard is poorly maintained and poorly lit.

One other crew is working in the yard at the moment, Job 304, which is shoving westward from the L lead into track 26.

Job 301 is shoving 20 empties and 5 loads eastward up leads H, A, and I into track 26. Track 25 is filled with cars and obstructs the foreman's view of track 26.

Scenario 3 (potential to pull into end of a standing cut)

It is 12 noon, humid, and 93°. The crew consists of a locomotive engineer with 2 yr experience and a yard foreman and helper who each have 1 yr of switchman experience. Their OJT took place in another terminal. All are in their 40s. This is their seventh straight day on the job. They are working the extra board. The yard is adequately maintained.

While typically only one other crew is working in the yard at the same time, because of some delays earlier in the day, two other crews are working in the yard at the moment. All jobs are trying to make up for lost time. Job 312 is currently standing on H, with the rear of the cut just short of A. They are waiting for other jobs to get in the clear before pulling westward, then shoving eastward to track 23 off the J lead. Job 324 is shoving eastward along E and into the F lead.

Job 301 is building a train. The foreman is standing at I and 25 pulling 30 loads out of 25 westward along I, A, and into H. Their next move is to shove eastward into track 29 and couple to more cars. His helper is riding the east end of the pull.

Scenario 4 (potential to pull into side of a moving cut)

It is 12 noon, humid, and 93°. The crew consists of a locomotive engineer with 2 yr experience and a yard foreman and helper who each have 1 yr of switchman experience. Their OJT took place in another terminal. All are in their 40s. This is their seventh straight day on the job. They are working the extra board. The yard is adequately maintained.

A westbound train, Job 316, is coming off track 9, onto D, to the B and T leads, and onto Main 1.

Job 301, promised an early quit, is pulling 30 loads out of 17 westward along the E lead to shove back eastward up the F lead and kick into track 19. The foreman is on the ground on the corner between E and G leads. The helper is riding the side of the cut. The crossover from E to B is currently lined to enter B.

Scenario 5 (potential to pull into own crewmember)

It is 4 a.m., windy, and in the 70s. The locomotive engineer has 30 yr experience as an engineer, and the yard foreman has 15 yr experience as a switchman. The helper is newer and has 6 mo experience as a switchman. Their OJT took place at this terminal. All are in their 50s. This is their regular job. This crew has worked the last 5 d straight. The yard is adequately maintained and adequately lit.

Job 301 is running a light engine eastward along H to enter track 21 off the J lead. It is currently west of the eastward crossover from H-to-E. The helper is already up at J, walking along track 21 making sure all the cars are coupled together. The foreman is walking east along E, expecting the locomotive to be moving eastward on H. The eastward crossover from H-to-E is currently lined for E.

Scenario 6 (potential to pull into other employee)

It is 4 a.m., windy, and in the 70s. The locomotive engineer has 30 yr experience and the yard foreman has 15 yr experience as a switchman. The helper is newer and has 6 mo experience as a switchman. Their OJT took place at this terminal. All are in their 50s. This is their regular job. This crew has worked the last 5 d straight. The yard is adequately maintained and adequately lit.

One other crew is working in the vicinity, Job 216, working westward off leads 101 and Z.

Job 301 is tripling over tracks 15, 16, and 17. In order to make a 120 car pull, the movement must enter into the Z lead. The switch is lined for track 62. An employee from another job is on the handbrake platform tying handbrakes on a cut that is standing on the east end of track 62.

Scenario 7 (potential to shove into own crewmember)

It is 6:30 a.m., cool in the mid-40s. The locomotive engineer has 4 yr experience as an engineer and the foreman and helper each have 4 yr experience as switchmen. Their OJT took place at this terminal. All are in their 20s. The yard is poorly maintained and poorly lit. This is an extra board assignment. Each crewmember just returned from 1 d rest.

Two other crews are working in the yard at the moment. Job 413 is pulling eastward on the Q lead to enter track 106. Job 424 is shoving westward along track 102.

Job 401 is shoving 15 empties and five loads westward on lead O, to N, up lead L, and into clear track 20. The switch on lead N is currently lined for track 19. The helper is walking westward along the north side of track 19 and is going between cars, adjusting knuckles and drawbars preparing for the next move.

Scenario 8 (potential to kick into other employee)

It is 6:30 a.m., cool in the mid-40s. The locomotive engineer has 4 yr experience as an engineer, and the foreman and helper each have 4 yr experience as switchmen. Their OJT took place at this terminal. All are in their 20s. The yard is poorly maintained and poorly lit. This is an extra board assignment. Each crewmember just returned from 1 d rest.

Two other crews are working in the yard at the moment. Job 413 is pulling eastward on the Q lead and onto track 106. Job 424 is shoving westward from track 101 onto track 102 .

Job 401 is shoving eastward along lead N, into leads P and R, and begins kicking cars into tracks 30-33. As Job 401 kicks 3 tank cars into track 32, a clerk (trackman) is walking across a gap in the cuts from tracks 34 to 31.

Scenario 9 (potential for hard coupling—perfect day scenario)

It is 9 a.m., 65° and sunny. The locomotive engineer has 20 yr experience as an engineer. The yard foreman and helper have 10 yr experience as switchmen. Their OJT took place at this terminal. They are all in their 30s. This is a regular assignment, and crewmembers have been working with each other for the past 2 yr. This crew has also just come off of 2 d of rest.

Job 315 is the only other job in the vicinity. A crewmember on Job 415 is standing up and stretching his legs inside his cab, while the crew is waiting for permission from the yardmaster to leave the yard for an industrial area. The locomotive is on the west end of a cut standing on track 106 on the east of the M lead just south of track 7.

Job 301 is shoving a heavy, 45 car cut eastward through leads B and M and towards track 106.

Scenario 10 (potential for unexpected movement)

It is 3 p.m., just above freezing. The locomotive engineer has 7 yr of engineer experience, the foreman has 1 yr of switchman experience, and the helper, new to the railroad, qualified 2 wk ago as a switchman. Their OJT took place at another terminal. All are in their 30s. This is a regular assignment. Each crewmember has also worked the last 6 d straight. The yard is poorly maintained.

Two other crews are working in the east yard.

Job 401, in a bit of a rush to get inside to warm up, moves eastward along leads O and Q, shoving 45 loads eastward into track 42. The locomotive engineer suddenly, and unannounced, applies the locomotive's brakes and causes heavy slack action. The foreman and helper are both riding the side of the cut.

Scenario 11 (potential to pull into side of standing cut)

For scenario 11 only, assessors are asked to imagine that the yard is now a hump operation (whereas previously it had been a flat yard).

It is 4 a.m., windy, and in the 70s. The locomotive engineer has 30 yr experience, and the yard foreman has 15 yr experience as a switchman. The helper is newer and has 6 mo experience as a switchman. Their OJT took place at this terminal. All are in their 50s. This is their regular job. This crew has worked the last 5 d straight. The yard is adequately maintained and adequately lit.

The crest is immediately to the left of the letter E in the yard diagram. The 301 hump job is instructed to hump cars on lead E into tracks 13-20. The crew is pulling westward along 101 to the cross over to H, to E, and then to lead W. Cars are hanging out to foul the east end of track 56.

Scenario 12 (common scenario—potential to shove over a derail)

It is 3 p.m., just above freezing. The locomotive engineer has 7 yr of engineer experience, the foreman has 1 yr of switchman experience, and the helper, new to the railroad, qualified 2 wk ago as a switchman. Their OJT took place at another terminal. All are in their 30s. This is a regular assignment. Each crewmember has also worked the last 6 d straight. The yard is poorly maintained.

Two other crews are working in the vicinity. Job 409 is moving westward along track 105. Job 411 is shoving eastward on the P lead into tracks 32 and 33.

Job 401, making its last move of the day and in a hurry to be done, is shoving eastward along lead Q to spot a car on oil spur 46. This spur has a derail located on the west end entrance to protect the tank cars on the spur. The helper is riding the point.

4.4.2 Study Design

The HEART and APJ exercises were conducted at two locations—a large city in the southern United States (location A) and a large city in the midwestern United States (location B)—to include multiple SMEs with experience in different yard environments under different operating procedures and environmental characteristics. Locations were identified with the assistance of the UTU.

HEART

HEART is traditionally used by one assessor, or a group of assessors participates in a consensus exercise to identify appropriate GTTs, EPCs, and APOAs. In this study, the HEART assessment comprised a within-subjects design where one SME participant completed a HEART assessment at each location, for a total of two participants. Each HEART session was scheduled for 4 h, which provided sufficient time for preparation, review, and evaluation of all of the RCL and conventional scenarios. Each participant was compensated for his/her participation.

A within-subjects design was selected for the HEART assessments because only one individual participated in each evaluation, and the assessment team believed that the structured assessment process of HEART helps minimize biases that the participant might have in favor of, or against, a particular method of operation (RCL versus conventional). The primary reason for having only one individual participate in the HEART assessment at a time was due to the amount of detail covered by the method, as well as the number of GTTs and EPCs that had to be reviewed and evaluated. The addition of other participants could have increased confusion, making it difficult to complete the assessment in the allotted time. Having one participant complete the HEART assessment at a time also increased the amount of attention and discussion that the facilitators could spend with the participant.

Each participant was first provided with an explanation of the exercise and the general research questions under investigation. Each participant then reviewed all of the scenarios included for the evaluation, to develop a better understanding of the kinds of scenarios and operational characteristics under consideration for the study.

Because each participant evaluated the RCL and the conventional scenarios, the presentation order for evaluation was counterbalanced to minimize order effects. The first participant evaluated all of the conventional scenarios first, whereas the second participant evaluated all of the RCL scenarios first.

APJ

The APJ assessments comprised a between-subjects design, with two groups of participants (one conventional, one RCL) participating at each location (for a total of four groups). Each APJ session was scheduled for 2 h, although this time proved insufficient for participants to review all the scenarios. Each participant was compensated for his/her participation.

Because the principal tenet behind APJ is that participants can generate reliable estimates based on personal experiences and feedback from other experts, the study team conducted APJ sessions with participants with similar amounts of experience.

A between-subjects design was selected for the APJ assessments due to the group nature of the

APJ method. To increase the likelihood that participants had similar operational experiences, the team recruited participants with similar experience in one type of operation or the other (i.e., RCL or conventional) for each APJ session. The use of a between-subjects design also helped prevent a group from deliberately evaluating one type of operation less favorably than the other. Although participants reviewed only conventional or RCL scenarios, the scenario order was counterbalanced in an effort to counter any effects of presentation order.

Participants

At each location, locomotive engineers and switchmen were recruited to participate in the conventional APJ sessions, and RCOs were recruited to participate in the RCL APJ sessions. For the HEART assessment, one individual with both RCO and conventional operations experience (as a switchman) was recruited to participate from each location.

Participants were recruited with the assistance of UTU (switchmen and RCOs) and the Brotherhood of Locomotive Engineers and Trainmen (locomotive engineers). Two selection criteria were established to help identify candidate participants:

- Participants in the conventional APJ sessions must have a minimum of 5 yr yard experience (as yard engineers or switchmen), while RCOs must have a minimum of 1 yr of RCO experience. Ideally, RCOs would have also had at least 5 yr of experience, but this was not feasible given the recent implementation of RCL operations in the United States
- Participants could not hold an elected union office position (e.g., local chairperson or secretary-treasurer of the local union chapter).

Table 11 presents a breakdown of the number of participants in each APJ/HEART session in each of the two locations.

Table 11. HEART and APJ participant demographics for main study

	Location A (southern United States)		**Location B (midwestern United States)**	
	Conventional	RCL	Conventional	RCL
HEART	1		1	
APJ	4	3	3	4

Table 12 presents demographic information for all 14 APJ participants while Table 13 presents demographic information for the two HEART participants.

Materials

Materials were similar to those used during the pilot study except that participants were also provided with laminated yard maps and dry-erase markers to facilitate visualization of each scenario and copies of the HTA lettered tasks to review the tasks and subtasks involved in each scenario.

Table 12. APJ main study participants

Participant number	Age	Current craft	Total yr experience in current craft	Total yr experience in railroad industry
1	33	RCO	1	2
2	41	RCO	2	5
3	61	RCO	2.25	30
4	54	Locomotive Engineer	30	33
5	60	Locomotive Engineer	26	32
6	53	Switchman	31.33	31.33
7	61	Switchman	25	27
8	46	Locomotive Engineer	13	28
9	56	Locomotive Engineer	27	32
10	52	Switchman	31	33
11	33	RCO	N/A*	8*
12	36	RCO	N/A*	11*
13	44	Switchman/RCO	10**	24
14	24	RCO	1.6	1.6
*Participants recorded switchmen experience and did not differentiate from RCO experience.				
** Experience includes as an RCO in another country and more recently in the United States				

Table 13. HEART main study participants

Participant number	Age	Current craft	Total yr experience in current craft	Total yr experience in railroad industry
1	55	RCO	1	33
2	51	RCO	1.5	31

HEART participants were provided with GTT and EPC lists (Appendix F and Appendix G), as well as response sheets (Appendix H), to record GTT, EPC, and APOA selections for each scenario. The team customized the GTT and EPC lists to improve understanding of the terms and information covered. For GTTs and EPCs, the team provided definitions and descriptions to help clarify potentially unfamiliar or confusing HEART terms.

The team provided APJ participants with a probability list (Appendix I), depicting the range of probabilities and related chances associated with each probability to consider for the evaluation, and response sheets (Appendix J) to record their first and second HEP for each scenario. The probability list provided a visual reference for participants to see how individual probability values translated into chances of occurrence, while also providing a scale to depict high versus low chances of making a mistake. The team also gave APJ participants slips of paper on which to record their first HEP estimate and then pass to the facilitator so it could be anonymously presented to the group during the Delphi discussion.

General procedure

Participants for both the HEART and APJ sessions were first provided with general instructions about the purpose of the exercise (to learn more about reliability and human-related risks associated with conventional and RCL operations) and were asked to provide general demographic information (not associated with their identity) regarding railroad experience. Participants were then given a list of the HTA lettered tasks to review, then the facilitator read aloud each scenario. Participants were encouraged to diagram and record information on the laminated map to better visualize the scenario and the move being described. All of the scenarios were initially read to participants before the evaluation process, including general information regarding the yard and crew characteristics (such as yard maintenance, general layout, types of equipment in use, general attitudes of the crew and yardmaster, and general procedures that were followed). Participants were encouraged to ask clarification questions as needed.

After clarifying any questions that participants had, the HRA session began with the facilitator providing the scenario identification number (to be recorded by each participant) and then reading through the specific scenario under evaluation. For each scenario, the move was described as though it were an instruction given by the yardmaster, supported by the yard map showing where the move would be made. After the scenario was described, participants could ask for clarification or repetition of the scenario as necessary to ensure they understood the scenario. Participants then followed the specific HEART or APJ procedure, as described in the next two sections.

Participants in both the HEART and APJ sessions conducted their first assessment with a baseline scenario (scenario # 12); the results of which were not included in the data analysis. This baseline scenario described a conventional move[12] and was provided so that participants could get some experience with the process and ask any clarification questions that they had about the process. For the baseline scenario, the facilitators provided feedback and guidance on how the process might be carried out. For the remaining scenarios, the facilitators did not provide feedback regarding the specific considerations that the participants should make in conducting their assessment.

HEART procedure

The facilitator first discussed the HEART assessment process, explaining how to use the GTT and EPC lists and how to code the selections on the response sheet.

---

[12] Participating RCOs also had conventional yard switching experience, so use of a conventional scenario provided a common denominator or baseline between the two groups.

For each scenario, the participant studied the move and consulted the list of task types (GTTs) to match the move to the most appropriate GTT. If the participant felt that multiple GTTs were applicable to the task, he/she recorded the most applicable GTT first, followed by other GTTs that may apply.

The participant then consulted the lists of conditions (i.e., EPCs) to identify each EPC that was believed to apply to the move and scenario under consideration. After recording each EPC, the participant recorded the degree to which the condition is believed to influence the task (small or large) in the impact on task (i.e., APOA) column.

When the process was complete, the facilitator introduced the next scenario, and the process was repeated.

APJ procedure

The facilitator first discussed the APJ assessment process, explaining how to think about the scenarios and estimate probabilities based on past experiences and observations, as well as how to record the probabilities on the response sheets.

For each scenario, participants considered the details of the scenario and examined the probability list to identify a probability that best fits with each participant's experience. This process often took a considerable amount of time, as participants tried to recall similar scenarios from their own experiences. After identifying an appropriate probability, each participant recorded the probability estimate on the response sheet.

To facilitate the next step, the Delphi discussion of initial reliability estimates, participants recorded a copy of their reliability estimate on a slip of paper that was handed to the facilitator. The facilitator collected the slips of paper and then led a discussion of the factors that participants considered in order to arrive at their reliability estimate, ensuring that each participant had an opportunity to share experiences and opinions to reduce potential peer influences. After the group discussion, the facilitator anonymously revealed the range of probability estimates contained on the slips of paper and provided an opportunity for additional discussion. After this discussion, the facilitator asked participants to revise their estimates if desired and to record the new estimate on their data collection sheet. If participants chose to retain their initial estimate, they recorded the same number twice.

The facilitator then introduced the next scenario for evaluation, and the process was repeated. After all of the moves and scenarios had been evaluated, the facilitator asked participants to discuss the strengths and weaknesses associated with the APJ method, as well as the positive and negative characteristics associated with RCL and conventional operations.

4.4.3 HRA Results

Both participants in the HEART sessions were able to assess all 11 scenarios provided for both conventional and RCL operations. However, one participant left his/her response sheet blank for one scenario, therefore a HEP was not available for this scenario (conventional scenario # 4).

All of the APJ participants recorded HEP estimates for all of the scenarios that were presented. However, due to the unanticipated amount of time spent discussing and assessing the scenarios, only the first seven scenarios were assessed before the 2 h period was up. Consequently, only about half of the scenarios that were developed for the study were assessed through APJ. To be consistent, APJ participants in both locations assessed the same seven scenarios.

Although HEART is a within-subjects design (i.e., the same participant assesses both methods of operation), each participant is not actually assigning HEPs. In this regard, the HEART method protects against a participant intentionally trying to generate biased data for or against one or the other methods of operation. In APJ, participants generate actual HEPs, but, since the APJ design is between subjects, participants assess either RCL operations or conventional operations, not both. Thus, participants are not in a position to bias results since they only provide the assessments for the method of operation for which they are responsible.

To examine the HEP data, a criterion of acceptable precision was adopted from Kirwan (1996) and applied to both examination of differences and reliability among HEP assessments. This criterion is based on the general practice used by analysts in the HRA field, where "most estimates are within a factor of 10 of the true value" (Kirwan, 1996, p. 362). Specifically, HEPs that are within 1 order of magnitude (OOM) are considered equal, while HEPs that are 1 OOM or more apart from each other are considered different. With regard to the reliability of HEP estimates, since true HEP values are not known for conventional and RCL operations, acceptable precision is defined as the maximum number of HEP estimates that fall within 1 OOM of each other based on all combinations of HEPs.

To clarify, consider the fictional HEP values in Participants often selected multiple GTTs during the assessment process. Due to this variability (discussed in more detail below), the HEP values were calculated in a manner that ensured the most consistent results possible. Following the best-practice recommendations from Kirwan (1997), when participants selected multiple GTTs, the GTT associated with the lowest HEP was used as the basis for the HEP calculation. Furthermore, Williams (1988) provides three unreliability values associated with each GTT: the nominal human unreliability value, an upper (95th percentile) unreliability value, and a lower (5th percentile) unreliability value. The nominal human unreliability values were used in calculating final HEPs.

Table 14. In this example, the greatest number of HEPs that are within 1 OOM of each other include 0.1, 0.3, and 0.5. Thus, in this example, three participants' HEPs were within 1 OOM of each other. Other combinations of HEP values are within 1 OOM of each other (e.g., 0.001 and 0.002); however, the largest number of HEP values within 1 OOM *from each other* is the 3 HEP values previously identified (0.1, 0.3, and 0.5). So, these three values are used to represent the common HEPs within 1 OOM.

HEART results

The HEPs from the HEART study were calculated for each scenario, for each HEART participant. The process of calculating each HEP is straightforward and discussed in full detail in Williams (1988). A brief summary of the process is as follows. The facilitator first consults each probability value associated with the GTTs and EPCs that were identified by the HEART participant. Each EPC probability value is then multiplied by a factor associated with the APOA (the small or large level of influence indicated by the participant in the impact on task column on the response sheet). For simplicity, an APOA of small was set at 25 percent of the maximum EPC probability value, and an APOA of large was set at 75 percent of the maximum EPC probability value. Thus, each EPC identified by the participant would be weighted by 25 or 75 percent of its full value, depending on the impact on task specified by the participant. The final step of the HEART calculation process is to multiply the GTT probability (which represents a baseline HEP level) by each weighted EPC probability to increase the HEP in accordance with the EPCs present in the scenario.

Participants often selected multiple GTTs during the assessment process. Due to this variability (discussed in more detail below), the HEP values were calculated in a manner that ensured the most consistent results possible. Following the best-practice recommendations from Kirwan (1997), when participants selected multiple GTTs, the GTT associated with the lowest HEP was used as the basis for the HEP calculation. Furthermore, Williams (1988) provides three unreliability values[13] associated with each GTT: the nominal human unreliability value, an upper (95th percentile) unreliability value, and a lower (5th percentile) unreliability value. The nominal human unreliability values were used in calculating final HEPs.

Table 14. Sample HEP values to illustrate calculation of common HEPs within 1 OOM

Participant number (example only)	HEP value (example only)	Associated with the largest number of HEPs within 1 OOM of each other
1	0.5	√
2	0.3	√
3	0.1	√
4	0.01	
5	0.002	
6	0.001	
7	0.0001	

Table 15 presents the resulting HEP data from the HEART sessions. The table identifies HEP estimates generated by each participant, listed by scenario and type of operation (conventional (CONV) or RCL). Within each scenario and participant, the less reliable HEP is presented in a grey shaded cell if the HEP is at least 1 OOM larger than the comparative HEP. As a more extreme comparison, HEPs that are at least 2 OOM larger than their comparative HEPs are presented in boldface in a grey shaded cell.

As is evident in Table 15, considerable variability exists in the HEP data. Using the 1 OOM criterion, both participants identified 4 conventional scenarios as more unreliable than their RCL counterparts, 3 RCL scenarios as more unreliable than their conventional counterparts, and the remaining scenarios with no difference. Using the 2 OOM criterion does not clarify the picture, with both participants generating HEP values that show a small number of scenarios favoring RCL or conventional and most scenarios showing no difference.

The HEPs generated by HEART participants resulted in a similar number of cases where (1)

---

[13] Unreliability refers to the likelihood of an error occurring and thus is another term to refer to HEP. Though the study refers to operator reliability, in practice this reliability is quantified as HEP. When discussing Williams' original HEP values for the GTT, this report uses his terminology (i.e., unreliability).

RCL scenarios were worse than conventional scenarios, (2) conventional scenarios were worse than RCL scenarios, and (3) no difference existed (see Table 15). At least two conclusions are possible. The first possibility is that the HEART data demonstrate that each method of operation is associated with some degree of risk, and that this risk depends on the scenario. The second possibility is that the HEART data demonstrate that, for whatever reason, the HEART method is insufficient, insensitive, or invalid as a technique for comparing human reliability in railroad yard switching operations as deployed in this study.

Table 15. HEART HEP data using GTT nominal human unreliability values

Scenario	Location A		Location B		Agreement between participants? (Common HEPs within 1 OOM)	
	CONV	RCL	CONV	RCL	CONV-CONV	RCL-RCL
S1	1.000	0.240	0.032	0.452	No	Yes
S2	0.066	0.001	1.000	1.000	No	No
S3	0.002	0.005	1.000	1.000	No	No
S4	(missing)	0.0007	**1.000**	0.0006	N/A	Yes
S5	0.0009	**0.013**	0.002	0.0008	Yes	No
S6	0.004	0.002	**0.098**	0.00006	Yes	No
S7	0.006	**1.000**	0.0004	**0.036**	Yes	No
S8	**1.000**	0.022	0.009	0.004	No	Yes
S9	0.340	0.014	0.015	0.013	Yes	No
S10	0.011	0.118	0.0002	**0.716**	No	Yes
S11	0.002	0.001	**0.011**	0.0004	Yes	Yes
Number of scenarios with greater HEPs (shaded cells; at least 1 OOM)	4 CONV worse than RCL 3 RCL worse than CONV 3 scenarios with no difference		4 CONV worse than RCL 3 RCL worse than CONV 4 scenarios with no difference		5 of 10 estimates for CONV agree	5 of 11 estimates for RCL agree
Number of scenarios with greater HEPs (boldface in shaded cells; at least 2 OOM)	1 CONV worse than RCL 2 RCL worse than CONV 7 scenarios with no difference		3 CONV worse than RCL 2 RCL worse than CONV 6 scenarios with no difference			

Potential insight into these possibilities is provided by looking at the degree of agreement between the two HEART participants for each scenario. The acceptable precision criterion used in the pilot study was applied, and HEPs were compared between participants for each common scenario. On the right-hand side of Table 15, in the agreement between participants column, comparisons are shown for HEPs generated by each participant for the same scenarios. For example, the CONV-CONV column displays whether the HEPs generated by both participants for the same conventional scenario are within 1 OOM of each other. For both types of operation (conventional and RCL), participants were within an acceptable degree of precision for about half the scenarios (5 of 10 HEPs for conventional, and 5 of 11 HEPs for RCL). Given that participants generated HEPs that were within 1 OOM for about half of the scenarios, this raises a question regarding the reliability of the HEART participants and possibly that of the HEART method.

One possible reason for the lack of consistency in the HEPs and level of agreement between participants may be due to the nature of the HEART GTT data that were used to calculate the final HEP values. The HEART method provides a range of values for GTTs, including the nominal unreliability value, a lower 5th percentile value, and an upper 95th percentile value. Nominal GTT values were used for the initial HEP calculations. However, it may be more appropriate to use the more reliable 5th percentile values when calculating the HEPs, since railroad yard employees are generally highly skilled and motivated workers. The lower range GTT value is more conservative and represents a lower chance of making an error.

HEPs were re-calculated using the 5th percentile GTT unreliability values to reflect an initial relatively high reliability. Table 16 presents the results. Because the GTT value is the dominant value in the HEP calculation, the effect of using the 5th percentile value versus the nominal value is that the HEPs decreased. Despite this overall decrease in HEP values, though, the comparison between conventional and RCL operations was not substantially changed. The HEP data still reveal a lack of agreement between participants and no clear pattern in favor of one type of operation over another. Similar to Table 15, within each scenario and participant, the less reliable HEP is presented in a grey shaded cell if the HEP is at least 1 OOM larger than the comparative HEP. As a more extreme comparison, HEPs that are at least 2 OOM larger than their comparative HEPs are presented in boldface in a grey shaded cell.

One notable change in the data is that the pattern of agreement appears to shift for the comparison of CONV-CONV HEPs and RCL-RCL HEPs across participants. While participants were within 1 OOM for about half of their HEP estimates for the CONV-CONV and RCL-RCL comparisons when the nominal GTT unreliability values were used, these numbers change when the 5th percentile GTT unreliability values are used. Using nominal GTT unreliability values, participants showed agreement for the conventional operations estimates for 5 of 10 scenarios, but using the lower 5th percentile GTT values, agreement decreased to only 2 of 10 scenarios. In contrast, participants showed agreement for the RCL operations estimates for 5 of 11 scenarios when the nominal GTT unreliability values were used, but using the lower 5th percentile GTT unreliability values, agreement increased to 8 of 11 scenarios. More generally, by using the lower 5th percentile GTT values, all of the HEPs decreased, revealing more agreement in estimates generated for RCL scenarios and less for conventional scenarios. Despite this change in the proportion of scenarios in which participants generated similar estimates, the bottom line result is that the HEPs were still unable to reveal a clear difference in reliability between RCL and CONV operations.

An additional aspect to consider is the source of the variability observed in the data. Because HEART is dependent on the selection of tasks and conditions from specific lists of information, the frequency of selection for GTTs and EPCs was examined for conventional and RCL scenarios.

Table 17 depicts the frequencies associated with the GTTs selected by the HEART participants for all scenarios. The first column presents the GTT description, followed by the total number of times each GTT was selected. The third and fourth columns show the number of times each GTT was selected for conventional versus RCL operations. The fifth and sixth columns depict the number of times the GTT was selected by each participant. The last column on the right shows the nominal unreliability value associated with the GTT, used as the baseline HEP before being modified by the weighted EPC values selected by the participant.

Table 16. HEART HEP data using GTT 5th percentile human unreliability values

Scenario	Location A		Location B		Agreement between participants? (Common HEPs within 1 OOM)	
	CONV	RCL	CONV	RCL	CONV-CONV	RCL-RCL
S1	1.000	0.180	0.008	**0.339**	No	Yes
S2	**0.013**	0.0002	1.000	1.000	No	No
S3	0.0003	0.001	1.000	1.000	No	No
S4	(missing)	0.0001	**1.000**	0.0001	N/A	Yes
S5	0.0002	0.003	0.0004	0.0002	Yes	Yes
S6	0.0009	0.0004	**0.065**	0.00002	No	Yes
S7	0.001	**0.948**	0.00009	**0.007**	No	No
S8	**1.000**	0.004	0.002	0.001	No	Yes
S9	**0.255**	0.003	0.003	0.003	No	Yes
S10	0.002	0.024	0.00006	**0.251**	No	Yes
S11	0.0004	0.0002	**0.002**	0.00008	Yes	Yes
Number of scenarios with greater HEPs (shaded cells; at least 1 OOM)	4 CONV worse than RCL 3 RCL worse than CONV 4 scenarios with no difference		3 CONV worse than RCL 3 RCL worse than CONV 5 scenarios with no difference		2 of 10 estimates for CONV agree	8 of 11 estimates for RCL agree
Number of scenarios with greater HEPs (boldface in shaded cells; at least 2 OOM)	3 CONV worse than RCL 1 RCL worse than CONV 7 scenarios with no difference		3 CONV worse than RCL 3 RCL worse than CONV 5 scenarios with no difference			

The most commonly-selected GTT was selected 26 times, and it was selected nearly equally for conventional and RCL scenarios. Both participants selected this GTT more often than they did any other GTT. Because GTT selection is a major driver of the final HEP values, an imbalance in GTTs represents a large contributor to variability in the HEP data. Indeed, the GTTs represented in the last five rows of the table reflect those that were selected by one participant but not the other. This type of imbalance demonstrates that the participants did not agree about the GTT assignment for a substantial number of scenarios.

Table 17. HEART GTT selection frequency

GTT description	Total	CONV	RCL	Location A participant	Location B participant	Nominal human unreliability value
Completely familiar, well-designed, highly practiced routine task, oft-repeated and performed by well-motivated, highly trained individual with time to correct failures but without significant job aids	26	12	14	16	10	0.0004
Complex task requiring high level of comprehension and skill	10	5	5	5	5	0.16
A task that requires a response to a system with an automated support tool providing the operator with accurate information of the current state of the system	3	1	2	0	3	0.00002
Totally unfamiliar, performed at speed with no idea of likely consequence	1	1	0	0	1	0.55
Fairly simple task performed rapidly or given scant attention	1	1	0	0	1	0.09
Routine, highly-practiced, rapid task involving relatively low level of skill	1	0	1	0	1	0.02
A task to restore or shift system to original or new state following procedures, with some checking	1	1	0	0	1	0.003

To further understand the inconsistencies associated with how participants selected GTTs, GTT assignments were examined in terms of which GTT each participant assigned to each scenario. Table 18 depicts the specific GTT selected for each scenario by each participant. In the table, A is used to indicate the GTT selected for each scenario by the first participant, while B is used to indicate the GTT selected for each scenario by the second participant. (The fourth scenario for conventional operations was not evaluated by the first participant.)

The GTT assignments illustrated in the table further emphasize the inconsistencies revealed by the GTT selection frequencies between the HEART participants. The second participant (B) selected a larger range of GTTs than the first participant (A), who restricted his selections to only the first two GTTs presented on the list. Of the total 22 scenarios that were evaluated, participants selected the same GTTs for only 8 scenarios, with 3 conventional scenarios being assigned the same GTT and 5 RCL scenarios being given the same GTT.

In addition to investigating the frequency of the GTTs selected by participants, the selection frequency of EPCs was also examined. Table 19 depicts each EPC, along with the total number of times it was applied by a participant to a scenario. The table also breaks down the total number of times the EPC was applied to a conventional or RCL scenario, as well as the number of times it was selected by each participant (A or B). The EPC multiplier is presented in the table for reference, depicting the degree to which the EPC can increase the HEP of the scenario.

While a total of 39 EPCs were available for consideration for each task, the participants never selected 14 EPCs. These EPCs are presented below the single solid line at the bottom of Table 19. Thus, while participants were encouraged to select all EPCs they felt applied to each task, about 36 percent of the EPCs were never deemed applicable to the scenarios under investigation. Although this is not a problem in and of itself, it highlights the possibility that many HEART EPCs may not be appropriate for railroad yard switching operations or at least the yard switching scenarios that were under investigation for this study.

Table 18. HEART GTT assignments by scenario

GTT description	Conventional scenarios											RCL scenarios										
	1	2	3	4	5	6	7	8	9	10	11	1	2	3	4	5	6	7	8	9	10	11
Completely familiar, well-designed, highly practiced…		A	A		A B	A	A B	B	B	A	A B		A	A	A B	A B	A	B	A	A B	A	A B
Complex task requiring high level of comprehension…	A		B	B				A	A			A B	B	B				A				
A task that requires a response to a system…										B							B		B			
Totally unfamiliar, performed at speed…		B																				
Fairly simple task performed rapidly…						B																
Routine, highly-practiced, rapid task…																					B	
A task to restore or shift system…	B																					

In contrast to the EPCs that were never selected by participants, the HEART participants repeatedly selected 5 EPCs. The HEART participants selected each of these EPCs for at least 10 of the scenarios. These EPCs are presented above the double-solid line at the top of Table 19. The fact that these EPCs were selected a number of times by both participants supports the notion that both participants saw the applicability of each EPC. However, it is important that the participants did not select these EPCs with equal frequency; some EPCs were selected more often by one participant than the other.

This imbalance in selection frequency is even more pronounced in the remaining 20 EPCs presented in the middle of the table. These EPCs were each selected at least one time by at least one of the participants, but many were selected by one HEART participant and not the other.

This lack of agreement in applying EPCs to scenarios could reflect regional differences in how yard operations take place (with only one participant seeing the applicability of an EPC based on his experiences and understanding of yard operations in his region), but it may also result from confusion stemming from how EPCs are worded or ambiguity in how a specific EPC might apply to a given railroad operating scenario.

Because the purpose of examining the EPC selection frequency is to highlight the sources of inconsistency in the HEART reliability outcomes, it is not informative to examine how each EPC was selected in detail. However, a small number of cases are reviewed to highlight some of the questions of interest that emerge from the use of the HEART method. For example, the second EPC listed in the table (task pacing caused by the intervention of others) was selected for a total of 25 scenarios, with the first participant (A) applying it to 15 scenarios, and the second participant (B) applying it to 10 scenarios. This EPC was applied to 14 conventional scenarios and 11 RCL scenarios. If both participants were in perfect agreement, then it would be expected that they would both select this EPC an equal number of times.

Table 19. HEART EPC selection frequency

Description	Total	CONV total	RCL total	A participant Total	B participant Total	EPC multiplier
Operator inexperience (such as a newly-qualified craftsman, but not an expert)	25	16	9	16	9	3.00
Task pacing caused by the intervention of others	25	14	11	15	10	1.06
Unfamiliarity with a situation which is potentially important but which only occurs infrequently or which is novel	19	10	9	12	7	17.00
The need to transfer specific knowledge from task to task without losing (forgetting) that knowledge	13	1	12	10	3	5.50
Task performance standards are unclear or confusing	10	6	4	4	6	5.00
Poor or confusing information conveyed by procedures and person-to-person interaction	8	5	3	0	8	3.00
Disruption of normal work-sleep cycles	6	4	2	5	1	1.10
A need for making decisions which are beyond the capabilities or experience of an operator	6	2	4	4	2	1.60
A poor or hostile environment (below 75% of health or life-threatening severity)	6	6	0	1	5	1.15
A danger that the physical abilities to perform task will be exceeded	5	1	4	0	5	1.40
A shortage of time available for error detection and correction	5	2	3	0	5	11.00

Description	Total	CONV total	RCL total	A participant Total	B participant Total	EPC multiplier
Inconsistency of meaning between displays and procedures	4	2	2	0	4	1.20
No clear or timely confirmation to the operator of a performed action	4	1	3	0	4	4.00
High-level emotional stress	4	1	3	4	0	1.30
A mismatch between perceived and real risk	4	1	3	1	3	4.00
No means of conveying technical information (position, location, system state) to operators in a form which they can readily understand	2	0	2	0	2	8.00
Alarms or signals are not easily heard over other noises present in the environment	2	1	1	1	1	10.00
Low workforce morale	2	1	1	2	0	1.20
Age of personnel performing perceptual tasks	2	2	0	0	2	1.02
A mismatch between the educational achievement level of an individual and the requirements of the task	2	0	2	0	2	2.00
Unclear allocation of function and responsibility	1	1	0	0	1	1.60
No obvious means of reversing an unintended action	1	1	0	1	0	8.00
Noticeably unreliable equipment (i.e., faulty gauges, inaccurate feedback, no feedback)	1	1	0	0	1	1.60
Poor, ambiguous, or ill-matched system feedback	1	1	0	0	1	4.00
Little or no intrinsic meaning in a task	1	0	1	0	1	1.40
Prolonged inactivity or highly repetitious cycling of low mental workload tasks (for first half-hour)	0	0	0	0	0	1.10
Prolonged inactivity or highly repetitious cycling of low mental workload tasks (for each hour thereafter)	0	0	0	0	0	1.05
No diversity of information input for veracity checks	0	0	0	0	0	2.50
Little or no independent checking or testing of output	0	0	0	0	0	3.00
A need to unlearn a technique and apply one which requires the application of an opposing philosophy	0	0	0	0	0	6.00

Description	Total	CONV total	RCL total	A participant Total	B participant Total	EPC multiplier
A mismatch between an operator's view of the world and that imagined by a designer	0	0	0	0	0	8.00
An easily accessible means of suppressing or over-riding information or features, such as disabling fail-safes and alarms	0	0	0	0	0	9.00
No obvious way to keep track of progress during an activity	0	0	0	0	0	1.40
Information overload, particularly caused by several pieces of information presented at the same time	0	0	0	0	0	6.00
Evidence of ill-health amongst operatives, especially fever	0	0	0	0	0	1.20
Little opportunity to exercise mind and body outside the immediate confines of the job	0	0	0	0	0	1.80
An incentive to use other more dangerous procedures	0	0	0	0	0	2.00
A conflict between immediate and long-term goals	0	0	0	0	0	2.50
Additional team members over and above those necessary to perform task normally and satisfactorily (per additional man)	0	0	0	0	0	1.03

To further illustrate the inconsistency in EPC selection, the first EPC displayed under the double line ("Poor or confusing information conveyed by procedures…") was selected for a total of eight scenarios, but it was selected by only the second participant. Although this participant applied the EPC to five conventional and three RCL scenarios, the fact that the first participant never selected this EPC highlights an inconsistency associated with the HEART method. The source of this inconsistency is not clear; it may result from differences in how the HEART participants understand and interpret each EPC, a difference in how each participant applied the EPC to the scenario, a regional difference, or another reason altogether. Regardless of the reason, this inconsistency in EPC selection, combined with the inconsistency in GTT selection discussed previously, highlights a source of concern associated with the HEART approach.

Despite the cautions that must be taken in interpreting the HEART data, it is important to consider that HEART is not usually applied in the manner it was applied in this study. HEART is an assessment technique that is traditionally deployed for use by one human reliability assessor, who may or may not work with SMEs to determine the applicability of the GTTs and EPCs to the scenarios under investigation. In a typical assessment procedure, the one evaluator will identify the tasks and scenarios under consideration, identifying the most applicable GTTs, EPCs, and APOAs for the assessment. After selecting the GTTs, EPCs, and APOAs, the evaluator then calculates the resulting HEPs and reports them as the final value for the assessment. Because additional evaluators are not engaged in the HEART assessment, no comparisons can be made and no assessment of inter-rater reliability addressed. However, the assessment team determined that several questions existed about the applicability of the HEART approach from the start and thus adopted an approach that relied on more than one evaluator and SME.

The substantial number of differences in the data demonstrates that the participants' understanding of the scenarios—and how the GTTs and EPCs applied to them—was inconsistent, leading to inconsistent HEPs. Due to the amount and degree of variability in HEPs across many of the scenarios, it is prudent to interpret the HEART data with caution. Although the data may indeed indicate that HEPs for conventional and RCL scenarios are heavily dependent on scenario-based factors, such as operating conditions and move types, the more likely explanation from the results is that participants were poorly calibrated to one another, either as a result of insufficient training on HEART, poor understanding of the scenarios, or a lack of fit between the HEART method and railroad yard operations. It is also possible that two assessors are simply too few to yield consistent results; with a greater number of HEART participants, greater consistency (central tendency theory) may emerge among scenario assessments. That is, the variability found here may be an artifact of the sample size; the two assessors may statistically reflect the two extremes of a distribution. It is also feasible that HEART simply works best with one assessor, as is common practice with HEART.

APJ results

Because the APJ sessions required participants to generate their own HEPs for each scenario, no calculation was necessary to arrive at a final HEP for each participant. Each participant's second estimate (potentially revised based on the group discussion process) represents the final HEP for a given scenario. Table 20 presents the results from the APJ sessions. Because the time required to brief APJ participants and conduct the initial scenarios was greater than expected, participants were able to complete assessments of only 7 of the 11 scenarios that were developed for the study. Table 20 presents median HEP values generated by the four APJ groups, listed by scenario and type of operation (conventional or RCL). Medians are presented instead of means because the extreme values generated by this type of exercise can skew measures of central tendency. For each scenario and group, the more unreliable HEP is presented in a grey shaded cell if the HEP is at least 1 OOM larger than the comparative HEP. As a more extreme comparison, HEPs that are at least 2 OOM larger than their comparative HEPs are presented in boldface in a grey shaded cell.

While the individual HEP values vary across a large range, the patterns in the data are consistent with a trend toward greater HEP for RCL scenarios than conventional scenarios. Using the 1 OOM criterion for the first location (A) data, six RCL scenarios have higher HEPs than their conventional counterparts, while only one conventional scenario was rated as higher than its RCL counterpart (sign test result: $s = 1$, $n = 7$, $p = .125$). For the second location data, all seven RCL scenarios were rated with higher HEPs than their conventional counterparts (sign test result: $s = 0$, $n= 7$, $p = .016$).

Despite the support for a potential trend toward higher HEP for RCL scenarios, only some of the APJ ratings met the criteria for acceptable precision (i.e., within 1 OOM of each other). Four of the seven HEPs for conventional scenarios met the criterion of acceptable precision, while only two of seven HEPs for RCL scenarios met the criterion.

Table 20. APJ HEP data (median values)

Scenario	Location A		Location B		Agreement between groups? (Common HEPs within 1 OOM)	
	CONV	RCL	CONV	RCL	CONV-CONV	RCL-RCL
S1	0.00055	0.001	0.001	**0.275**	Yes	No
S2	**0.3**	0.001	0.005	**0.5**	No	No
S3	0.00075	**0.01**	0.001	**0.5**	Yes	Yes
S4	0.000075	0.0005	0.01	0.5	No	No
S5	0.000005	**0.0001**	0.000005	**0.5**	Yes	No
S6	0.000055	0.0001	0.0001	**0.255**	Yes	No
S7	0.00001	**0.01**	0.01	0.3	No	Yes
Number of scenarios with greater HEPs (shaded cell; at least 1 OOM)	1 CONV worse than RCL 6 RCL worse than CONV 0 scenarios with no difference		0 CONV worse than RCL 7 RCL worse than CONV 0 scenarios with no difference		4 of 7 estimates for CONV agree	2 of 7 estimates for RCL agree
Number of scenarios with greater HEPs (boldface in shaded cell; at least 2 OOM)	1 CONV worse than RCL 3 RCL worse than CONV 3 scenarios with no difference		0 CONV worse than RCL 5 RCL worse than CONV 2 scenarios with no difference			

Because the APJ study was designed as a between-subjects study, the comparison of RCL and conventional HEPs does not need to be restricted to comparing values within each location. Although the argument could be made that data from participants at each location should be compared only with other data generated from the same location (possibly due to similar operating procedures or geographic yard characteristics), it may be informative to compare the data between locations, such as comparing the conventional data from the first location (A) with the RCL data from the second location (B). Table 21 presents results from this comparison. For each scenario and group, the more unreliable HEP is presented in a grey shaded cell if the HEP is at least 1 OOM larger than the comparative HEP. As a more extreme comparison, HEPs that are at least 2 OOM larger than their comparative HEPs are presented in boldface in a grey shaded cell.

The results for the A conventional-B RCL comparison indicate that six RCL scenarios were associated with greater HEPs than their conventional counterparts (sign test result: s = 0, n = 6, p =.031). However, most scenarios showed no difference in HEP ratings in the B conventional-A RCL comparison (sign test result: s = 1, n = 3, p = 1.000).

Due to the lack of consistent agreement among the four APJ groups, data for each group was analyzed through analysis of variance (ANOVA) to determine the degree of statistical variability because of differences in participant responses (i.e., to examine individual differences). Before ANOVAs were run, the raw HEPs were log-transformed to counter the influence of extremes in the data, as recommended by Kirwan (1994). Table 22 presents the resulting ANOVA data.

Table 21. Cross-location comparison of APJ HEP data (median values)

Scenario	A CONV—B RCL		B CONV—A RCL	
S1	0.00055	**0.275**	0.001	0.001
S2	0.3	0.5	0.005	0.001
S3	0.00075	**0.5**	0.001	0.01
S4	0.000075	**0.5**	**0.01**	0.0005
S5	0.000005	**0.5**	0.000005	**0.0001**
S6	0.000055	**0.255**	0.0001	0.0001
S7	0.00001	**0.3**	0.01	0.01
Number of scenarios with greater HEPs (shaded cell; at least 1 OOM)	0 CONV worse than RCL 6 RCL worse than CONV 1 scenario with no difference		1 CONV worse than RCL 2 RCL worse than CONV 4 scenarios with no difference	
Number of scenarios with greater HEPs (boldface in shaded cell; at least 2 OOM)	0 CONV worse than RCL 6 RCL worse than CONV 1 scenario with no difference		1 CONV worse than RCL 1 RCL worse than CONV 5 scenarios with no difference	

The ANOVAs show reliable main effects for scenarios for each APJ group. This result indicates that participants generated substantially different HEPs depending on the different scenarios being evaluated and is somewhat expected because different scenarios were designed to result in different HEPs. A reliable main effect of participants for three of the four APJ groups also exists, indicating that participants generated substantially different HEPs from each other. This result is not desirable, as it indicates a considerable degree of variability in the data based on the individual who was generating the HEP. This variability is further reflected in the intraclass coefficient, which represents the degree to which the variance from participants correlate with each other. A higher coefficient (up to a value of 1.0) is more desirable, as it signifies the degree with which participant ratings are in agreement with each other.

Another way to look at the agreement between how participants generate HEPs is by examining the correlations between pairs of participants. Correlations between log-transformed HEPs for each APJ participant were examined for conventional and RCL operations and are presented in Table 23 (conventional scenarios) and Table 24 (RCL scenarios). HEP data from the two HEART participants were also included in the correlation for comparison.

Three points are worth noting in the correlation tables. First, relatively few correlations were statistically significant. Seven correlations were statistically significant (two-tailed, $p<0.05$) among conventional participants, while four correlations were statistically significant among RCL participants. Statistically significant correlations are denoted with an asterisk in Table 23 and Table 24. The likely explanation for so few statistically significant correlations is the small sample size ($n = 7$); the more participants there are, the greater the power to yield a statistically significant correlation. Since correlations were conducted to look only at the degree of agreement among pairs of participants and not to make any type of inference about the general population of yard employees, the practical meaning of the coefficient values is more important than whether a correlation is statistically significant.

Table 22. ANOVAs for APJ HEP data (based on log-transformed data)

	ANOVA for scenarios	ANOVA for participants	Intraclass coefficient
A CONV	F(6,27)=24.41, p=.0000001	F(3,27)=4.317, p=.018	0.322
A RCL	F(6,20)=8.728, p=.0008	F(2,20)=5.286, p=.023	0.380
B CONV	F(6,20)=11.790, p=.0002	F(2,20)=1.703, p=.223	0.091
B RCL	F(6,27)=2.697, p=.048	F(3,27)=6.291, p=.004	0.430

Table 23. Correlation for log-transformed APJ and HEART HEPs for conventional scenarios

	P11	P12	P13	P14	P8	P9	P10	HEART B participant	HEART A participant
P11	1.000								
P12	0.984*	1.000							
P13	0.916*	0.930*	1.000						
P14	0.911*	0.942*	0.945*	1.000					
P8	0.517	0.404	0.484	0.437	1.000				
P9	0.492	0.383	0.252	0.294	0.752	1.000			
P10	0.634	0.566	0.382	0.428	0.672	0.927*	1.000		
HEART B participant	0.714	0.642	0.674	0.701	0.532	0.345	0.257	1.000	
HEART A participant	0.583	0.547	0.629	0.384	0.435	0.464	0.479	0.185	1.000
* p<0.05, two-tailed test									

This leads to the second point worth noting, which is that the degree of correlation among participants varies considerably. While some variability is expected, correlations near zero indicate that participants are generally assigning HEP values in a completely inconsistent manner with each other. The third observation based on the correlation data is that several negative correlations among RCL scenario participant pairs exist. Negative correlations indicate that, for a given pair of participants, they are actually rating scenarios in an *opposite* manner to one another, with one participant providing increasingly greater (i.e., less reliable) HEP values for a set of scenarios and the other providing increasingly smaller (i.e., more reliable) HEP values for the same set of scenarios. At the very least, this type of pattern indicates a lack of agreement in how participants are evaluating the same scenarios. A closer look at the correlations indicates that most of the negative correlations appear to result from a small number of participants (namely P2, P5, and the location A participant in the HEART session).

Table 24. Correlation for log-transformed APJ and HEART HEPs for RCL scenarios

	P1	P2	P3	P4	P5	P6	P7	HEART B participant	HEART A participant
P1	1.000								
P2	0.784*	1.000							
P3	0.845*	0.603	1.000						
P4	0.349	-0.115	0.321	1.000					
P5	-0.526	-0.375	-0.521	-0.013	1.000				
P6	0.625	0.563	0.119	0.118	-0.167	1.000			
P7	0.296	-0.050	0.132	0.900*	0.318	0.318	1.000		
HEART B participant	0.775*	0.741	0.632	0.343	-0.334	0.444	0.365	1.000	
HEART A participant	0.372	0.612	0.602	-0.311	0.028	-0.129	-0.279	0.284	1.000
* $p<0.05$, two-tailed test									

Overall, the APJ data indicate a trend toward greater HEP for RCL scenarios than conventional scenarios, with little support for greater HEPs associated with conventional scenarios. As was the case with the HEART participants, the APJ participants generated HEPs with a considerable degree of variability among them, including some evidence for disagreement in how RCL scenarios were assessed (based on correlations between participants). However, despite the variability and disagreement in the HEP values, a trend toward greater HEP for RCL scenarios was still in evidence in the APJ data. As with the HEART assessment, a larger number of APJ participants might reveal greater consistencies among assessors of each method of operation, thereby fortifying the trend identified here toward greater RCL HEP (and thus, reduced reliability).

5. Key Findings and Recommendations

Section 5.1 discusses the study's key findings, while Section 5.2 discusses many of the methodological challenges that limit the interpretation of the results. Lastly, Section 5.3 discusses some possible directions for future research into RCL operations safety, especially with regard to risk assessment.

5.1 Key Findings

Taken as a whole, this study found a difference between RCL and conventional methods of yard switching operations, with RCL operations tending to be somewhat less reliable (i.e., associated with greater risk). However, the study was not able to assess the magnitude of this difference in reliability due to a variety of methodological challenges and limitations. Section 5.1.1 presents the key findings from the PHA, and Section 5.1.2 presents the key findings from the HRAs (HEART and APJ).

5.1.1 PHA Key Findings

PHA can provide an ordinal means of evaluating the relative risk of RCL and conventional yard operations by comparing the worst credible scenario rating totals for each method of operation. The worst credible scenarios are discussed here since the purpose of risk assessment is to identify and then eliminate or mitigate the most egregious possibilities associated with a system or operation.

In the PHA that was conducted, RCL worst credible scenarios yielded a statistically significant and higher total hazard rating score than their conventional counterparts for the 19 outcome types that were identified: 197 versus 143. Examination of the average and median values for each method of operation for the worst credible scenarios also revealed greater relative risk for RCL operations. The average rating for worst credible scenarios for RCL operations was 10.4 compared to 7.5 for conventional worst credible scenarios. The median value for RCL worst credible scenarios was 12 compared to 6 for conventional worst credible scenarios. Lastly, pair-wise comparisons for the 19 worst credible scenarios indicate that RCL scenarios were associated with greater risk six times, conventional scenarios were associated with greater risk one time, and risk ratings were equal for each method of operation for the remaining six scenarios.

These findings suggest that, at least in terms of risk associated with worst credible scenarios, RCL operations are associated with greater relative risk compared to conventional operations. Given the subjectivity of the assessment and the inherent subject matter knowledge limitations of the assessors, additional interpretation of the PHA data is not recommended. Risk ratings were generated to inform a comparison of risk associated with one method of operation versus another. The true meaning of any PHA value, or its magnitude, remains unclear. Furthermore, these values have not been validated. As more is known about RCL operations, and quantitative data on RCL accidents/incidents, including exposure data, are collected, more insightful risk assessment and analysis can be performed.

5.1.2 HRA Key Findings

HEART key findings

The HEART assessment revealed no difference between the two methods of operation. Analysis of the first HEART participant's data reveals four conventional scenarios where the HEP is at least 1 OOM greater than the RCL counterpart, three where the RCL scenario is associated with greater HEPs, and three scenarios where no difference exists (i.e., the different HEPs are within 1 OOM of each other). Analysis of the second HEART participant's data shows a similar trend: four conventional scenarios where the HEP is at least 1 OOM greater than their RCL counterparts, three where the RCL scenario is associated with greater HEPs, and four scenarios where no difference exists.

To summarize, HEPs generated by both HEART participants resulted in a nearly equal number of cases where RCL was seen to be worse than conventional, conventional was worse than RCL, and where the two types of operation yielded no difference. Using the lower 5th percentile GTT values rather than the nominal unreliability values, all of the HEPs decreased, revealing more agreement in estimates generated for RCL scenarios and less for conventional scenarios. Despite this change in the proportion of scenarios in which participants generated similar estimates, the bottom line result is that the HEPs were still unable to reveal a critical difference in reliability between RCL and conventional operations.

Two conclusions are possible. The first is that the HEART data demonstrate that RCL and conventional operations are associated with some risks that result in greater HEPs for one type of operation over the other, depending on the scenario. The second possibility is that the HEART data demonstrate that the HEART method is insufficient, insensitive, or invalid as a technique for comparing HEP (and thus, risk) in railroad yard operations as deployed in this study.

HEPs were compared across participants for each scenario and each method of operation to determine the degree of agreement between the two HEART participants. For both types of operation, participant HEPs were within an acceptable degree of precision (i.e., within 1 OOM of each other) for only about half the scenarios (5 of 10 HEPs for conventional, and 5 of 11 HEPs for RCL). Given that participants generated HEPs that were within 1 OOM for only about half of the scenarios, this raises a concern over the reliability of the HEART participants and possibly that of the HEART method.

One possible reason for the lack of consistency in the HEPs and level of agreement between participants may result from the nature of the HEART GTT data that were used to calculate the final HEP values. Because HEART is dependent on the selection of tasks and conditions from specific lists of information, the frequency of selection for GTTs and EPCs was examined for conventional and RCL scenarios.

Analysis reveals an imbalance in GTT selection for the different scenarios, and GTT selection is a major driver of the final HEP values. Of the total 22 scenarios that were evaluated, participants selected the same GTTs for only 8 scenarios. This type of imbalance demonstrates that the participants did not agree about the GTT assignment for a substantial number of scenarios, resulting in substantial variability in the HEP data.

In addition to investigating GTT selection, EPC selection was also examined. While a total of 39 EPCs were available for consideration for each task, 14 EPCs were never selected by participants, and 5 EPCs were repeatedly selected by the HEART participants for at least 10 of the scenarios. For the remaining 20 EPCs, each was selected at least one time by at least one of the participants, but many were selected by one HEART participant and not the other. This lack of agreement in applying EPCs to scenarios could reflect regional differences in how yard operations take place (with only one participant seeing the applicability of an EPC based on his experiences and understanding of yard operations in his region), but it may also result from confusion stemming from how EPCs are worded or ambiguity in how a specific EPC might apply to a given scenario.

The substantial number of differences in the data demonstrates that the participants' understanding of the scenarios—and how the GTTs and EPCs applied to them—was inconsistent, leading to inconsistency in the resulting HEPs. Due to the amount and degree of variability in HEPs across many of the scenarios, it is prudent to interpret the HEART data with caution. Although the data may indeed indicate that HEPs for conventional and RCL scenarios are heavily dependent on scenario-based factors, such as operating conditions and move types, the more likely explanation from the results is that participants were poorly calibrated to one another, either as a result of insufficient training on HEART, poor understanding of the scenarios, or a lack of fit between the HEART method and railroad yard operations. It is also possible that two assessors are simply too few to yield consistent results, and with a greater number of HEART participants, greater consistency (central tendency theory) may emerge among scenario assessments. That is, the variability found here may be an artifact of the sample size; the two assessors may statistically reflect the two extremes of a distribution.

APJ key findings

Analysis of individual APJ HEP values within each location reveals that, while individual HEP values vary across a large range, the patterns in the data are consistent with a trend toward greater HEPs for RCL scenarios than conventional scenarios. Using the 1 OOM criterion for the first location (A) data, six RCL scenarios have higher HEPs than their conventional counterparts, while only one conventional scenario was rated as higher than its RCL counterpart. For the second location data, all seven RCL scenarios were rated with higher HEPs than their conventional counterparts.

Analysis across locations, for example, location A conventional operations scenario HEPs versus location B RCL operations scenario HEPs, revealed a similar pattern as above. In this case, six RCL scenarios were associated with greater HEPs than their conventional counterparts. However, when comparing HEPs between location B conventional operations scenario HEPs to location A RCL operations scenario HEPs, most scenarios showed no difference in HEP ratings.

Despite the support for a potential trend toward higher HEPs for RCL scenarios, only some of the APJ ratings met the criteria for acceptable precision (i.e., within 1 OOM of each other) for these scenarios. Four of the seven HEPs for the conventional scenarios met the criterion of acceptable precision, while only two of seven HEPs for the RCL scenarios met the criterion. This suggests some degree of variability across HEP estimates.

In fact, participants generated substantially different HEPs depending on the different scenarios being evaluated, as would be expected since different scenarios were made up of different PSFs, but participants also generated substantially different HEPs from each other, suggesting a considerable degree of variability among participants.

Overall, the APJ data indicate a trend toward greater HEPs for RCL scenarios than conventional scenarios, with little support for greater HEPs associated with conventional scenarios. As was the case with the HEART participants though, the APJ participants generated HEPs with a considerable degree of variability among them, including some evidence for disagreement in how RCL scenarios were assessed (based on correlations between participants). However, despite the variability and disagreement in the HEP values, a trend toward greater HEPs for RCL scenarios was still in evidence in the APJ data. As with the HEART assessment, a larger number of APJ participants might reveal greater consistencies among assessors of each method of operation, thereby likely fortifying the trend identified here toward greater RCL HEP. As with the HEART HEPs that were generated, it is imperative to keep in mind that assessments are relative and should not be used as absolute estimates of either RCL or conventional operations reliability. The value in the APJ HEPs is in their simple ability to distinguish between RCL and conventional methods of operation.

5.2 Methodological Challenges and Limitations

This section contains a number of methodological challenges that were experienced, either directly or indirectly, in the conduct of this study. The section organizes challenges and limitations into two categories, general challenges and challenges specific to the application of HEART and APJ.

5.2.1 General Methodological Imitations

A significant limitation to this study is that the PHA and HRA were based on limited knowledge and experience of RCL operations. This is due in large part to the recent implementation of RCL operations. Consequently, it was not possible to rely on participants with decades of experience to generate HEP data for RCL operations. Furthermore, sufficient RCO-related train accident/incident data did not exist at the time the study was conducted to serve as a source of possible RCO HEP data.

Another significant challenge was the fact that, at the time the study was conducted, no HRA techniques had been developed and validated explicitly for the railroad operating environment, though the United Kingdom is currently validating one such HRA method for selected railroad tasks (though not yard switching operations). As such, no HRA techniques were especially well suited for the railroad yard switching environment. The search for an applicable HRA technique was somewhat akin to finding a square peg to place inside a hole. Despite this limitation, it was possible to identify candidate HRA methods that provided the best fit to the railroad yard switching environment due to the vast number of candidate HRA techniques available.

A third challenge was the tremendous amount of variation among railroad implementation of RCL equipment and operations, and the fact that RCL operations are continually changing and equipment is continually modified as railroads learn more about the operation and the technology’s capabilities and limitations. The result is that a practice that exists one day may not exist the next day, or a rule that did not exist yesterday may be in place today. As such, it is difficult to conduct a risk assessment over any period of time because of the changes that have occurred in that time. To counteract some of these changes, assumptions were stipulated that provided a snapshot in time and that provide the context for the risk assessment; however, it is possible that, several months or years later, these assumptions will be invalid.

Tremendous variation exists across all railroad yard switching methods in terms of yard layout, grade, equipment used, operating rules, the number of crewmembers (a range of 1-4 per crew), and number of other jobs working at one time. More than one acceptable way to carry out a given scenario exists. Scenarios depend, for example, on which crewmember is in control of the move, where precisely a crewmember is standing, and on which car and where the crewmember may be riding. These variables result in a highly dynamic work environment. Since railroad yard switching operations are so highly dynamic with so many variables in play at any one time, development of operating scenarios was necessarily going to address only a small fraction of all possible yard operating scenarios. An analogous situation would be where an experiment has over 100 variables, each variable has three conditions, and the experiment controls for only a handful of these variables, and among those, only some of the possible conditions.

Another challenge was the inability to assess all 11 scenarios using APJ. Because of the unanticipated time it took to assess the scenarios using APJ, participants were able to complete assessments of the first seven scenarios only.

Some additional limitations of the study include the following:

- The study assessed only a fraction of all human-related risks.
- The study did not explicitly address mechanical or electrical failures associated with either type of operation.
- The study did not address exposure to EMR associated with wearing an RCD.
- The study did not address risks to the public nor risks associated with operational delays.

5.2.2 Limitations and Challenges of Selected HRA Techniques

Although the team evaluated HEART and APJ to be the most applicable HRA methods available for use in the railroad operations domain, the HRA techniques themselves posed a number of challenges relative to the assessment of RCL and conventional railroad yard switching activities. The following identifies these limitations and challenges according to HRA technique.

HEART limitations and challenges

- The list of HEART EPCs does not include many relevant railroad operating PSFs, such as fatigue and the effect of the physical environment (e.g., operating in freezing weather when it is snowing).
- HEART does not capture interactions between EPCs (such as time and complexity) and thus may underestimate reliability in cases where interactions are likely.
- Most HEART GTT and EPC values are based on laboratory performance data, including data from the nuclear/process-plant industry, that may not be particularly applicable or relevant to railroad yard operations.
- HEART was designed to look at one state of a system (e.g., monitoring a closed-loop process). Railroading involves multiple states (e.g., planning a move, initiating the move, monitoring the move, and stopping the move). As such, HEART does not adequately address the dynamic environment of railroad operations.

- HEART does not provide the practitioner with a concrete method for determining the APOA. The assessment team must generate rules and criteria to enable the determination of an appropriate proportion and, as such, can vary widely from one assessment to the next.
- HEART fails to capture many of the social, environmental, and dynamic variables that are critical to railroading, but that may not be so integral to process control environments.
- Several GTT descriptions are vague and overlapping.
- Overlap exists between some of the GTT and EPC descriptions.
- HEART reliability ranges are conservative. The selection of one GTT and multiple EPCs with high APOAs will quickly drive a HEP number to unity (i.e., the likelihood of an error is one).
- HEART does not explicitly address collaboration or interactions among team members (e.g., HEART does not distinguish between one individual performing a task and three people performing the same task).
- HEART does not expressly account for the ability to recover from an error.

APJ limitations and challenges

- Although the APJ sessions were moderated by an experienced facilitator who worked to limit the influence of group factors, these factors are always present and may have influenced the probability estimates generated by group members.
- The recent implementation of RCL operations and longevity of conventional operations may subconsciously bias participants' HEP estimations in that RCL operations are assessed to be less safe.
- Some APJ participants felt the scenarios contained too many constraints to generate an accurate probability, while other participants felt that the scenarios were too open-ended for an accurate assessment.
- In general, participants in APJ studies often lack an accurate understanding of probabilities, regardless of the amount of preparation and examples provided. This misunderstanding can lead to biases in generating accurate probabilities.

5.3 Future Research

The ultimate goal of conducting human factors RCL operations research is to identify any operational hazards that create potentially unsafe working conditions for railroad operating employees and to eliminate or mitigate these hazards. Risk assessment methods, such as those used in this study, are a proactive way to identify, prioritize, and eliminate/mitigate such operational hazards. However, risk assessment methods have their limitations. Section 5.3 discusses some additional candidate research activities, including further risk assessment approaches that may help to identify, prioritize, and/or eliminate many of these operational hazards. These research activities are advantageous because they may overcome many of the methodological challenges that this study encountered.

5.3.1 Conduct FMECA of RCL Operations

One method of identifying operational hazards is through the conduct of a FMECA. FMECA is a risk assessment method in which failure modes, their effects, and the criticality of the failures are systematically identified and described. FMECA is a qualitative approach to determining what can go wrong and what is likely to happen in each case if something does go wrong. FMECAs can support risk assessments or can serve as a stand-alone method. FMECA is particularly attractive, given the current lack of quantitative data to use to assess the safety of RCL operations. The results from this report, as well as the RCO focus group and RCL RCA reports, provide some preliminary insights into how RCL operations can be problematic. A FMECA would more systematically identify potential failure modes and effects and would determine what the likely consequences of these failures would be. FMECA could assist FRA and the railroad industry in prioritizing potential RCL operations risks and in developing appropriate corrective actions or countermeasures to eliminate or reduce high priority risks.

5.3.2 Develop HEP Database for Yard Switching Operations

No source of HEP data currently exists that is specific to the U.S. railroad industry. The United Kingdom is generating such a database to inform their railroad safety risk model (SRM); however, the United Kingdom is focusing on operations other than switching, for instance, dispatchers and over-the-road train crews. Developing an HEP database for yard operations would provide a rich source of information for future HRA activities and would help address many of the shortcomings of other HRA methods based on operations in other domains. Initial database development might consist of an analysis of tasks commonly performed in the railroad yard environment and then developing operational definitions that can be used to identify specific HEP data needs. Estimates of reliability could be derived from accident and incident databases, FRA investigation reports, interviews with SMEs, and activities, such as APJ and the Success Likelihood Index Methodology.

5.3.3 Modify HEART for Railroad Yard Switching Operations

Despite the limitations of the HEART method identified in this report, the method holds promise as an efficient and expedient process to develop assessments for yard-related tasks. The current HEART approach can be adopted if GTT and EPC definitions are developed for the railroad yard domain, and HEP values are culled from the existing human factors literature. The literature to be included would not focus on process-control, such as nuclear power operations, but rather on more dynamic environments, such as transportation, factory floor operations, and military operations.

5.3.4 Refine the APJ Approach for Railroad Yard Switching Operations

Given the absence of an HEP database, a reasonable alternative for developing HEPs is provided by the APJ approach. Future APJ activities might include the development of scenarios and tasks that RCL and conventional operation SMEs feel are well-suited for HEP generation. Several APJ sessions could be conducted with SMEs of varying levels of experience and familiarity with yard operations to identify potential biases associated with experience. APJ activities could also include probability estimation exercises grounded with known examples from yard operations to help anchor HEP estimates and provide a reference against which other HEPs can be based.

5.3.5 Develop Nonpunitive Incident Reporting System

The dearth of HEP data in the railroad industry reflects the importance and benefit that could be provided from an industrywide, nonpunitive or anonymous near miss or close call incident reporting system. Such systems are currently in place in numerous domains, including aviation (Aviation Safety Reporting System), nuclear power (International Atomic Energy Agency/Nuclear Energy Agency Incident Reporting System), health care (Patient Safety Reporting System), and food/drug safety (Adverse Event Reporting System). The benefit of implementing such a system is that it enables incidents and occurrences that may be indicative of a potential reliability problem to be recorded and analyzed without punitive consequences for the individuals involved in the incident. An incident reporting system that included yard switching operations would provide researchers with a robust source of information for reliability issues, as well as information that could be used to develop HEPs based on actual accidents/incidents and activities occurring in the railroad yard switching environment.

6. References

Ang, A. & Tang, W. (1975). *Probability concepts in engineering planning and design, Volume 1, basic principles*. Hoboken, NJ: John Wiley & Sons, Inc.

Apostolakis, G. (1990). The concept of probability in safety assessments of technological systems, *Science, 250*, 1359-1364.

Arthur D. Little. (1997). *Assessment of human reliability in the use of driver reminder appliances. Final report.* London, UK: Railtrack.

Canadian National. (2000, November 16). *Canadian national experience with locomotive remote control technology: Review of the design, implementation, use and safety record of the BELTPACK® system at CN.* Retrieved February 17, 2005 from http://www.canac.com/docs/164_1.pdf

Comer, M., Seaver, D., Stillwell, W. & Gaddy, C. (1984). *Generating human reliability estimates using expert judgment. Vol. I. main report*. NUREG CR-3688/10F2.5 and 84-7115, GP-R-213022.

Embrey, D. (1981). The use of quantified expert judgment in the assessment of human reliability in nuclear power plant operation. In *Proceedings of the Human Factors Society 25th Annual Meeting*. Santa Monica, CA: Human Factors Society.

Federal Railroad Administration. (2000). *Technical conference remote control locomotives minutes of meeting July 19, 2000.* Retrieved December 21, 2004 from http://dmses.dot.gov/docimages/pdf51/107527_web.pdf

Federal Railroad Administration. (2001). *Recommended minimal guidelines for the operation of remote control locomotives*. FRA Safety Advisory 2001-01. 66 Fed. Reg. 10340, (February 14, 2001).

Federal Railroad Administration. (2003). *FRA guide for preparing accident/incident reports*. DOT/FRA/RRS-22. FRA Office of Safety. Washington, DC: Author.

Gamst, F. (Ed.). (1977). Golden anniversary special issue on industrial ethnology. *Anthropological Quarterly*, 50 (1).

Gamst, F. (1990). Industrial ethnological perspectives on the development and characteristics of the study of organizational culture. In T. Hamada & A. Smith (Eds.), Cross-cultural management and organizational culture. *College of William and Mary Studies in Third World Societies, 42,* 13-47.

Gamst, F. (2001). Work, sociology of. In N. Smelser & P. Baltes (Eds.), *International encyclopedia of the social and behavioral sciences*, (pp. 16575-16579). Oxford: Pergamon.

Gibson, W. & Megaw, T. (1999). *The implementation of CORE-DATA, a computerised human error probability database*. UK Health & Safety Executive Contract Research Report No. 245/1999. Norwich, UK: Her Majesty's Stationery Office.

Global Aviation Information Network (GAIN). (2003). *Guide to methods and tools for safety analysis in air traffic management*. Prepared by GAIN Working Group B, Analytical Methods and Tools.

Handwerker, W. (2001). *Quick ethnography.* Walnut Creek, CA: AltaMira Press.

Kaplan, S. & Garrick, B. (1981). On the quantitative definition of risk. *Risk Analysis, 1(1)*, 11-27.

Kastenberg, W. & Solomon, K. (1985). On the use of confidence levels in risk management. *Journal of Hazardous Materials, 10*, 263-278.

Kirwan, B. (1992). Human error identification in human reliability assessment. Part I Overview of approaches. *Applied Ergonomics, 23(5)*, 299-318.

Kirwan, B. (1994). *A guide to practical human reliability assessment*. London, UK: Taylor and Francis.

Kirwan, B. (1996). The validation of three human reliability quantification techniques–THERP, HEART and JHEDI: Part 1–technique descriptions and validation issues. *Applied Ergonomics, 27 (6)*, 359-373.

Kirwan, B. (1997). The validation of three human reliability quantification techniques–THERP, HEART and JHEDI: Part III–practical aspects of the usage of the techniques. *Applied Ergonomics, 28,* 27-39.

Kirwan, B. & Ainsworth, L. (Eds.). (1992). *A guide to task analysis*. London, UK: Taylor and Francis.

Kirwan, B., Kennedy, R., Taylor-Adams, S., & Lambert, B. (1997). The validation of three human reliability quantification techniques–THERP, HEART and JHEDI: Part II–results of validation exercise. *Applied Ergonomics, 28,* 17-25.

Moorhouse, D. (2001). *Job demands analysis–yard foreman/helper*. Retrieved January 25, 2005 from http://www.utubc.com/pub/Yardman_JDA.pdf.

Rail Safety and Standards Board (2005). *Rail-specific human reliability assessment technique for driving tasks: User Manual*. London, UK: Author.

Reinach, S. & Gertler, J. (2001). *An examination of railroad yard worker safety*. Technical Report No. DOT/FRA/ORD-01-20. Washington, DC: Federal Railroad Administration.

Schwartzman, H. (1993). *Ethnography in organizations.* Newbury Park, CA: Sage.

Strater, O. 2000. *Evaluation of human reliability on the basis of operational experience.* Dissertation. GRS-170. ISBN 3-931995-37-2.

Swain, A. & Guttman, H. (1983). *Handbook of human reliability analysis with emphasis on nuclear power plant applications final report*. NUREG/CR-1278 SAND80-0200 RX, AN, United States NRC. Washington, DC.

Switching Operations Fatality Analysis (SOFA) Working Group. (1999). *Findings and recommendations of the SOFA working group*. DOT/FRA/ORD-00/04. Washington, DC: Author.

U.S. Department of Defense. (1993). *Mil-Std-882C military standard system safety program requirements*. Retrieved January 28, 2005 from http://www.reliasoft.org/mil_std/mil_std_882c.pdf .

Williams, J. (1988). A data-based method for assessing and reducing human error to improve operational performance. Proceedings of the *IEEE Fourth Conference on Human Factors and Power Plants*. Monterey, CA, 5-9 June, pp. 436-450. IEEE: New York.

Appendix A.
Qualitative Analysis of Mine Fatalities Involving RCE

Since RCL operations were new when this study began in early 2002, a preliminary analysis was conducted on MSHA mine fatalities involving RCE from January 1995 through March 2002. This study was initiated when little was known about RCL operations since the operations were in their infancy. The mine fatality analysis was conducted to provide the study team with some early insights on some of the potential risks that may be present in RCL operations in railroad yards. Although the results of the mine RCE analysis were not directly incorporated with the other methods used in the risk assessment study, the analysis provides an analogous reference point in the more general study of remote controlled operations and aided the study team in better understanding some of the potential risks associated with RCL operations early in the project.

A.1 Introduction

The U.S. mining industry has used RCE, such as trams and power haulage units, for decades. In contrast, RCLs have been used only by a handful of U.S. railroads, until the beginning of 2002. Although numerous differences exist between mining operations and railroad operations (e.g., mining operations generally occur in more confined physical spaces than railroad operations), there is potential to learn from the mining industry when assessing the risk of RCL operations. To obtain a preliminary look at some of the potential risks involved in RCL operations, online reports of MSHA fatal mine accidents in which RCE were involved were analyzed in early 2002, just as RCL operations in the U.S. railroad industry were starting up. This analysis was conducted to provide some early potential insights into potential risks associated with RCL operations in the railroad industry.

A.2 Methods

MSHA's "Fatal Alert Bulletins, Fatalgrams and Fatal Investigation Reports" Web site (http://www.msha.gov/fatals/fab.htm) contains investigative reports from coal and metal/non-metal mine fatalities in the United States. A search of this database from January 1995 to March 2002 using the words *remote control* resulted in 71 hits. Each hit, or citation, was examined to determine (1) if, in fact, the fatality occurred during a remote control operation (some citations included mention of remote control but not in the direct context of the accident) and (2) if the remote control operation directly contributed to the fatality (versus simply being a remote control operation when the fatal accident occurred). Based on these criteria, 38 fatalities involved remote control operations, and of these 38, the remote control operation directly contributed to 14 fatal accidents. Each of these 14 accidents was reviewed to determine probable RCO-contributing factors to the fatality.

The sources of error that were identified are based strictly on a review of the online fatal investigation reports; original source data that went into these investigations were not available. Further, according to the MSHA Web site, these reports are preliminary.[14] Thus, this analysis

---

[14] A disclaimer on the Web site reads, "The information provided in these notices is based on preliminary data ONLY and does not represent final determinations regarding the nature of the incident or conclusions regarding the causes of the fatality."

contains certain inherent limitations. In spite of these limitations, analyses of fatal accident reports can identify potential sources of error in remote control mining operations that may be similar to those found or expected in RCL operations.

An attempt was also made to classify the error sources using a formal top-down structure, Reason's Generic Error Modeling System, as well as an informal bottom-up structure. For the latter approach, the study team attempted to derive a *post hoc* classification system based on the error sources identified. However, due to the lack of in-depth information regarding the circumstances of the fatal accident, neither approach proved successful. The information contained in the online reports was descriptive but provided neither sufficient background nor circumstantial information to allow further identification and categorization of sources of error. For example, information that describes the operator's training curriculum and operating procedures was unavailable; thus an operator's actions could have been due to inadequate training, inadequate rules or procedures, inadequate supervision, or a rule violation. To a great extent, the sources of error that are identified here are based on those identified by the MSHA investigators who produced the online reports.

A.3 Mine Fatality Summaries and Contributing Factors

The following provides summaries of each of the 14 accidents where RCE was directly involved in the fatality. Results from each accident are presented separately. The date corresponds to the date of the accident; a one-sentence action-oriented sentence that describes the accident follows, and then the likely contributing factors are identified.

<u>March 24, 1995</u>

Action: Conveyor belt of remotely controlled machine (operated by an RCE operator[15]) struck and killed a maintenance trainee serving as a helper.

Contributing factors:

- RCE operator was not properly trained to use machine.
- Helper was standing in an unsafe position near equipment.
- RCE operator operated machine where the light source blocked his view so he could not determine if people were in an unsafe area around the machine before he began tramming.
- Management assigned a newly employed inexperienced individual to work on a machine he was not trained on.
- Worksite was understaffed; the result was that workers in the area were not performing their normal tasks for which they were trained. In this instance, the maintenance trainee was working as a helper.

<u>April 18, 1995</u>

Action: A short circuit occurred, which caused part of the machine on which the worker was sitting on (to perform maintenance on the machine) to move and crush a worker.

---

[15] In this analysis, to avoid confusion, those operating mining-related RCE are referred to as RCE operators unless the individual is operating an RCL, in which case he/she is referred to as an RCO.

Contributing factors:

- Operator failed to de-energize equipment before performing maintenance on machine.
- RCD unit had not been properly maintained before this event.

<u>October 21, 1996</u>

Action: A trailing cable fell from the carrying position of the RCD, causing the remotely controlled tram (RCE) to move, trapping and killing the RCE operator.

Contributing factors:

- An RCD safety device (which could have prevented the accident) had been taped in a upward position, rendering this safety feature ineffective.
- RCE operator stood in an unsafe position near the tramming equipment.

<u>March 28, 1997</u>

Action: Malfunctioning remotely controlled tramming machine pinned and killed a miner.

Contributing factors:

- Mining machine was poorly maintained (it was malfunctioning and thus responded only intermittently to the tram controls).
- Miners, including the victim, were in a tight space and could not escape the machine once it started moving.
- The machine was set up to only respond to a remote control (i.e., no manual operation), extending the length of time the persons were trapped, possibly adding to the severity of the initial injury.

<u>April 23, 1997</u>

Action: Malfunctioning remote reset control switch on coal feeder RCD started unexpectedly due to its power cable having been previously severed, exposing wires that became crossed while a person was performing maintenance work on the equipment (RCE). The equipment unexpectedly lifted the victim and crushed him against the mine roof.

Contributing factors:

- The person maintaining the RCE did not power down the RCE before performing maintenance work.
- Maintenance person or RCE operator did not detect RCD severed power cord.
- Possible inadequate maintenance that resulted in exposed equipment wires

<u>May 04, 1998</u>

Action: RCL entered repair area, struck a car, and killed one worker.

Contributing factors:

- RCO could not see lead end of RCL when moving it into a repair area where people were working.

- Repair area did not have a derail to prevent cars from accidentally entering repair area.

July 26, 1999

Action: Victim fell onto continuous mining machine as it was moving over uneven roadway, causing the machine to crush the victim's head against the roof.

Contributing factors:

- Victim positioned too close to operating equipment.

January 21, 2000

Action: Continuous mining machine with a past history of malfunctions with de-energization switch unexpectedly powered up during maintenance of equipment's cutting head.

Contributing factors:

- Operator failed to de-energize RCE before performing maintenance work (equipment was turned off but not de-energized).
- Inadequate maintenance contributed to use of faulty equipment (de-energization switch).

May 12, 2000

Action: RCE operator crushed by own equipment.

Contributing factors:

- RCE operator positioned himself between equipment and mine rib.
- RCE operator was not properly trained on the RCD.
- RCD did not have an effective emergency stopping device (it did have an emergency stopping device, but this device could not have prevented this type of accident).
- Mechanical interlock (safety device) ineffective because it had been tampered with.

June 23, 2000

Action: Employee standing too close to RCE hydraulic lift, which errantly dropped its load, killing the employee.

Contributing factors:

- Employee had not received adequate training for working near RCDs/hydraulic lifts.
- RCE hydraulic lift arm did not adequately grip the tire, and the tire fell.
- Employee positioned too close to RCE.

August 15, 2000

Action: Two individuals, an RCO and another employee, were crushed between RCE and mine rib.

Contributing factors:

- RCD had history of problems in past. RCE tested OK, however.
- RCO had himself and his helper in an unsafe place, between RCE and mine rib.

April 12, 2001

Action: Two separate pieces of RCE collided with each other, killing one person.

Contributing factors:

- RCE operator moved machine into an area where he/she could not observe (blind shove; machines are large and visibility was obstructed); thus he/she did not see the other RCE and RCE operator.
- A lack of communication between the two RCE operators contributed to the accident.

November 21, 2001[16]

Action: RCE operator was found pinned between RCE cutting head and mine rib.

March 22, 2002[17]

Action: RCE operator struck by the end of a conveyor boom and was found crushed between the conveyor boom and mine rib.

A.4 Results

Analysis of the MSHA online fatal RCE-involved investigation reports suggests several general categories of potential contributing factors. The following briefly discusses them.

Staffing and Training

- Inadequate RCO training: RCO not adequately trained to use RCE.
- Inadequate staffing and training of RCE support personnel: Inadequately trained personnel working around RCE.

Position of RCE operator and other personnel

- Proximity to RCE: RCE operator and others working too close to RCE.

RCE operation (including RCL operation) and maintenance

- Blind operation: An RCL RCO made a blind shove into a repair area where others were working on live track.
- Failure to de-energize RCE before performing maintenance activity.
- Inadequate RCE maintenance.
- RCE safety device overridden/tampered with.
- Safety protocol not used (derail not used to protect unauthorized entry into repair facility).
- Inadequate/poor communication between RCE operators.

---

[16] Full report not available at time of analysis, thus contributing factors undetermined.

[17] Ibid.

RCE

- Equipment did not have adequate safety feature for particular use.

Appendix B.
Catalog of Potential Hazards and Errors Associated with RCL Operations

B.1 Introduction

Information and communication technologies using the Internet as a medium engender new kinds of social networks and novel communication capabilities. The Internet, and these emerging Internet communities, provide a new cyber ethnographic field research tool for sociocultural and behavioral scientists. The Internet permits inexpensive, fast, easy, and permanently recordable communication among SMEs active in a particular domain, in this case, railroad yard operations, and between researchers and SMEs. As with structured interviews and focus groups, Internet reporting by SMEs is an indirect form of ethnographic observation into a particular research subject area.

Ethnography is a research approach used to study, learn about, and describe human sociocultural phenomena. Ethnography refers to writing and reporting about a particular people. Ethnographic methods were originally developed for the field of anthropology but also have over a century of use in sociology (Gamst, 2001). Ethnography also has a long history, at least since 1930, of use for study of business organizations and aspects of them (Gamst, 1977, 1990; Schwartzman, 1993). Strengths of ethnography include its deeply probing penetration of everyday activities and its concern with details of social actions and their interrelations and contexts.

The ethnographic findings in Appendix B come from information gathering across a continentally dispersed social network with subjects of research linked mainly via the Internet. This network supports a technique in social scientific research for gathering volunteered, written, self-reported narratives. The technique's utility is not just in the speed, low cost, and ease of gathering information, but it is also a means of obtaining esoteric material difficult to gather by older techniques. As such, it can be a valid method of quick ethnography (Handwerker 2001).

Over the course of 2 ½ yr, from July 2002 through November 2004, a social anthropologist and member of the study team collected, through the Internet, a myriad of written SME narratives pertaining to RCL operations. Data came from RCO and conventional yard crewmembers, other train crewmembers, and other railroad operating employees, such as front-line supervisors (e.g., yardmasters and dispatchers) and railroad officers, from U.S. Class I freight railroads, a number of short-line and regional railroads across the country, and Canadian railroads. Data include self-reported written information mainly through the Internet but also include some paper comments and enclosures. The information these operating employees provided consists largely of self-reported problems they have experienced, as well as reports of close calls and accidents/incidents with which they are familiar. No attempt was made to validate any of the information that was collected, though followup correspondence did occur occasionally to clarify a narrative or other information.

Based on the narratives, the study team classified and produced a catalog of ways in which RCL tasks and equipment could be a potential problem (difficult to deal with to the point of creating a hazard) in U.S. RCL operations in railroad yards. A hazard is defined as a condition (process or state) that could lead to a loss. A hazard could be a person, energy, mass, toxicity, or duration of time that, if not controlled, could result in a loss. Loss includes injury and death to humans; damage to property and environment; and harm to business and government procedures, well-being, reputation, and good will. For the reporting in this section, and consistent with the scope of the rest of the study, hazards are limited to loss as injuries (including fatalities) to railroad employees and damage to railroad equipment. For example, hazards that may affect trespassers or motorists at public grade-crossings, or hazards to the general public, are not addressed.

Because this catalog covers an extensive time period and given the fluid nature of RCL operations, some of the issues identified in the catalog may have already been addressed, in whole or in part, by new operating rules, changes to the RCL technology or equipment, or changes in practices and procedures. This catalog provided the research team with a qualitative look at some of the potential risks of RCL operations in the absence of many years' worth of RCL event data and helped to inform study team members for such activities as the PHA. The catalog, however, was not directly used for the HEART or APJ assessment.

Section B.2 presents an abridged version of the RCL catalog. The items are listed in alphabetical order. The original collection of RCO and other railroad operating employee narratives extended over 200 pages and thus was too large to include in this report. Consequently, the study team attempted to extract the primary potential hazards and sources of error that were identified. Because of the non-statistical approach to data collection, the catalog is far from exhaustive or complete. Rather, it was intended to provide the study team with examples of some of the hazards that exist for RCL operations as an informational tool only. Given the non-statistical approach to data collection, no way exists to estimate the prevalence of the potential hazards that are identified. The hazards and potential sources of error that are listed in the catalog are generally, though not always, unique to RCL operations.

B.2 Catalog of Potential Hazards and Sources of Error Associated with RCL Operations

Blind Shoves

Blind shoves occur when no one provides point or path protection. The amount of walking by groundmen increases in RCL operations. Consequently, an RCO might seek to save bodily or mental effort in an RCL task, resulting in a blind shove. As an experienced Canadian RCO notes, a problem in RCL operations is: "The dangerous lack of point protection owing to not wanting to walk long distances…."

Cut-Back Engineer Working an RCL Job

Locomotive engineers cut back from such status, and working as RCOs may no longer retain their former situation awareness needed for working on the ground around live track.

Defeating Electronic Pullback Protection

For various authorized and unauthorized causes, an RCL crew can pull cars without the safeguard of an electronic pullback protection system (a.k.a., positive stop protection) and without anyone on the locomotive to protect the point. An RCO observes: "It's a common practice now to override the Electronic Position Detection (EPD) system even when you don't plan on having to pull beyond the far limit of the zone [in this case, to expedite a move]…."

Delay in Supervisory Response to Man-Down Alarm

As an RCO notes, "We have experienced several cases where an RCL has broadcast 'XYZ 999, Man Down' and, after waiting some time for the yardmaster to inquire if everyone on the 'XYZ 999; is OK, another switch crew or road crew has had to call and ascertain."

Distractions and Impediments

RCO problems of RCL operations-based distractions and impediments that were reported are described in the following 11 paragraphs.

1. RCO behind a vision-obstructing structure

   If the RCO crewmembers are in a building or behind a structure for any purpose (including getting switch lists), they cannot give firsthand attention to their RCL. A number of RCOs have commented that, at times, they have not been able to see the movement they controlled because of a vision-obstructing structure.

2. Weather distraction

   Weather can distract or otherwise divert the attention of a primary RCO operating outside the cab since the RCO is directly exposed to the elements, such as snow, hail, rain, and wind.

3. Required reading distraction

   An RCL movement might be in motion when the primary RCO must read a switch list, an RCD message, operating directive, or other information.

4. RCD display distraction

   According to RCOs, having to read or interpret displays on the RCD can be a distraction, whether riding or standing. One RCO explains: "I still firmly believe that the box [RCD] has the potential to divert our attention from something important if it chirps at us at the wrong time."

5. Ground surface distraction

   At times, the RCO could divert a major part of attention to personal safety concerns of footing on loose surface materials, uneven surfaces, debris-strewn surfaces, and surfaces slick from slippery substances, such as water, ice, snow, or oil.

6. Car-riding distraction

   If a primary RCO rides with three-point contact on the side of a car while manipulating the RCD, the potential for error in controlling the movement increases. Operating an RCL with a heavy cut of cars under varying track and traffic conditions involves a number of tasks. A Canadian RCO explains: "This is not to say it [riding the side of a car while operating the RCD] cannot be done safely in most instances but only that the risk associated with riding the car is increased by virtue of performing multiple tasks." Furthermore, given a particular combination of events, an RCO simply does not have enough hands to cope adequately with an operating situation. Depending upon the combination of events, this inadequate coping could be a hazard. An RCO reports that a danger in RCL operations is: "not having the use of both hands while riding cuts."

Another RCO reports: “Riding on car ladders is awkward and it is difficult to both hang on and activate…[the RCD] controls.”

7. The RCO could become too busy manipulating the RCD controls to concentrate on the movement

As one RCO explains, it is “Unavoidable…while operating my box [RCD] that my attention was divided between the movement of the cars and mastering the sometimes complex RCO functions needed to control a movement.”

8. Distraction from slipping but not letting go of a supporting ladder, stirrup, or grab iron while operating the RCD

9. Distraction from dropping to the ground from a car-side stance, but not falling, while operating the RCD

10. Distraction from brushing against an object while operating the RCD

11. General distraction because of a need to maintain personal safety

Divided Attention due to the Need to Multitask or due to a Complex Switching Movement

An RCO can simultaneously handle an RCL, plan the next switching move(s), switch cars, read written materials, work the voice-radio, coordinate with crewmember(s), deal with other engine and train movements, protect himself from danger, and monitor an RCZ. A group of RCOs explain: “We have a lot to think about, like how we are going to make the moves to block the train correctly, is the list wrong, what is the footing like on the ground, where is the next cut (to name just a few examples). Now we have to think about what the locomotive is doing and who should be operating the box. I think this is information overload for us.” As one RCO concludes: “Unavoidable is while operating my box [RCD] that my attention was divided between the movement of the cars and mastering the sometimes complex RCO functions needed to control a movement.” Another RCO explains: “The question is to what extent does such a divided attention impinge on safe movements. I’m going to wait and see. The risk factor here is not whether an operator is neglectful or inattentive. The risk is in where the operator’s attention is directed.” An RCO could also become distracted while contemplating and handling a complex movement. Concentration on a several-step sequence of switching moves may result in less cognition available for a specific sequence of actions in operating the RCD. As one railroader notes: “Sometimes a chess-like mental concentration is required for ‘car handling,’ that is, switching cars, (while also caring for safety of one’s body).”

Divided Attention due to Operation of a Motor Vehicle while Controlling the RCL

Some RCOs operate a motor vehicle to increase their productivity. Whatever the governing rule, RCOs sometimes operate both the motor vehicle and RCL at one time, which divides cognitive and psychomotor attention. As one railroader notes: “I do know they are allowing RCOs to operate all terrain vehicles (ATV) to expedite switching movements… human nature being as it is I doubt the RCO would comply or the railroad would [locally] enforce such a rule.” A railroader reports: “The derailment was due to [a] hard joint. The RCO was riding in a vehicle while operating the [RCD], and he did not correctly estimate the speed of his cut [of cars].”

Inadequate RCO Training

A widespread complaint received from RCOs is insufficient training for RCL handling and for other matters. Sufficient skill and judgment acquisition and retention are vital for the RCO (and other railroaders). RCO problems of these kinds are noted in the following four paragraphs.

1. No training for the class of service to be performed

   Some RCOs report they are not formally trained and tested for the most demanding kind of service they will perform. One RCO comments on training: "2 weeks of training for me was NOWHERE NEAR ENOUGH!" Another RCO comments: "The new workers are being rushed through training, and given too much responsibility too soon. The most capable new worker cannot absorb the complicated procedures associated with the new technology, the layout of a large number of unfamiliar yards, the inertial characteristics of car cuts of a variety of weights, lengths, and speeds, the individual braking characteristics of the locomotives he uses, and simultaneously navigate the social integration problems deriving from being the new person on the block."

2. Inadequate OJT

   Regarding RCO training, one RCO reports: "The OJT [on-the-job-training] can be hit or miss on the kinds of moves [that an RCO can make] and knowledge of track layout." Another RCO notes: "Training for an RCO is sometimes just observing the two regular RCOs get out the work with little or no spoken instruction from these two men." Thus, the training can be observation with no hands-on participation.

3. Insufficient RCO training time

   A number of RCOs reported receiving insufficient time for RCL training, including insufficient time for particular tasks, overall training, and opportunity for hands-on experience (other than instruction by observation alone) during the scheduled time. One RCO concluded: "We'll all eventually get the experience I suppose, but the training regimen does not exist…."

4. RCOs as OJT instructors

   On some carriers, hands-on training of student RCOs is now done in the field by an RCO crew. The crew has been given no instruction on how to train students or what the content of the hands-on training should be. One RCO comments: "We are now 'training' the new RCL new hires 'on-the-job'. The old rule of thumb, 'If they ask you to do something that you have not yet done, ask for a trainer' is pretty much irrelevant. We are the trainers." Another RCO notes: "Most RCOs who train students receive no instruction on how to be trainers and nothing about what to include and what to stress in their training of an RCO." This can also result in a task conflict between getting the work done and serving as instructors for one or two student RCOs. One RCO instructor reports: "We are providing the on-the-job RCL training for new hires while trying to get the work done and keep the management happy.... Our prime directive is to train these people to work safely. But we have to get the cars switched and the trains made up." Another RCO instructor comments: "The …[railroad] hiring frenzy is resulting [in] some interesting situations. Several times now we have had two students on our job, one a boxer [having an RCD] and the other box less. Makes for even more difficulties in trying to plan the work if you are the foreman. I'm not sure how that is supposed to work."

Inadequately Trained and Experienced RCL Classroom Instructors

Some RCOs complained that their classroom instructors had insufficient training and experience in RCL operations. Such instructors did not understand all that was happening in RCL operations, could not answer the more involved RCL questions, and had no experience with the consequences of certain kinds of RCL moves. This included moving long, heavy cuts with and without the automatic air cut in.

Increased Workload and Reduced RCO Situation Awareness

Because the work environment consists of live tracks, railroad switching operations require a high level of situation awareness using visual, auditory, and kinesthetic cues. Overburdened multitasking of an RCO who controls an RCL while switching cars and coordinating with other personnel could lead to errors of omission or commission. According to some reports, an RCO's need for a high level of situation awareness can compete with his/her limited time and attention to keep out of harm's way. And the reverse is true; limited time and high-level concentration on a task can degrade an RCO's situation awareness to protect himself.

Insufficient Experience for a Particular Location or Switching Assignment

RCOs report occasions where they have insufficient experience for a particular location or switching assignment. For example, one RCO reports that he and other RCOs are assigned RCL tasks and locations which are quite different than those for which they have experience: "They send us to places where we haven't a clue to what we are supposed to do." Regarding an RCL crew that experienced a serious accident, another RCO reports: "[One RCO] had worked this job maybe 3 times in the 2 1/2 yr he's been with the [railroad]….. His helper hired out in [recent month] and had never worked …[the particular job assignment]."

Insufficient General Railroad Operating Experience

Overall rail operating experience matters for operational safety and efficiency. When junior switchmen and conductors are force-assigned into RCO positions, there exist persons who are less task experienced and situationally aware overall in railroad operations. As one RCO reports: "… this class of [RCO] students are rank beginners in the rail industry. NO EXPERIENCE [in railroading]." With only a year or so of experience, an RCO is more prone to commit errors (SOFA Working Group, 1999). As a second RCO explains, "It is the new hires who are having the most difficulty adapting to this new [RCL] technology. The old switchmen already knew how to switch without thinking too much about it and can concentrate on the train handling aspect." Another RCO cites an accident where an RCL moving a long, heavy cut ran out of a yard, past a stop signal, through a power switch, and into a train on the main track. In this accident, the two inexperienced RCOs did not provide point protection for their movement when they should have. Another RCO explains: "The person that was helping [name] has quit because he [had three accidents resulting in damage to equipment] all with remotes. The guy had minimal training as a switchman (5 weeks) and then went right in to RCO training."

Man-Down Feature Not Tested

The man-down feature of the tilt safety function is not always tested at the beginning of a shift. An RCO group reports: "Quite often when shifts change and the boxes [RCDs] are handed off to the relieving crew (either by the preceding crew or by the yardmaster) they are still linked to the RCL that will be used."

Mechanical Maintenance Personnel Not Trained for RCLs

RCOs noted that maintenance personnel are not always either trained or knowledgeable about RCL technology. One RCO opines: "They [maintenance personnel] have poor or no understanding of what goes wrong with an engine [RCL]." RCOs report incorrect installations and repairs, some leading to loss or lack of RCL control under particular conditions.

Mental Fatigue

Owing to the increased workload for the reduced RCL crew size, RCOs may be subject to greater fatigue pressures, including from walking and multitasking, and the distractions of these.

Misunderstanding about Which RCO Controls the Movement

Although rules exist to prevent misunderstandings about which of a pair of RCOs controls the movement, such events do occur, a number of RCOs report. One RCO reports on a surprising kick move after he thought his secondary RCO had not accepted a pitch: "Lesson to be learned: Depending on what you are displaying on your box's LED (e.g., do you have it set to show SPEED or some other variable?), it may not be clearly indicated that you have gone from being primary to secondary operator. In the instance related above, nothing disastrous happened. But what if I, thinking I was still in control, had gone between cars to couple hoses, something that we regularly do on this assignment, in preparation for transferring the cars to their industries?"

Movement with a Stopped RCL without Safeguard of Vigilance Button

An RCO can go to coast mode and coast to a complete stop (against the resistance of grade, track, or rolling equipment), remain there for a while and then unintentionally move the speed control lever only (without any vigilance button precursor) and start moving. Here the RCL safeguard of requiring two separate control manipulations on the RCD to begin an RCL movement is negated. One RCO reports "…there is one scenario where an RCO could be stopped, think he was stopped, and yet unintentionally bump a lever and move, without reference to the vigilance button (at least for the duration of its 50-second [s] cycle)."

Non-Crewmembers Providing Point Protection

Reports from RCOs discussed otherwise busy yardmasters and officers providing point protection for RCL crews. One RCO explains: "This can be a problem because the [officer] is not a member of the crew and is not attuned to our procedures." Moreover, the primary attention of a non-crewmember such as a yardmaster is often directed to more complex, global, and pressing matters apart from a particular move. Thus, the non-crewmember may become distracted or otherwise inattentive and fail to adequately protect the point.

No Sense of Vehicular Kinesthetic Motion

The Primary RCO on the ground does not have the sense of kinesthetic feedback afforded an engineer in the cab of a locomotive. One RCO notes regarding this lack of feedback: "When very far from the end of his cut, an RCO can move it in the wrong direction. This is especially so at night or in fog." If the RCO is not observing his RCL, this error can result in a move of some distance, and, if distant from his RCL, it could take some time before slack is adjusted and he can see his cut move. Another RCO observes: "One [RCO] thinking that he was moving forward … was actually in reverse shoving out the end of a track." Even a few car lengths of movement in the wrong direction can cause an accident, from loss of situation awareness plus lack of kinesthetic feedback.

OCC Autonomy

RCOs have reported autonomous actions by the OCC. Thus, an RCO can be subjected to undesired slack action, continued movement after collision with equipment or a barrier, and stopping when undesired. One railroader comments on autonomous slack action: "Another incident…caused broken ribs and lacerations when a helper who was riding the point of a long cut of cars experienced a comm[unication] break. The locomotive responded as it had been programmed, and applied full independent and automatic brake. When the slack ran out, the helper was thrown from the end of the cars." Separately, an RCO reports: "There was a recent RCL accident…involving an inexperienced RCO riding a…shove and being thrown off when the air dumped [air brakes went into an emergency application]. Let's see. What does that beeping mean? What do I have to do to recover - oooops. Too late." Another RCO explains: "The locomotive could run up against an obstacle, or could even pull a cut of cars with a derailment down in the string. It would keep adding throttle amps attempting to attain the set speed until it was unable to move. Only then would it interpret a problem condition, cut throttle, apply brakes, and transmit a 'locomotive movement failure' radio alert, requiring further action from the RCO." A fourth RCO recognizes, "the consequences of ceding braking decisions to the RCL computer, for example on a grade where the [better] choice may be to reserve braking capability rather than regulate for a particular set speed." While some OCC autonomy (and subsequent OCC decisions, such as to apply the RCL brakes) will be clear to RCOs, other times it will not, creating a hazard that could result in an injury or accident.

OCC Cannot Verify the Intention of an RCD Command

When an RCO erroneously commands the RCL to move in a direction that is opposite of what it should be, for example, the OCC will not correct that error. An engineer explains: "The most common problem I run across is being told to 'Come Ahead' when they really mean back up, or vice versa. It happens at least once daily, sometimes multiple times, and is because the engine is sometimes turned north, sometimes south…someone could get crushed as the movement moves in the direction opposite of what was anticipated."

One-Person Operations

With one-person crewing in RCL operations, some RCOs report that the temptation to make blind shoves will mount. Further, some RCOs expressed concern over the safety of, or medical response to, a one-person crew, for example if the RCO falls, is struck by, runs into equipment, or is attacked and becomes incapacitated.

Operating an RCL While Rendering Point Protection for Another Job

A hazard exists when the primary RCO of one job, while controlling a movement, renders point protection or other service to another job. In discussing an RCL collision, an RCO explains: "It seems clear now that the Primary RCO on job 2 was attempting to do two things at the same time; remotely control his own RCL and shove while protecting the shove of another job 1. He didn't wait to clear Track 99 and stop his own movement before taking on the other task."

Potential Miscommunication between or among RCL Crewmembers in Controlling a Movement Still Exists

The use of hand- or voice-communication to control and move a cut of cars is not necessarily eliminated with the elimination of the engineer in the cab. Rather, in RCL operations, the communication is between RCOs or other groundmen. Thus, a miscommunication hazard still may exist in RCL operations as when a conventional groundman either hand- or voice-radio signals to an engineer in the cab. RCOs reported the following three specific examples of where the potential for miscommunications still exists.

1. RCOs may not always use pitch-n-catch

   As one RCO notes: "When an [RCO] uses a hand signal or the [voice] radio to guide an RCO who is handling a movement with the box [rather than pitching the control of the movement], the safety result is the same as when a [conventional] groundman uses voice-radio communication to guide an engineer who is handling a movement."

2. The railroad provides only one RCD for a multi-person RCL crew

   When a two- or three-person RCL crew must work with only one RCD, a crewmember sometimes uses hand-signal or voice-radio communication to guide the primary RCO who is handling a movement from a position not at the point of the movement. The safety effect on miscommunication is about the same in this continued practice as when a conventional groundman either hand- or voice-radio signals to an engineer in the cab. One RCO reported that an RCO student in class… "asked twice and was told twice that they [the railroad] have no problem with running a job with one remote user and one non-user. Now doesn't that seem to negate any claim to enhanced safety through eliminating the danger from confusion entering into the COMMUNICATION between a man not in control of the movement and the man in control?"

3. One of two RCDs becomes defective and is not replaced

   When the second RCD of a pair becomes defective and is not replaced, the crewmember without an RCD must hand- or voice-radio signal to the other one. The crewmember sometimes, then, uses hand-signal or voice-radio communication to guide the primary RCO who is handling a movement. The safety effect on miscommunication is about the same in this continued practice as when a conventional groundman either hand- or voice-radio signals to an engineer in the cab. As one RCO trainee reported: "Stated in the [RCL] class that if one of the belt packs malfunctioned that the one with the bad order beltpack can use his handheld [voice] radio to give instructions to the member with the good belt pack and continue to switch."

Railroad and Contractor Employees Unfamiliar with RCL Operations

A number of RCOs separately report that some employees, including conventional switching crews and crews of road trains, as well as contractors who work around RCL operations, are not familiar with the operations, including the limitations and requirements of RCL operations and what to do when interacting in and around a RCZ. One possible consequence is an individual fouling a live track where point protection is not being afforded.

RCO Error Due To Inexperience, Training, or Other

RCOs reported that an RCO can use improper judgment for moving his consist with regard to the operating environment. A number of specific examples of RCO error were identified; some are described below.

1. An RCO might move his consist too fast

   A railroader reported an RCL-involved derailment and consequent pair of collisions as follows: "An RCO moved his speed control to 10 mph, instead of taking the slack and gradually increasing the speed of his cut [of cars]. Using poor judgment and too much throttle [power], the RCO broke his cut in two. The uncoupled cars rolled away and collided with standing cars and shoved some of these into the side of a standing train."

2. An RCO might not use enough braking force for his consist

Regarding the kinetic energy of a movement, one railroader explains: "Ten mph with a cut of cars takes some time to stop and if you are switching without [the automatic, all of cars] air that momentum ain't gonna go away just because you have the [independent, locomotive] brakes on full!"

3. An RCO might exceed the mechanical ability of his braking system(s)

Stopping distance is relative to the variables of tonnage handled, gradient, speed, rolling resistance, number of operable engine brakes, and adhesion quality of the ball of the rails. RCOs complain that they have little or no training on this matter. An RCO reported a probable exceeding of the braking capacity of an RCL. In this case, the two RCOs of an RCL-powered cut of 20 cars could not stop their movement. Their cut collided with two standing tank cars carrying hazardous chemical loads, which consequently burst into flame. Authorities evacuated some 140 neighboring residents from their houses in pre-dawn hours but allowed them to return in about 4 h. Local employees think that the weight of the cut exceeded the braking capacity of the independent brakes of the RCL. A railroader, however, thought that the RCOs did not have a "seat-of-the-pants feel" (a kinesthetic feedback) from their handling of the heavy movement.

RCO-Induced Stops Can Be Undesired

Certain RCO actions or inactions can, by design, cause the RCL to stop. However, times occur when an unplanned stop of a movement can be unsafe. One RCO explains: "There are times when dead in the water is the last thing you want to be." Undesired stops include halting on a public grade-crossing; in the area of a fire, hazardous material spill, or other hazardous event; in the path of uncontrolled runaway car(s); and when not in the clear of an approaching movement.

Reduced Situation Awareness from Radio Chatter about Movements

The reduction of the human-voice chatter of crews directing their engineers by voice-radio in conventional switching operations proportionately reduces the crews' situation awareness from the information imparted by radio chatter. Listening to chatter is an informal means of inter-crew communication. An RCO typifies: "There is an ongoing problem with respect to communications with other jobs [crews]. The associated radio communication that formerly provided additional information about what other jobs are doing has been drastically reduced by the RCOs."

Removing the RCD

If an RCO removes an RCD from his body for any reason, such as to clean a switch, remove debris from underfoot, or replace a knuckle, this nullifies the tilt feature. The RCO can then subsequently fall on live track and not have the protection afforded by the tilt feature. An RCO group reported: "People who have to couple air on a whole track will take the box [RCD] off and leave it on the locomotive." Another RCO group reports: "Some here have begun to take regular breaks where they remove the vest and box for awhile."

Supervisors Not Trained in RCL Operations and Physical Systems

Some RCOs have noted that the operating officers and supervisors who oversee them have had no or only superficial training in RCO tasks and RCL operations and about RCL physical systems and their components. According to these RCOs, operating officers and supervisors often do not know the limitations of RCL performance and of what an RCO can do or can safely do.

Tilt Feature Does Not Always Protect an RCO

When the tilt feature activates as a safeguard, it cannot ensure stopping in time to avoid an accident/incident, given certain combinations of a movement's tonnage, speed, track gradient, and rolling resistance. Thus, an accident/incident can occur within the parameters of the normal cycle of the tilt feature.

Tilt Feature Can Cause Hurried Action

To avoid activation of the tilt alarm and subsequent RCL brake application, some RCOs hurry their task. A group of RCOs report: "The tilt feature can cause hurried [human] movement, thereby increasing the chance of an accident/incident ranging from bumping into rolling equipment to falling." Separately, an RCO group reports: "When coupling air hoses, when the Tilt Alarm countdown starts screaming, one is motivated to move quickly to stand up before a Man Down situation develops. This rushing is not safe." This rushing could lead to the RCO hitting part of their body against stationary equipment or stumbling.

Tilt Feature Can Cause Bodily Stress and Discomfort

Because the tilt feature requires body-tensioning positions, the added physical fatigue and stressed body positions can lead to lessening of attention to the task at hand. One RCO notes: "Further…to avoid activating the tilt feature you cannot relax; you are forced to assume unnatural attitudes of posture and also to stay vigilant about your posture, which is to say, in a state of constant mild stress."

RCL Not Placed in Manual Mode When Its Crew Leaves It

Some rules direct that when an RCL crew leaves its RCL, the crew must put the RCL in manual mode and secure it. For various reasons, a crew does not always perform this safeguard. An RCO reports: "We don't always put the engine [RCL] in manual when we leave it for beans [meal time]."

Unauthorized Operations in an RCZ

RCOs report that an RCZ does not prevent all possible accidents/incidents in the RCZ. RCOs report various unauthorized intrusions and unauthorized misaligned switches in an RCZ. The following three paragraphs note RCO problems of unauthorized operations in a RCZ.

1. Autonomously controlled remote control switch in the wrong position in an RCZ

   RCOs reported a number of occasions where remote control switches in an RCZ were in the wrong position, due to autonomous control of the switch (i.e., directed by the switch computer logic or other hardware/software, and not by the RCO or other human). An RCO says: "While working the 'XXX' Yard RCL switch job, we observed the following: We were going to go against a track and pull it out for switching. I had no intention of putting anyone on the locomotive as the zone was still ours. I never heard the radio toning commands but did hear that a switch that is within our RCL zone announced that it was now in the wrong position for our movement. The primary operator heard nothing. If I had not heard the announcement we would have made a trailing point movement through a wrongly lined switch and then shoved back."

2. RCO's memory lapse allows overlapping movements in his RCZ

Because of pressures on the RCO's memory (fatigue, multiple tasks, threatening incident), the RCO could, in an error of omission, allow two movements to overlap and occupy the same space and collide in his RCZ. Several RCOs opined this circumstance. As one group of RCOs reports on this matter: "The only recording that gets done here are the instances of 'activating' and 'deactivating' the Remote Control Zones…. The RCO-foreman is definitely responsible for keeping track of who he has allowed to enter the zone and who has left…."

3. Imprecise rules and practices for RCZ use

A number of RCOs have noted imprecise rules and practices for operations in RCZs. One RCO explains: "The point of all this is to reinforce the argument that these (and many others) [RCL-related] rules are being cobbled together and interpreted by people who have little appreciation for what is going on out in the field." A railroader describes a situation where two hostlers were moving light engines and they, "called the yardmaster to ask if they could cross over and come back to the roundhouse. The yardmaster fumed: 'You're in a remote control zone; how did you get there?' They had not heard from anyone that an…[RCZ] had been established while they were in it. It may have been the mere fact that they were on [one] channel…and the yardmaster gave the…[RCZ] to the RCOs on [another] channel…and did not bother to inform everyone else in the yard…."

Appendix C.
HTA of Railroad Yard Switching Operations

Appendix C presents the complete HTA for a selected subset of all yard switching activities. Specifically, the HTA addresses the following yard switching tasks:

1. Switch cars (flat yard).
2. Operate locomotive/light engines.
3. Switch cars (hump yard).
4. Trim cars.

A prerequisite condition that must occur before any yard switching as described in the HTA is that cars must be available and ready to switch (e.g., the air has been bled out of the air hoses of the individual cars to be switched). Section C.1 presents the HTA tasks, Section C.2 presents the plans for various tasks, and Section C.3 presents a matrix (table) that contains the subtasks associated with each of the lettered tasks.

C.1 HTA Tasks

0. Switch cars in a railroad yard
1. Receive assignment and switch list
2. Conduct safety briefing
3. Take control of RCZ
    - 3.1. Activate RCZ
        - 3.1.1. Inspect tracks for readiness and fouling equipment
        - 3.1.2. Line and lock switches
        - 3.1.3. Notify appropriate authority (e.g., yardmaster) of RCZ activation
    - 3.2. Take over control of active RCZ
        - 3.2.1. Notify appropriate authority (e.g., yardmaster) of zone control transfer
        - 3.2.2. Conduct job briefing with existing RCL crew
4. Prepare equipment
    - 4.1. Start locomotive
    - 4.2. Conduct daily locomotive inspection
        - 4.2.1. Inspect locomotive from ground
            - 4.2.1.1. Check the wheels for cracks and hot or flat spots
            - 4.2.1.2. Check the brake shoes for extensive wear
            - 4.2.1.3. Check the brake piston travel
            - 4.2.1.4. Check the brake rigging

        - 4.2.1.5. Check the fuel gage and look for fuel leakage
        - 4.2.1.6. Check under the locomotive
        - 4.2.1.7. Check for missing or broken parts on the truck, wheels, gears, and coupler
        - 4.2.1.8. Check operation of sanders
    - 4.2.2. Inspect walkway and engine compartment
        - 4.2.2.1. Check for full water and oil tanks
        - 4.2.2.2. Check walkways for trip or slip hazards
        - 4.2.2.3. Check condition of handrails, handholds, and steps
        - 4.2.2.4. Check condition of exhaust stacks
        - 4.2.2.5. Check for water leaks
    - 4.2.3. Inspect locomotive cab
        - 4.2.3.1. Check fuse and breaker panel
        - 4.2.3.2. Check engine control panel
        - 4.2.3.3. Check the engineer's control stand, including lights and gauges
        - 4.2.3.4. Check to make sure the seats are secure
        - 4.2.3.5. Check windows for clear view
        - 4.2.3.6. Check the operation of the headlights, horn, and bell
    - 4.2.4. Sign inspection checklist
- 4.3. Set locomotive to remote control mode
    - 4.3.1. Apply full independent brake
    - 4.3.2. Ensure that throttle is off
    - 4.3.3. Set reverser in neutral
    - 4.3.4. Remove reverser handle
    - 4.3.5. Turn generator field to off
    - 4.3.6. Place remote control operation tag on control stand
- 4.4. Link-up RCD(s)
    - 4.4.1. Power up RCD
    - 4.4.2. Power on locomotive-mounted OCC
    - 4.4.3. Set OCC selector to appropriate controller position
    - 4.4.4. Link RCD to OCC
        - 4.4.4.1. Press appropriate assignment sequence of buttons on OCC
        - 4.4.4.2. Place RCD near appropriate linking spot on OCC
        - 4.4.4.3. Power off RCD

4.4.4.4. Power on RCD
4.5. Check RCD safety features
4.5.1. Conduct tilt protection feature test
4.5.2. Conduct vigilance feature test
4.5.3. Conduct emergency test
4.5.4. Conduct locomotive brake test
5. Classify inbound train
5.1. Attach yard locomotive (light engine) to inbound train
5.1.1. Line switch(es)
5.1.1.1. Check switch list A
5.1.1.2. Locate target track B
5.1.1.3. Determine track route C
5.1.1.4. Locate switch(es) to line D
5.1.1.5. Line switch(es) E
5.1.2. Move Locomotive
5.1.2.1. Check path to be sure it is free of obstructions F
5.1.2.2. Ensure coupler knuckles are open and aligned G
5.1.2.3. Adjust coupler assembly H
5.1.2.4. Check reverser position I
5.1.2.5. Change reverser position J
5.1.2.6. Initiate locomotive movement K
5.1.3. Couple locomotive to car(s)
5.1.3.1. Maintain locomotive movement L
5.1.3.2. Stop locomotive N
5.1.3.3. Test coupling
5.1.3.3.1. Reverse locomotive
5.1.3.3.1.1. Check path to be sure it is free of obstructions F
5.1.3.3.1.2. Check reverser position I
5.1.3.3.1.3. Change reverser position J
5.1.3.3.1.4. Initiate locomotive movement K
5.1.3.3.2. Inspect coupling O
5.1.3.3.3. Stop locomotive N
5.2. Prepare train

- 5.2.1. Line switch(es)
  - 5.2.1.1. Check switch list A
  - 5.2.1.2. Locate target track B
  - 5.2.1.3. Determine track route C
  - 5.2.1.4. Locate switch(es) to line D
  - 5.2.1.5. Line switch(es) E
- 5.2.2. Pull cars out of inbound track
  - 5.2.2.1. Prepare car(s) for removal
    - 5.2.2.1.1. Obtain 3-point protection P
    - 5.2.2.1.2. Ensure air has been bled out of air hoses between standing cars Q
    - 5.2.2.1.3. Release standing car handbrake(s) R
    - 5.2.2.1.4. Cancel 3-point protection S
  - 5.2.2.2. Move locomotive
    - 5.2.2.2.1. Check path to be sure it is free of obstructions F
    - 5.2.2.2.2. Ensure coupler knuckles are open and aligned G
    - 5.2.2.2.3. Adjust coupler assembly H
    - 5.2.2.2.4. Check reverser position I
    - 5.2.2.2.5. Change reverser position J
    - 5.2.2.2.6. Initiate locomotive movement K
  - 5.2.2.3. Maintain locomotive movement L
  - 5.2.2.4. Stop locomotive N

5.3. Shove cars

- 5.3.1. Line switch(es)
  - 5.3.1.1. Check switch list A
  - 5.3.1.2. Locate target track B
  - 5.3.1.3. Determine track route C
  - 5.3.1.4. Locate switch(es) to line D
  - 5.3.1.5. Line switch(es) E
- 5.3.2. Move locomotive
  - 5.3.2.1. Check path to be sure it is free of obstructions F
  - 5.3.2.2. Ensure coupler knuckles are open and aligned G
  - 5.3.2.3. Adjust coupler assembly H

5.3.2.4. Check reverser position I
5.3.2.5. Change reverser position J
5.3.2.6. Initiate locomotive movement K
5.3.3. Couple car(s)
5.3.3.1. Maintain locomotive movement L
5.3.3.2. Stop locomotive N
5.3.3.3. Test coupling
5.3.3.3.1. Reverse locomotive
5.3.3.3.1.1. Check path to be sure it is free of obstructions F
5.3.3.3.1.2. Check reverser position I
5.3.3.3.1.3. Change reverser position J
5.3.3.3.1.4. Initiate locomotive movement K
5.3.3.3.2. Inspect coupling O
5.3.3.3.3. Stop locomotive N
5.3.4. Place car(s)
5.3.4.1. Maintain locomotive movement L
5.3.4.2. Stop locomotive N
5.3.5. Detach car(s)
5.3.5.1. Move locomotive
5.3.5.1.1. Check path to be sure it is free of obstructions F
5.3.5.1.2. Check reverser position I
5.3.5.1.3. Change reverser position J
5.3.5.1.4. Initiate locomotive movement K
5.3.5.2. Pull pin T
5.3.5.3. Stop locomotive N
5.3.5.4. Tie down car handbrake(s) U
5.3.6. Reverse locomotive
5.3.6.1. Check path to be sure it is free of obstructions F
5.3.6.2. Check reverser position I
5.3.6.3. Change reverser position J
5.3.6.4. Initiate locomotive movement K
5.3.7. Stop locomotive N
5.3.8. Re-lines switch

5.3.8.1. Locate switch(es) to line D
5.3.8.2. Line switch(es) E
5.4. Kick cars
5.4.1. Line switch(es)
5.4.1.1. Check switch list A
5.4.1.2. Locate target track B
5.4.1.3. Determine track route C
5.4.1.4. Locate switch(es) to line D
5.4.1.5. Line switch(es) E
5.4.2. Move locomotive
5.4.2.1. Check path to be sure it is free of obstructions F
5.4.2.2. Ensure coupler knuckles are open and aligned G
5.4.2.3. Adjust coupler assembly H
5.4.2.4. Check reverser position I
5.4.2.5. Change reverser position J
5.4.2.6. Initiate locomotive movement K
5.4.3. Detach car(s) in motion
5.4.3.1. Identifies car(s) to be released V
5.4.3.2. Pull pin T
5.4.4. Stop locomotive N
5.4.5. Reverse locomotive
5.4.5.1. Check path to be sure it is free of obstructions F
5.4.5.2. Check reverser position I
5.4.5.3. Change reverser position J
5.4.5.4. Initiate locomotive movement K
5.4.6. Stop locomotive N
5.4.7. Re-line switch
5.4.7.1. Locate switch(es) to line D
5.4.7.2. Line switch(es) E
5.5. Hump cars
5.5.1. Line switch
5.5.1.1. Check switch list A
5.5.1.2. Locate target track B

  5.5.1.3. Determine track route C
  5.5.1.4. Locate switch(es) to line D
  5.5.1.5. Line switch(es) E
5.5.2. Move locomotive
  5.5.2.1. Check path to be sure it is free of obstructions F
  5.5.2.2. Ensure coupler knuckles are open and aligned G
  5.5.2.3. Adjust coupler assembly H
  5.5.2.4. Check reverser position I
  5.5.2.5. Change reverser position J
  5.5.2.6. Initiate locomotive movement K
5.5.3. Maintain hump speed W
5.5.4. Detach car(s) in motion
  5.5.4.1. Identifies car(s) to be released V
  5.5.4.2. Pull pin T
5.5.5. Stop locomotive N
5.5.6. Reverse locomotive
  5.5.6.1. Check path to be sure it is free of obstructions F
  5.5.6.2. Check reverser position I
  5.5.6.3. Change reverser position J
  5.5.6.4. Initiate locomotive movement K
5.5.7. Stop locomotive N
5.5.8. Shove cars
  5.5.8.1. Move locomotive
    5.5.8.1.1. Check path to be sure it is free of obstructions F
    5.5.8.1.2. Ensure coupler knuckles are open and aligned G
    5.5.8.1.3. Adjust coupler assembly H
    5.5.8.1.4. Check reverser position I
    5.5.8.1.5. Change reverser position J
    5.5.8.1.6. Initiate locomotive movement K
  5.5.8.2. Couple cars
    5.5.8.2.1. Maintain locomotive movement L
    5.5.8.2.2. Stop locomotive N
    5.5.8.2.3. Test coupling

5.5.8.2.3.1. Reverse locomotive

5.5.8.2.3.1.1. Check path to be sure it is free of obstructions F

5.5.8.2.3.1.2. Check reverser position I

5.5.8.2.3.1.3. Change reverser position J

5.5.8.2.3.1.4. Initiate locomotive movement K

5.5.8.2.3.2. Inspect coupling O

5.5.8.2.3.3. Stop locomotive N

5.5.9. Detach car(s)

5.5.9.1. Move locomotive

5.5.9.1.1. Check path to be sure it is free of obstructions F

5.5.9.1.2. Check reverser position I

5.5.9.1.3. Change reverser position J

5.5.9.1.4. Initiate locomotive movement K

5.5.9.2. Pull pin T

5.5.9.3. Stop locomotive N

5.5.9.4. Tie down car handbrake(s) U

5.5.10. Reverse locomotive

5.5.10.1. Check path to be sure it is free of obstructions F

5.5.10.2. Check reverser position I

5.5.10.3. Change reverser position J

5.5.10.4. Initiate locomotive movement K

5.5.11. Stop locomotive N

6. Build new outbound train

6.1. Attach locomotive (light engine) or lead car to standing car(s)

6.1.1. Line switch(es)

6.1.1.1. Check switch list A

6.1.1.2. Locate target track B

6.1.1.3. Determine track route C

6.1.1.4. Locate switch(es) to line D

6.1.1.5. Line switch(es) E

6.1.2. Move locomotive

6.1.2.1. Check path to be sure it is free of obstructions F

6.1.2.2. Ensure coupler knuckles are open and aligned G

    - 6.1.2.3. Adjust coupler assembly H
    - 6.1.2.4. Check reverser position I
    - 6.1.2.5. Change reverser position J
    - 6.1.2.6. Initiate locomotive movement K
  - 6.1.3. Couple locomotive or lead car to standing car(s)
    - 6.1.3.1. Maintain locomotive movement L
    - 6.1.3.2. Stop locomotive N
    - 6.1.3.3. Test coupling
      - 6.1.3.3.1. Reverse locomotive
        - 6.1.3.3.1.1. Check path to be sure it is free of obstructions F
        - 6.1.3.3.1.2. Check reverser position I
        - 6.1.3.3.1.3. Change reverser position J
        - 6.1.3.3.1.4. Initiate locomotive movement K
      - 6.1.3.3.2. Inspect coupling O
      - 6.1.3.3.3. Stop locomotive N
- 6.2. Confirm car placement and ordering X
- 6.3. Confirm coupling(s)
  - 6.3.1. Inspect coupling(s) N
  - 6.3.2. Move locomotive
    - 6.3.2.1. Check path to be sure it is free of obstructions F
    - 6.3.2.2. Ensure coupler knuckles are open and aligned G
    - 6.3.2.3. Adjust coupler assembly H
    - 6.3.2.4. Check reverser position I
    - 6.3.2.5. Change reverser position J
    - 6.3.2.6. Initiate locomotive movement K
  - 6.3.3. Couple cars
    - 6.3.3.1. Maintain locomotive movement L
    - 6.3.3.2. Stop locomotive N
    - 6.3.3.3. Test coupling
      - 6.3.3.3.1. Reverse locomotive
        - 6.3.3.3.1.1. Check path to be sure it is free of obstructions F
        - 6.3.3.3.1.2. Check reverser position I
        - 6.3.3.3.1.3. Change reverser position J

6.3.3.3.1.4. Initiate locomotive movement K
6.3.3.3.2. Inspect coupling O
6.3.3.3.3. Stop locomotive N
6.4. Pull pin to detach cut of cars T
6.5. Remove car(s) from track
6.5.1. Prepare car(s) for removal
6.5.1.1. Obtain 3-point protection P
6.5.1.2. Ensure air has been bled out of air hoses between standing cars Q
6.5.1.3. Couple up air hoses Y
6.5.1.4. Release standing car handbrake(s) R
6.5.1.5. Cancel 3-point protection S
6.5.2. Move locomotive
6.5.2.1. Check path to be sure it is free of obstructions F
6.5.2.2. Ensure coupler knuckles are open and aligned G
6.5.2.3. Adjust coupler assembly H
6.5.2.4. Check reverser position I
6.5.2.5. Change reverser position J
6.5.2.6. Initiate locomotive movement K
6.5.3. Stop locomotive N
6.6. Re-line switch(es)
6.6.1. Locate switch(es) to line D
6.6.2. Line switch(es) E

C.2 HTA Plans

Plan 0: Do 1 and 2 in order. If remote control, also do 3 if applicable. Do 4. Then do 5 and/or 6.

Plan 3: Do either 3.1 or 3.2.

Plan 3.1: Do 3.1.1, 3.1.2, and 3.1.3 in order.

Plan 3.2: Do 3.2.1 and 3.2.2.

Plan 4: Do 4.1 and/or 4.2 as necessary. If remote control operation, do 4.3, 4.4, and/or 4.5 as necessary.

Plan 4.2: Do 4.2.1, 4.2.2, and 4.2.3.

Plan 4.2.1: If applicable, do 4.2.1.1, 4.2.1.2, 4.2.1.3, 4.2.1.4, 4.2.1.5, 4.2.1.6, 4.2.1.7, and 4.2.1.8.

Plan 4.2.2: If applicable, do 4.2.2.1,4.2.2.2, 4.2.2.3, 4.2.2.4, and 4.2.2.5.

Plan 4.2.3: If applicable, do 4.2.3.1, 4.2.3.2, 4.2.3.3, 4.2.3.4, 4.2.3.5, and 4.2.3.6.

Plan 4.3: Do 4.3.1, 4.3.2, 4.3.3, 4.3.4, 4.3.5, and 4.3.6 in order.

Plan 4.4: Do 4.4.1, 4.4.2, 4.4.3, and 4.4.4 in order.

Plan 4.4.4: Do 4.4.4.1 and 4.4.4.2 in order. For two RCOs, primary RCO does 4.4.4.1, 4.4.4.2, and 4.4.4.3. Secondary RCO does 4.4.4.1 and 4.4.4.2. Primary RCO then does 4.4.4.4.

Plan 4.5: Each RCO separately and in order does 4.5.1, 4.5.2, and 4.5.3 and 4.5.4 as appropriate.

Plan 5: Do 5.1 and 5.2 in order. Then, do 5.3, 5.4, or 5.5. Repeat 5.3, 5.4, or 5.5 as necessary.

> Plan 5.1: Do 5.1.1, 5.1.2, and 5.1.3 in order. Repeat 5.1.2 through 5.1.3 if coupling did not take.
>
> > Plan 5.1.1: Do 5.1.1.1, 5.1.1.2, 5.1.1.3, 5.1.1.4, and 5.1.1.5 in order.
> >
> > Plan 5.1.2: Do 5.1.2.1 and 5.1.2.2. If knuckles must be adjusted, then do 5.1.2.3. Then do 5.1.2.4. If reverser needs changing, do 5.1.2.5. Then do 5.1.2.6.
> >
> > Plan 5.1.3: Do 5.1.3.1, 5.1.3.2, and 5.1.3.3 in order.
> >
> > > Plan 5.1.3.3: Do 5.1.3.3.1, 5.1.3.3.2, and 5.1.3.3.3 in order.
> > >
> > > > Plan 5.1.3.3.1: Do 5.1.3.3.1.1 and 5.1.3.3.1.2. If reverser direction must be changed, do 5.1.3.3.1.3. Then, do 5.1.3.3.1.4
>
> Plan 5.2: Do 5.2.1 and 5.2.2 in order.
>
> > Plan 5.2.1: Do 5.2.1.1, 5.2.1.2, 5.2.1.3, 5.2.1.4, and 5.2.1.5 in order.
> >
> > Plan 5.2.2: Do 5.2.2.1, 5.2.2.2, 5.2.2.3, and 5.2.2.4 in order.
> >
> > > Plan 5.2.2.1: Do 5.2.2.1.1. Do 5.2.2.1.2 if necessary. Then do 5.2.2.1.3.
> > >
> > > Plan 5.2.2.2: Do 5.2.2.2.1. Then do 5.2.2.2.2 and 5.2.2.2.3 if applicable. Then do 5.2.2.2.4. If reverser direction must be changed, do 5.2.2.2.5. Then do 5.2.2.2.6.
>
> Plan 5.3: Do 5.3.1 and 5.3.2 in order. Then do either 5.3.3 or 5.3.4. Then do 5.3.5, 5.3.6, 5.3.7, and 5.3.8 in order.

Plan 5.3.1: Do 5.3.1.1, 5.3.1.2, 5.3.1.3, 5.3.1.4, and 5.3.1.5 in order.

Plan 5.3.2: Do 5.3.2.1 and 5.3.2.2 in order. If knuckles must be adjusted, do 5.3.2.3. Then do 5.3.2.4. If reverser direction must be changed, do 5.3.2.5. Then do 5.3.2.6.

Plan 5.3.3: Do 5.3.3.1, 5.3.3.2, and 5.3.3.3 in order.

Plan 5.3.3.3: Do 5.3.3.3.1, 5.3.3.3.2, and 5.3.3.3.3 in order.

Plan 5.3.3.3.1: Do 5.3.3.3.1.1 and 5.3.3.3.1.2. If reverser direction must be changed, do 5.3.3.3.1.3. Then do 5.3.3.3.1.4.

Plan 5.3.4: Do 5.3.4.1 and 5.3.4.2 in order.

Plan 5.3.5: Do 5.3.5.1, 5.3.5.2, and 5.3.5.3 in order. If necessary, do 5.3.5.4.

Plan 5.3.5.1: Do 5.3.5.1.1 and 5.3.5.1.2. If reverser directions must be changed, do 5.3.5.1.3. Then do 5.3.5.1.4.

Plan 5.3.6: Do 5.3.6.1 and 5.3.6.2. If reverser direction must be changed, do 5.3.6.3. Then do 5.3.6.4.

Plan 5.3.8: Do 5.3.8.1 and 5.3.8.2 in order.

Plan 5.4: Do 5.4.1, 5.4.2, 5.4.3, 5.4.4, 5.4.5, 5.4.6, and 5.4.7 in order.

Plan 5.4.1: Do 5.4.1.1, 5.4.1.1, 5.4.1.2, 5.4.1.3, and 5.4.1.4 in order.

Plan 5.4.2: Do 5.4.2.1 and 5.4.2.2 in order. If knuckles must be adjusted, do 5.4.2.3. Then do 5.4.2.4. If reverser direction must be changed, do 5.4.2.5. Then do 5.4.2.6.

Plan 5.4.3: Do 5.4.3.1 and 5.4.3.2 in order.

Plan5.4.5: Do 5.4.5.1 and 5.4.5.2. If reverser direction must be changed, do 5.4.5.3. Then do 5.4.5.4.

Plan 5.4.7: Do 5.4.7.1 and 5.4.7.2 in order.

Plan 5.5: Do 5.5.1, 5.5.2, 5.5.3, and 5.5.4 in order. Repeat 5.5.3 and 5.5.4 as necessary. If pin does not release after 5.5.4, do 5.5.5, 5.5.6, and 5.5.7 in order, then repeat 5.5.1 through 5.5.4. For cars that cannot be humped, start with 5.5.8 and then do 5.5.9, 5.5.10, and 5.5.11. Repeat starting with 5.5.1 as necessary.

Plan 5.5.1: Do 5.5.1.1, 5.5.1.1, 5.5.1.2, 5.5.1.3, and 5.5.1.4 in order.

Plan 5.5.2: Do 5.5.2.1 and 5.5.2.2 in order. If knuckles must be adjusted, do 5.5.2.3. Then do 5.5.2.4. If reverser direction must be changed, do 5.5.2.5. Then do 5.5.2.6.

Plan 5.5.4: Do 5.5.4.1 and 5.5.4.2 in order.

Plan 5.5.6: Do 5.5.6.1 and 5.5.6.2. If reverser direction must be changed, do 5.5.6.3. Then do 5.5.6.4.

Plan 5.5.8: Do 5.5.8.1 and 5.5.8.2 in order. If coupling did not take, then repeat 5.5.8.1 through 5.5.8.2.

Plan 5.5.8.1: Do 5.5.8.1.1 and 5.5.8.1.2 in order. If knuckles must be adjusted, do 5.5.8.1.3. Then do 5.5.8.1.4. If reverser direction must be changed, do 5.5.8.1.5. Then do 5.5.8.1.6.

Plan 5.5.8.2: Do 5.5.8.2.1, 5.5.8.2.2, and 5.5.8.2.3 in order.

Plan 5.5.8.2.3: Do 5.5.8.2.3.1, 5.5.8.2.3.2, and 5.5.8.2.3.3 in order.

Plan 5.5.8.2.3.1: Do 5.5.8.2.3.1.1 and 5.5.8.2.3.1.2. If reverser direction must be changed, do 5.5.8.2.3.1.3. Then do 5.5.8.2.3.1.4.

Plan 5.5.9: Do 5.5.9.1, 5.5.9.2, and 5.5.9.3 in order. If necessary, do 5.5.9.4.

Plan 5.5.9.1: Do 5.5.9.1.1 and 5.5.9.1.2. If reverser direction must be changed, do 5.5.9.1.3. Then do 5.5.9.1.4.

Plan 5.5.10: Do 5.5.10.1 and 5.5.10.2. If reverser direction must be changed, do 5.5.10.3. Then do 5.5.10.4.

Plan 6: Do 6.1. If working a bowl or trim job, do 6.2 and 6.3 in order. Do 6.4 if necessary. Then do 6.5 and 6.6 in order. If flat switching, do 6.4 if necessary, and then do 6.5 and 6.6 in order.

Plan 6.1: Do 6.1.1, 6.1.2, and 6.1.3 in order. Repeat 6.1.2 through 6.1.3 if coupling did not take.

Plan 6.1.1: Do 6.1.1.1, 6.1.1.1, 6.1.1.2, 6.1.1.3, and 6.1.1.4 in order.

Plan 6.1.2: Do 6.1.2.1 and 6.1.2.2 in order. If knuckles must be adjusted, do 6.1.2.3. Then do 6.1.2.4. If reverser direction must be changed, do 6.1.2.5. Then do 6.1.2.6.

Plan 6.1.3: Do 6.1.3.1, 6.1.3.2, and 6.1.3.3 in order.

Plan 6.1.3.3: Do 6.1.3.3.1, 6.1.3.3.2, and 6.1.3.3.3 in order.

Plan 6.1.3.3.1: Do 6.1.3.3.1.1 and 6.1.3.3.1.2. If reverser direction must be changed, do 6.1.3.3.1.3. Then do 6.1.3.3.1.4.

Plan 6.3: Do 6.3.1. Then do 6.3.2 and 6.3.3 in order, as necessary. Repeat 6.3.2 through 6.3.3 until entire cut of cars is coupled.

Plan 6.3.2: Do 6.3.2.1 and 6.3.2.2 in order. If knuckles must be adjusted, do 6.3.2.3. Then do 6.3.2.4. If reverser direction must be changed, do

6.3.2.5. Then do 6.3.2.6.

Plan 6.3.3: Do 6.3.3.1, 6.3.3.2, and 6.3.3.3 in order.

Plan 6.3.3.3: Do 6.3.3.3.1, 6.3.3.3.2, and 6.3.3.3.3 in order.

Plan 6.3.3.3.1: Do 6.3.3.3.1.1 and 6.3.3.3.1.2. If reverser direction must be changed, do 6.3.3.3.1.3. Then do 6.3.3.3.1.4.

Plan 6.5: Do 6.5.1, 6.5.2, and 6.5.3 in order.

Plan 6.5.1: Do 6.5.1.1 and 6.5.1.2. If necessary, do 6.5.1.3 and/or 6.5.1.4. Lastly, do 6.5.1.5.

Plan 6.5.2: Do 6.5.2.1 and 6.5.2.2. If necessary do 6.5.2.3. Then do 6.5.2.4. If reverser direction must be changed, do 6.5.2.5. Then do 6.5.2.6.

Plan 6.6: Do 6.6.1 and 6.6.2 in order.

C.3 HTA Subtask Matrix

The last part of the HTA is a breakdown of the lowest level tasks (e.g., move locomotive) into subtasks. Each of the lowest level tasks in the HTA is associated with a unique letter. It is at this (lowest) level where most of the differences exist between the two different switching methods of operation. At higher levels of the HTA, the tasks are the same (e.g., switch cars) for each method of operation; it is in how the actual activity is carried out where differences exist. For each lettered task of each method of operation, crewmember activity is broken down into specific subtasks.

The three-person conventional crew consists of a locomotive engineer and two switchmen (usually a yard foreman and a helper). The engineer operates the locomotive through a control stand inside the locomotive cab, controlling the movement of the train. The switchmen move around the yard by riding on the locomotive or car, or walking along side a track. Switchmen line switches, couple/uncouple cars, adjust couplers, tie down or release car handbrakes, and direct the movement of the train.[18] The two-person RCL crew consists of two RCOs. Each RCO has an RCD and can alternate who has primary responsibility for controlling the RCL through inputs to the RCD. Each may ride on the RCL or a car or walk along side a track while performing his/her tasks. The RCO who controls the movement of the RCL is designated as the primary RCO (RCO-P) while the secondary RCO (RCO-S) assists the RCO-P as a switchman. The RCO-S does have some safety functions available on his/her RCD, however. RCOs take turns controlling the movement of the RCL, lining switches, and coupling and uncoupling cars.

Some abbreviations that are used in the subtask descriptions include the following:

- T1: The yard foreman
- T2: A second switchman (a.k.a., a helper)
- E: Locomotive engineer
- RCO-P: Primary RCO who has control of the movement)
- RCO-S: Secondary RCO

---

[18] Controlling the movement of the train and directing the movement of the train are distinguished from each other. Controlling the movement of the train involves actual inputs to move and stop the locomotive, while directing the movement of the locomotive involves determining the route and authorizing the movement of the locomotive. One individual, such as an RCO, may perform both functions, or two individuals may share these responsibilities, such as in the case of a locomotive engineer and yard foreman.

Table C-1. Railroad yard switching HTA subtasks

Letter	Task	3-person conventional crew subtasks	2-person remote control crew subtasks
A	**Check Switch List**	T1 reviews switch list and matches car(s) numbers on switch list with car(s) in yard.	RCO-P or RCO-S reviews switch list and matches car(s) numbers on switch list with car(s) in yard.
B	**Locate Target Track**	T1 or T2 locates target track where car(s) are to be placed.	RCO-P or RCO-S locates target track where car(s) are to be placed.
C	**Determine Track Route**	T1 determines track route between current car(s) location and target track.	RCO-P or RCO-S determines track route between current car(s) location and target track.
D	**Locate Switch(es) to Line**	T1 and/or T2 locates switch(es) to line.	RCO-P and/or RCO-S locates switch(es) to line.
E	**Lines Switch(es)**	T1 and/or T2 physically lines switch(es).	RCO-P and/or RCO-S physically lines switch(es). RCOs right self or activate tilt time-out extension if necessary.
F	**Check path**	T1, T2, and/or E look ahead of movement to ensure path is free of obstructions and fouling equipment. They also check to be sure that route is properly lined.	RCO-P and/or RCO-S look ahead of movement to ensure path is free of obstructions and fouling equipment. They also check to be sure that route is properly lined.
G	**Ensure Coupler Knuckles are Open and Aligned Properly**	T2 visually inspects coupler assembly to ensure knuckles are open.	RCO-P or RCO-S visually inspects coupler assembly to ensure knuckles are open.
H	**Adjust Coupler Assembly**	T2 adjusts knuckles and drawbar to ensure proper coupling.	RCO-P or RCO-S adjusts knuckles and drawbar to ensure proper coupling. RCOs right self or activate tilt time extension if necessary.
I	**Check Reverser Position**	E checks reverser to make certain it is in correct position for desired direction of movement.	RCO-P checks reverser to make certain it is in correct position for desired direction of movement.
J	**Change Reverser Position**	E changes reverser to correct position.	RCO-P changes reverser to correct position.

Letter	Task	3-person conventional crew subtasks	2-person remote control crew subtasks
K	**Initiate Locomotive Movement**	T1 instructs E through radio or hand/lantern signal to initiate movement. E releases independent brake and applies throttle. E must be prepared to stop short of any obstructions, fouling equipment, or switches lined against move.	RCO-S may instruct RCO-P to move locomotive, or RCO-P may make this decision. RCO-P presses a prespecified button and moves speed selector to desired speed. RCO-P acknowledges RCD vigilance alarm as necessary. RCO-P must be prepared to stop short of any obstructions, fouling equipment, or switches lined against move.
L	**Maintain Locomotive Movement**	T1, T2, and/or E observe remaining distance between locomotive/lead car and standing car(s), and looks for obstructions, fouling equipment, or switches lined against move. T1 or T2 may instruct E, through radio or hand/lantern signal, on remaining distance to travel or to stop if necessary. T1 or T2 may mount or dismount moving equipment as necessary. E maintains speed, increases speed, or decreases speed by adjusting brake and throttle as necessary.[19]	RCO-P and/or RCO-S observes remaining distance between locomotive/lead car and standing car(s), and looks for obstructions, fouling equipment, or switches lined against move. RCO-S may instruct RCO-P, through radio or hand/lantern signal, on remaining distance to travel or to stop if necessary. RCO-P must be prepared to stop short of any obstructions, fouling equipment, or switches lined against move. RCO-P adjusts speed selector as necessary.[20] RCO-P/S may mount or dismount moving equipment as necessary. RCO-P/S may ride side of moving equipment as necessary. RCO-P acknowledges RCD vigilance alarm as necessary.
M	**Slow Locomotive**[21]	N/A	N/A

---

[19] Adjustment will depend on speed, gradient, tonnage, number of units, power, and braking characteristics, as well as other factors (e.g., slippery railhead).

[20] Adjustment will depend on speed, gradient, tonnage, number of units, power, and braking characteristics, as well as other factors (e.g., slippery railhead).

[21] "Slow Locomotive" subtask letter M was removed in an earlier version of the HTA since its function was subsumed under "maintain locomotive movement" and "stop locomotive." A placeholder is maintained in Table C-1, however, so that the overall lettering scheme used in the subtask matrix would otherwise be unaffected.

Letter	Task	3-person conventional crew subtasks	2-person remote control crew subtasks
N	**Stop Locomotive**	T1 or T2 instructs E to stop locomotive (shoving movement). E adjusts throttle to idle and applies independent brake to stop locomotive.	RCO-S may instruct RCO-P to stop locomotive (shoving/pulling movement). RCO-P moves speed selector to stop and applies independent brake if (1) standard operating practice or (2) necessary.
O	**Inspect Coupling**	T2 observes coupling to determine if coupling is successful.	RCO-P or RCO-S observes coupling to determine if coupling is successful.
P	**Obtain 3-Point Protection**	T2 requests 3-point protection from E. E turns off generator field, applies brakes, and moves reverser to neutral (or checks to be sure that these three steps are in place). E then informs T2 that 3-point protection has been granted.	RCO-S may request 3-point protection from RCO-P. Otherwise, RCO-P wants 3-point protection for self. RCO-P moves speed selector to stop, moves reverser position to neutral, and applies brakes[22] (or checks to be sure that the three steps are in place). If RCO-S has requested the 3-point protection, then RCO-P informs RCO-S that 3-point protection has been granted.
Q	**Bleed Off Cars**	T1 or T2 bleeds off cars as necessary.	RCO-P or RCO-S bleeds off cars as necessary.
R	**Release Hand Brake**	T2 checks each car's handbrake. If necessary, T2 climbs ladder(s) and releases handbrake(s). T1 may assist T2 in releasing additional cars' handbrakes.	RCO-P and/or RCO-S checks each car's handbrake. If necessary, an RCO climbs ladder(s) and releases handbrake(s). RCO rights self or activates tilt time-out extension if necessary.
S	**Cancel 3-Point Protection**	T2, the crewmember who requested the 3-point protection, requests cancellation of 3-point protection from E. E acknowledges cancellation of 3-point protection and re-engages generator field.	If RCO-S requested the 3-point protection, then RCO-S requests cancellation of 3-point protection from RCO-P. RCO-P acknowledges cancellation of 3-point protection. RCO-P releases independent brake.

---

[22] In RCL operations, the locomotive's generator field has already been cut-out; thus this step is not possible for 3-point protection in RCL operations. As a result, the new step in providing 3-point protection (in addition to moving the reverser to neutral and applying the brakes) is to set the RCD speed selector to stop.

Letter	Task	3-person conventional crew subtasks	2-person remote control crew subtasks
T	**Pull Pin**	T2 observes bunching at knuckle where separation will occur and judges when there is sufficient bunching and pulls in.	RCO-P or RCO-S observes bunching at knuckle where separation will occur and judges when there is sufficient bunching and pulls pin. RCOs right selves or activate tilt time extension if necessary.
U	**Tie Down Car Handbrake(s)**	T2 climbs ladder of each car and ties down car handbrake. T1 may assist.	RCO-P or RCO-S climbs ladder of each car and ties down car handbrake. Other crewmember may assist.
V	**Identify Cars to be Released**	T1 checks switch list to determine car(s) to detach. T1 then identifies and verifies actual car(s) at lead end of train to be detached.	RCO-P or RCO-S checks switch list to determine car(s) to detach. Same crewmember then identifies and verifies actual car(s) at lead end of train to be detached.
W	**Maintain Hump Speed**	E adjusts throttle and brake, as necessary, to maintain desired speed.	RCO-P adjusts speed selector, as necessary, to maintain desired speed. RCO-P acknowledges vigilance alarm as necessary.
X	**Confirm Car Order**	T2 walks length of track and compares cars against switch list. T1 may assist T2.	RCO-P or RCO-S walks length of track and compares cars against switch list. Other crewmember may assist.
Y	**Lace Up Air Hoses**	T2 checks air hoses between cars and laces up air hoses between cars as necessary.	RCO-P or RCO-S checks air hoses between cars and laces up air hoses between cars as necessary.

Appendix D.
Railroad Yard Switching Activities PHA

Table D-1. Conventional operations outcomes and worst credible scenarios

	First order outcome	Second order outcome	Third order outcome	Worst credible scenario	Likelihood of occurrence	Severity	Total
1	Collision	Conventionally operated cut (COC) pulls into standing/ moving cut	COC hits end of cut	COC crew fails to provide point protection and pulls into standing/moving cut, and due to sudden impact, employee riding cut falls into red zone and is killed.	F	I	
					1	4	4
2			COC sideswipes cut	COC crews pulls into standing/moving cut, and due to sudden impact, employee riding cut falls into red zone and is killed.	F	I	
					1	4	4
3		COC pulls into employee	COC hits own crewmember	Locomotive engineer fails to provide point protection and runs over and kills own crewmember.	F	I	
					1	4	4
4			COC hits other employee	Locomotive engineer fails to provide point protection and runs over and kills other employee.	F	I	
					1	4	4
5		COC shoves/ kicks into standing/ moving cut	COC hits end of cut	Crewmembers fail to assess correct distance, and engineer shoves/kicks into end of another cut, knocking employee on other crew off the car he is riding, and he gets run over and is killed.	D	I	
					3	4	12
6			COC sideswipes cut	Crewmembers fail to provide point protection and shove/kick into side of cut, damaging a HAZMAT car and releasing HAZMAT into the environment, killing at least one person.	D	1	
					3	4	12
7		COC shoves/ kicks into employee	COC hits own crewmember	Crewmember fails to provide point protection, and engineer runs over and kills own crewmember.	C	I	
					4	4	16
8			COC hits other employee	Crewmembers fail to provide point protection and run over and kill other employee.	D	I	
					3	4	12

	First order outcome	Second order outcome	Third order outcome	Worst credible scenario	Likelihood of occurrence	Severity	Total
9		COC breaks cut in two, resulting in rollaway car(s)		Engineer applies brakes too hard on a grade, and the severe slack actions causes cars to break in two and roll away, colliding with equipment and causing damage.	E	II	
					2	3	6
10	Derailment	COC pulls/ shoves over broken rail		Locomotive engineer/groundman fails to provide point protection and pulls/shoves locomotives over broken rail which results in derailment and damage.	D	III	
					2	2	6
11		COC pulls/ shoves over rail that turns under the cut		Locomotive engineer fails to perceive rail has turned under his movement; derailment and damage result.	E	IV	
					2	1	2
12		COC pulls/ shoves over wide gauge		Locomotive engineer fails to perceive wide gauge, resulting in derailment and damage.	E	IV	
					2	1	2
13		COC pulls/ shoves over previously run-through switch		Locomotive engineer/groundman fails to provide point protection and pulls/shoves over run though switch, resulting in derailment and damage.	D	III	
					3	2	6
14		COC pulls/ shoves over derail		Locomotive engineer/groundman fails to provide point protection and pulls/shoves over derail, resulting in derailment, and car topples on groundman, killing him.	D	I	
					3	4	12
15		Locomotive engineer-induced brake application causes a whip-crack of slack		Due to unexpected excessive slack, crewmember is knocked to ground and then run over and killed.	F	I	
					1	4	4
16	Hard coupling	COC travels too fast for coupling		Due to hard coupling, crewmember is knocked to ground and is injured.	D	II	
					3	3	9

	First order outcome	Second order outcome	Third order outcome	Worst credible scenario	Likelihood of occurrence	Severity	Total
17	Unexpected movement	Unexpected movement of cut throws crewmember to ground		Locomotive engineer acts upon the wrong signal to move causing crewmember to be thrown into red zone where he is run over and killed.	E	I	
					2	4	8
18	Slips/trips/ falls	Crewmember trips over yard debris and falls		Crewmember falls into red zone in front of moving cut and is killed.	D	I	
					3	4	12
19		Crewmember slips/trips/falls while mounting/ dismounting standing equipment		Crewmember falls and sprains/strains back or limb.	C	III	
					4	2	8

Table D-2. Conventional operations outcomes and most likely scenarios

	First order outcome	Second order outcome	Third order outcome	Most likely scenario	Likelihood of occurrence	Severity	Total
1	Collision	COC pulls into standing/moving cut	COC hits end of cut	COC crew fails to provide point protection and pulls into standing/moving cut, and due to sudden impact, employee riding on side is knocked to ground and fractures bone(s).	E	III	
					2	2	4
2			COC sideswipes cut	COC crews pulls into standing/moving cut, and due to sudden impact, employee riding on side is knocked to ground and bruised.	D	IV	
					3	2	6
3		COC pulls into employee	COC hits own crewmember	Locomotive engineer fails to provide point protection and bumps own crewmember.	F	IV	
					1	1	1
4			COC hits other employee	Locomotive engineer fails to provide point protection and bumps other employee.	F	IV	
					1	1	1
5		COC shoves/ kicks into standing/moving cut	COC hits end of cut	Crewmember fails to assess correct distance, and engineer shoves/kicks into end of another cut, resulting in little or no damage.	C	Non-reportable	
					4	0	0
6			COC sideswipes cut	Crewmember fails to provide point protection and sideswipes cut, damaging cars and cargo.	C	III	
					4	2	8
7		COC shoves/ kicks into employee	COC hits own crewmember	Crewmember fails to provide point protection and end of cut bumps own crewmember.	C	III	
					4	2	8
8			COC hits other employee	Crewmember fails to provide point protection and bumps other employee.	D	III	
					3	2	6
9		COC breaks cut in two, resulting in rollaway car(s)		Engineer applies brakes too hard on a grade, and the severe slack actions causes cars to break in two and roll away, resulting in hard coupling with a standing cut on track.	E	IV	
					2	1	2
10	Derailment	COC pulls/ shoves over broken rail		Locomotive engineer/groundman fails to provide point protection and pulls/shoves locomotive over broken rail, which results in slight derailment (one wheel on ground) and no damage.	B	Non-reportable	
					5	0	0

	First order outcome	Second order outcome	Third order outcome	Most likely scenario	Likelihood of occurrence	Severity	Total
11		COC pulls/ shoves over rail that turns under the cut		Locomotive engineer recognizes rail has turned under his movement and subsequently stops movement before much damage occurred.	E	Non-reportable	
					2	0	0
12		COC pulls/ shoves over wide gauge		Locomotive engineer recognizes wide gauge after it occurs under his movement and stops locomotive before much damage occurred.	C	Non-reportable	
					4	0	0
13		COC pulls/ shoves over previously run-through switch		Locomotive engineer/groundman fails to provide point protection and pulls/shoves locomotive over run through switch, resulting in slight derailment (one wheel on ground) and no damage.	A	Non-reportable	
					6	0	0
14		COC pulls/ shoves over derail		Locomotive engineer/groundman fails to provide point protection and pulls/shoves locomotive over derail, resulting in slight derailment (one wheel on ground) and no damage.	B	Non-reportable	
					5	0	0
15		Locomotive engineer-induced brake application causes a whip-crack of slack		Due to unexpected excessive slack, crewmember is knocked to ground and is injured.	E	III	
					2	2	4
16	Hard coupling	COC travels too fast for coupling		Hard coupling, but no or negligible damage occurs.	B	Non-reportable	
					5	0	0
17	Unexpected movement	Unexpected movement of cut throws crewmember to ground		Locomotive engineer acts upon the wrong signal to move, causing crewmember riding locomotive/end of cut to be thrown to ground and bruised.	C	IV	
					4	1	4
18	Slips/trips/ falls	Crewmember trips over yard debris and falls		Crewmember falls and is bruised.	A	Non-reportable	
					6	0	0
19		Crewmember slips/trips/falls while mounting/ dismounting standing equipment		Crewmember falls and scrapes limb/torso.	A	Non-reportable	
					6	0	0

Table D-3. RCL operations outcomes and worst credible scenarios

	First order outcome	Second order outcome	Third order outcome	Worst credible scenario	Likelihood of occurrence	Severity	Total
1	Collision	RCL pulls into standing/ moving cut	RCL hits end of cut	RCL crew fails to provide point protection and pulls into standing/moving cut, and due to sudden impact, employee riding side of cut falls into red zone and is killed.	D	I	
					3	4	12
2			RCL sideswipes cut	RCL crew fails to provide point protection and pulls into cut, and due to sudden impact, employee riding side of cut falls and fractures bone(s).	C	II	
					4	3	12
3		RCL pulls into employee	RCL hits own crewmember	RCO fails to provide point protection and runs over and kills own crewmember.	C	I	
					4	4	16
4			RCL hits other employee	RCO fails to provide point protection and runs over and kills other employee.	D	I	
					3	4	12
5		RCL shoves/ kicks into standing/ moving cut	RCL hits end of cut	RCO fails to assess correct distance and shoves/kicks into end of cut, knocking crewmember riding cut to the ground, and he gets run over.	D	I	
					3	4	12
6			RCL sideswipes cut	RCO fails to provide point protection and shoves/kicks into side of cut, damaging a HAZMAT car, releasing HAZMAT into the environment, killing at least one person.	D	I	
					3	4	12
7		RCL shoves/ kicks into employee	RCL hits own crewmember	RCO fails to provide point protection and runs over and kills own crewmember.	C	I	
					4	4	16
8			RCL hits other employee	RCO fails to provide point protection and runs over and kills other employee.	D	I	

	First order outcome	Second order outcome	Third order outcome	Worst credible scenario	Likelihood of occurrence	Severity	Total
					3	4	12
9		RCL breaks cut in two, resulting in rollaway car(s)		RCO or RCL applies heavy brake application, and the severe slack action causes cars to brake from train and roll away, colliding into equipment and causing damage.	D	II	
					3	3	9
10	Derailment	RCO pulls/ shoves over broken rail		RCO fails to provide point protection and pulls/shoves RCL over broken rail, resulting in derailment and damage.	D	II	
					3	3	9
11		RCO pulls/ shoves over rail that turns under you		RCO fails to perceive rail has turned under his movement, resulting in derailment, and cars are dragged and damaged.	E	III	
					2	2	4
12		RCO pulls/ shoves over wide gauge		RCO fails to perceive wide gauge under his movement, resulting in derailment and damage result.	E	III	
					2	2	4
13		RCO pulls/ shoves over previously run-through switch		RCO fails to provide point protection and pulls/shoves over run though switch, resulting in derailment and damage.	D	II	
					3	3	9
14		RCL pulls/ shoves over derail		RCO fails to provide point protection and pulls/shoves over derail, resulting in derailment and damage.	D	III	
					3	2	6
15	Excessive slack	RCO-induced brake application causes a whip-crack of slack		Due to unexpected excessive slack, crewmember is knocked to ground and then run over and killed.	E	I	
					2	4	8

	First order outcome	Second order outcome	Third order outcome	Worst credible scenario	Likelihood of occurrence	Severity	Total
16	Hard coupling	RCL or cut of cars moves too fast for coupling		Due to hard coupling, crewmember is knocked to ground and is injured.	C	II	
					4	3	12
17	Unexpected movement	Unexpected movement of cut throws crewmember to ground	*RCO inadvertently moves lever	RCO unexpectedly causes a change in movement, resulting in crewmember being thrown into red zone where he is run over and killed.	D	I	
					3	4	12
18	Slips/trips/ falls	Crewmember trips over yard debris and falls		Crewmember falls into red zone in front of moving cut and is killed.	D	I	
					3	4	12
19		Crewmember slips/trips/ falls while mounting/ dismounting equipment		Crewmember falls and sprains/strains back or limb.	C	III	
					4	2	8

Table D-4. RCL operations outcomes and most likely scenarios

	First order outcome	Second order outcome	Third order outcome	Most likely scenario	Likelihood of occurrence	Severity	total
1	Collision	RCL pulls into standing/ moving cut	RCL hits end of cut	RCL crew fails to provide point protection pulls into standing/moving cut, and due to sudden impact, employee riding side of cut is knocked to ground and is bruised.	C	IV	
					4	1	4
2			RCL sideswipes cut	RCL crew fails to provide point protection and pulls into standing/moving cut, and due to sudden impact, employee riding side of cut is knocked to ground and is bruised.	B	IV	
					5	1	5
3		RCL pulls into employee	RCL hits own crewmember	RCO fails to provide point protection, and cut of cars bumps own crewmember.	B	III	
					5	2	10
4			RCL hits other employee	RCO fails to provide point protection, and cut of cars bumps other employee.	C	III	
					4	2	8
5		RCL shoves/ kicks into standing/ moving cut	RCL hits end of cut	RCO fails to assess correct distance, and cut makes a hard coupling, resulting in little or no damage.	C	Non-reportable	
					4	0	0
6			RCL sideswipes cut	RCO fails to provide point protection, and sideswipes cut damaging cars and cargo.	B	IV	
					5	1	5
7		RCL shoves/ kicks into employee	RCL hits own crewmember	RCO fails to provide point protection and bumps own crewmember.	B	III	
					5	2	10
8			RCL hits other employee	RCO fails to provide point protection and bumps other employee.	C	III	
					4	2	8
9		RCL breaks cut in two, resulting in rollaway car(s)		RCO or RCL applies brake application on a grade, and the severe slack action causes cars to brake from train and roll away, resulting in hard coupling with a standing cut on track.	C	III	
					4	2	8

	First order outcome	Second order outcome	Third order outcome	Most likely scenario	Likelihood of occurrence	Severity	total
10	Derailment	RCO pulls/ shoves over broken rail		RCO fails to provide point protection and pulls/shoves locomotive over broken rail, resulting in slight derailment (one wheel on ground) and no damage.	B	Non-reportable	
					5	0	0
11		RCO pulls/ shoves over rail that turns under you		RCO recognizes rail has turned under his movement and subsequently stops movement before much damage occurred.	E	IV	
					2	1	2
12		RCO pulls/ shoves over wide gauge		RCO recognizes wide gauge after it occurs under his movement and stops locomotive before much damage occurred.	C	Non-reportable	
					5	0	0
13		RCO pulls/ shoves over previously run-through switch		RCO fails to provide point protection and pulls/shoves locomotive over run-through switch, resulting in slight derailment (one wheel on ground) and slight damage.	B	IV	
					5	1	5
14		RCL pulls/ shoves over derail		RCO fails to provide point protection and pulls/shoves locomotive over derail, resulting in slight derailment (one wheel on ground) and no damage.	B	Non-reportable	
					5	0	0
15	Excessive slack	RCO-induced brake application causes a whip-crack of slack		Due to unexpected excessive slack, crewmember is knocked to ground and is injured.	B	IV	
					5	1	5
16	Hard coupling	RCL or cut of cars moves too fast for coupling		Hard coupling occurs but does not result in any damage.	A	Non-reportable	
					6	0	0
17	Unexpected movement	Unexpected movement of cut throws crewmember to ground	*RCO inadvertently moves lever *OCC has failure and autonomously moves on its own accord	RCO or OCC unexpected change in movement causes crewmember to be thrown to ground and bruised.	C	IV	
					4	1	4

	First order outcome	Second order outcome	Third order outcome	Most likely scenario	Likelihood of occurrence	Severity	total
18	Slips/trips/ falls	Crewmember trips over yard debris and falls		Crewmember falls and is bruised.	A	Non-reportable	
					6	0	0
19		Crewmember slips/trips/ falls while mounting/ dismounting equipment		Crewmember falls and scrapes limb/torso.	A	Non-reportable	
					6	0	0

Appendix E.
HRA Pilot Study

E.1 General Overview of Pilot Study

Before conducting the HRA, the assessment team conducted a pilot study to evaluate the feasibility and applicability of the HEART and APJ methods for railroad yard switching operations. The pilot study also provided the team with an opportunity to refine the processes, establish standards for participants, and evaluate the effectiveness of instructions and resources. Two operating scenarios were created for the pilot study, and for each scenario, a set of lettered tasks that made up each scenario were identified based on the HTA.

In addition, materials were developed to facilitate the HEART and APJ assessment activities. These materials and the scenario descriptions were developed to help participants understand the scenarios and tasks under evaluation, as well as to facilitate communications and understanding between participants and the assessment team. In addition to an instruction sheet that was provided to participants (and read by the facilitator), HEART participants received lists containing GTTs and EPCs. The team customized these lists to improve understanding of the terms and information covered. For GTTs and EPCs, definitions and descriptions were provided to help clarify potentially unfamiliar or confusing HEART or APJ terms. EPCs were grouped according to the general type of information referred to, such as environment, task, and operator conditions. APJ participants were provided with a reference sheet showing a series of probability values (e.g., 0.1) and their corresponding chances (e.g., 1 in 10). This sheet provided a visual reference for participants to see how individual probability values translated into chances of occurrence while also providing a scale to depict high versus low chances of making a mistake.

E.2 Pilot Study Methods and Results

E.2.1 Pilot Study Participants

The pilot study took place over three sessions in a medium-sized city in the southern part of the United States, and involved a total of 13 individuals employed by two Class I railroads operating in the area. Participants were recruited with the assistance of the UTU. The only criteria for participation were that participants were FRA-certified RCOs and were willing to share their experiences with the study team.

Since the goal of the pilot study was to evaluate the feasibility and applicability of the APJ and HEART methods for use with railroad yard operations, not to evaluate the comparative differences in reliability between conventional and RCL operations, it was not necessary to include conventional yard switching crews in the pilot. The restriction of tasks to RCL operations simplified the recruitment process and enabled the team to focus its efforts on setting up the pilot to help shed light on the applicability of the HRA methods to railroad switching operations.

Eight participants participated in two separate HEART sessions, and five participants participated in one APJ session. Each session had representatives from both railroads. Each participant was compensated for their time (approximately 2 h). The HEART sessions were held between 4:30-6:30 p.m. one day and between 8 and 10 p.m. that evening. The APJ session was held the following morning between 9 and 11 a.m.

Before participating in the study, the assessment team asked participants to provide demographic information regarding their age and associated experience as an RCO, switchman, and total time on the railroad. Participants in both the HEART and APJ groups had substantial experience as switchmen, including RCO experience. HEART participants had an average of 20 yr of experience as switchmen (ranging from 1.5 to 36 yr), with an average of 16 mo of RCO experience (ranging from 8-24 mo). APJ participants had an average of 14 yr of switchman experience (ranging from 4-30 yr) and an average of 15 mo of RCO experience (ranging from 12-18 mo). Tables E-1 and E-2 present further demographic information.

Table E-1. Participant demographics for HEART pilot session

Participant	Age (yr)	RCO experience (mo)	Switchman experience (yr)	Total railroad experience (yr)
1	59	24	34	34
2	57	24	36	36
3	28	18	5	5
4	52	8	27	27
5	43	10	6	6
6	26	15	1.5	1.5
7	46	15	26	26
8	47	14	27	27
Average	45	16	20.3	20.3

Table E-2. Participant demographics for APJ pilot session

Participant	Age (yr)	RCO experience (mo)	Switchman experience (yr)	Total railroad experience (yr)
9	53	15	24	25
10	49	18	7	7
11	53	18	30	30.5
12	33	12	4	4
13	29	12	5	8
Average	43	15	14	14.9

E.2.2 Pilot Study General Procedure and Materials

Several materials were developed to facilitate the HEART and APJ sessions, including a general overview that the facilitator used to guide the pilot study, scenario descriptions, facilitator scripts, and HEART and APJ support materials.

As participants arrived at the meeting room where the pilot session was held, they were introduced to the facilitators and the other participants and encouraged to help themselves to refreshments. Participants were asked to provide information on age, railroad experience, and experience as an RCO and switchman.

At the beginning of each session, the facilitator provided a general overview to the participants, providing them with some background information for the RCL study and an explanation of the goals for the pilot project. After participants were provided with the general overview, the facilitator provided detailed instructions for the HRA technique targeted for the session (i.e., HEART or APJ).

In both the HEART and APJ pilot sessions, participants assessed the HEP associated with two scenarios associated with a typical flat switching move (shoving a cut of cars). The two scenarios were developed to provide participants with details that may increase or decrease the HEP associated with the move. One scenario was designed to provide participants with a favorable case scenario baseline that could be used to anchor HEP ratings in favorable operating conditions, such as good weather, well-rested crewmembers, and the absence of other jobs in the yard that might foul the tracks or distract personnel. The other scenario was designed to provide an unfavorable case scenario comparison to the first scenario, with adverse weather conditions, fatigued workers, and multiple jobs taking place in the yard. Assuming that the conditions specified in the two scenarios have an influence on HEP, the HEART and APJ assessments should reveal differences in the level of HEP associated with tasks performed under the two scenarios. Using these two scenarios therefore served as a means to provide a general measure of the sensitivity of the HEART and APJ approaches to distinguish between variations in operational characteristics.

In addition, RCO and system characteristics that remained fixed across both scenarios to be assessed were specified and conveyed to participants. Operator characteristics included the following:

- RCOs were considered competent at work.
- RCOs were generally motivated to work by the rules (i.e., positive attitude) but understood that not all rules can be followed all the time and that sometimes rules are bent to get the job done.
- RCOs had a good relationship with local management and fellow employees.
- RCOs were current on all rules and other qualifications (e.g., RCO or locomotive engineer certification, rules, or HAZMAT refresher training).
- RCOs had no work-impairing distractions at home.
- RCOs had no previously reported railroad infractions or rule violations.

- RCOs were initially a bit reluctant using the RCD but have made every effort to learn how to use the box.
- RCOs had a 30 min commute each way, to and from work.
- The yardmaster is overworked and does not particularly like, nor understand, RCL operations.
- RCOs wore appropriate PPE.

System characteristics included the following:

- 25 yr old road engines were used for yard switching.
- RCLs were minimally maintained.
- The automatic train air was not cut-in.
- The newest generation of RCDs was used.
- The maximum speed selector setting was 10 mph.
- Remote control safety features included tilt protection, vigilance alarm, and use of the RCL's independent brake.
- Both RCOs have an RCD, though only one operates the RCL at a time.
- Both RCOs have two-way radios.
- Night work was performed with flashlights or lanterns provided by the railroad.
- The yardmaster on duty is overworked and does not know anything about RCL operations.

In addition to those variables that were constant for each scenario, a number of variables differed across the two scenarios. Table E-3 presents a comparison of the different operating scenario variables that were part of the two scenarios that were assessed in the pilot study.

To help participants perform the HEART or APJ assessment, they were shown a yard diagram (see Figure E-1) upon which the two scenarios were based. The yard was designed to be a typical but non-specific flat classification yard.

Table E-3. Operating scenario variables for the HRA pilot study

	Favorable case	Unfavorable case
Crew age	50s	20s
Crew experience	20+ yrs as switchman 2 yr as RCO	1 yr as switchman 1 mo as RCO
Crewmembers familiar with each other?	Yes	No
Regular/extra work assignment	Regular	Extra board
Last workday	3 d ago	Yesterday
Number of consecutive days worked	1 (This is the first day back after 2 d off)	9
Training (RCO)	40 h classroom + 40 h hands-on OJT. OJT was one-on-one instruction so RCOs had full opportunity to practice.	3 d classroom + 30 d (trips) OJT. OJT involved shadowing RCO mentor; opportunity to operate the box was about 1/3 of the time.
Time-of-day	3 p.m.	3 a.m.
Weather	Sunny, 60s	Mid-30s, frost on ground and rails
PPE	Work gloves, safety glasses, safety boots	Thick winter gloves, safety glasses, safety boots
Condition of yard	Well-maintained	Poorly maintained
Size of cut	5 empties	45 loads
Urgency	None	High
Location of other crews	No other crews in vicinity	Two other crews in the vicinity

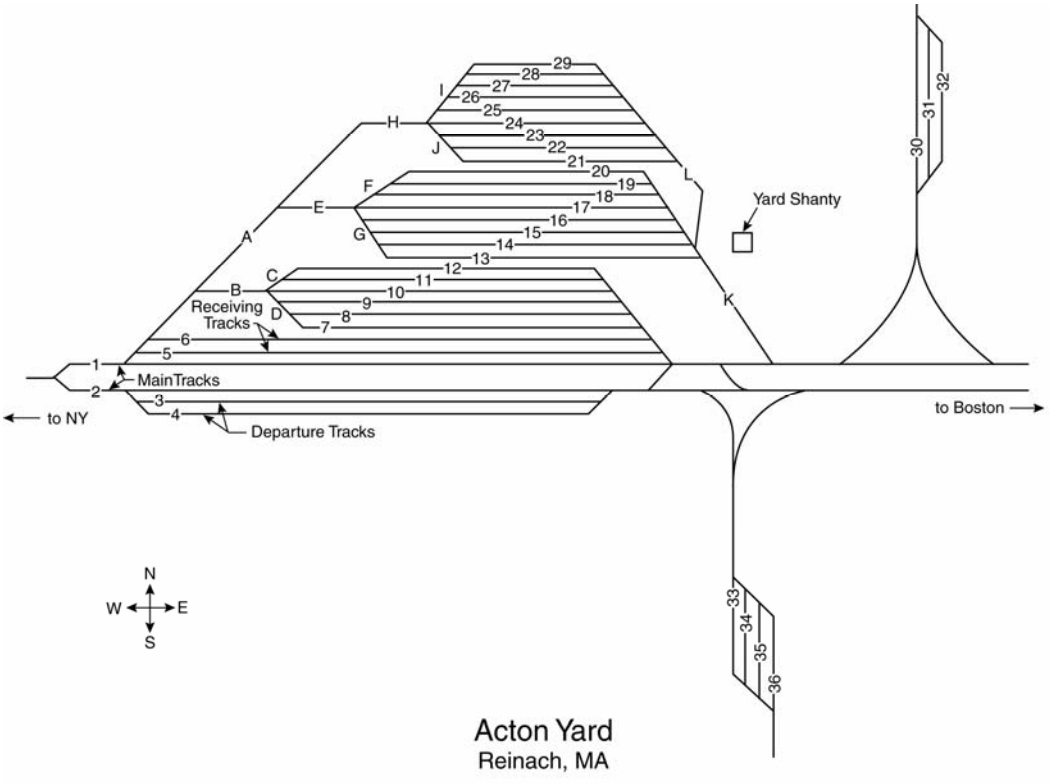


Figure E-1. Yard diagram used in the HRA pilot study

The following is the description of the favorable case scenario:

> It's a beautiful afternoon with bright sun and nice temperature. The goal of our RCL crew—consisting of an experienced yard foremen and helper—is to shove five empty boxcars up the A lead and around the curve to the E lead to the F lead and couple for of the five empty cars to some loaded hopper cars halfway down track 20 (see Figure E-1). Each crewmember has worked as a groundman for over 20 yr, and each has worked RCL jobs ever since they began in Acton Yard 2 yr ago. Their RCO training was thorough. The yard is well-maintained. This is their regular assignment. Both crewmembers are coming off 2 d rest. They are the only crew switching in the yard at the moment.
>
> The yard foreman, in charge of the move, is on the ground near the E switch. The helper rides the side of the lead box car up the A lead. The foreman lines the E switch for the move, and then walks to, and lines, the F switch, with his back to the move. The cut of cars moves down the A lead, to the E lead, and then to the F lead and into track 20, traveling at about 4 mph. The yard foreman, now positioned where lead F meets track 20, maintains the movement and stops the locomotive about one car length away from the joint, for a safety stop, and the helper dismounts the car. The yard foreman then pitches control of the RCL to the helper. The helper then couples up the cars to 10 loaded hopper cars, about half-way down track 20. The helper pulls the pin to leave four of the five empty cars. The locomotive and one attached car then moves back up track 20, still under the control of the helper.

Table E-4 presents a breakdown of the task steps involved in the scenario.

Table E-4. Pilot study favorable case scenario task breakdown

Task step	Scenario script	HTA lettered tasks
1	The foreman lines the E switch for the move, then walks to and lines the F switch with his back to the move.	Line switch (A, B, C, D, E)
2	The cut of cars moves down the A lead to the E lead, and then to the F lead and into track 20, traveling at about 4 mph.	Move locomotive (F, G, H, I, J, K)
3	The yard foreman, now positioned where lead F meets track 20, maintains the movement…	Maintain locomotive movement (L)
4	…stops the locomotive about one car length away from the joint for a safety stop, and the helper dismounts the car.	Stop locomotive (N)
5	The yard foreman then pitches control of the RCL to the helper.	N/A[23]
6/7	The helper then couples up the cars to 10 loaded hopper cars, about half-way down track 20.	Move locomotive (F, G, H, I, J, K) Couple cars (L, N, F, I, J, K, O, N)
8	The helper pulls the pin to leave four of the five empty cars.	Pull pin (T)
9	The locomotive and one attached car then move back up track 20, still under helper's control.	Move locomotive (F, G, H, I, J, K)

The following is the description of the unfavorable case scenario:

> It's 3 a.m., just above freezing, and there is frost on the rails and ties. The goal of our RCL crew—consisting of a yard foreman and helper—is to shove 45 loaded hopper cars full of grain up lead A, into lead E, lead F, and into track 19, and to leave all 45 cars there. Track 19 holds 50 cars. Each crewmember is relatively new to the railroad—they have about 1 yr of switching experience and 1 mo as RCOs. Our crew received minimal training, since the railroad needed RCOs on the job. The yard is poorly-maintained. This job is an extra board job, as both RCOs have little experience. Both crewmembers have also worked the last 9 d straight. While there is typically only one other crew working in the yard at the same time, because of some bad weather earlier in the day that caused delays, there are two other crews working in the yard at the moment. One is an RCL job and the other is a conventional job with engineer, yard foreman and helper. This

---

[23] Since lettered tasks were designed to be at a high enough level to apply to both RCL and conventional switching operations, the pitch-and-catch function was not assigned to a lettered task because this operation does not exist in conventional switching operations, and therefore it is not analyzed as part of this scenario.

> second RCL crew is working up lead K into track 20 on the other side, pulling several cars out of track 20. The conventional crew is working further up lead A, and into Lead H to sort cars into tracks 24 and 25. All three crews are working somewhat quickly to make up for the earlier delays.
>
> The helper, standing at the E switch, and in charge of the move, initiates the move up lead A. The yard foreman is riding in the locomotive cab at the rear of the move. The helper then lines the E lead switch, and walks over to and lines lead F switch. He then checks his switch list to see what the next move will be (to bring the locomotive back out and down lead G to track 15 to begin pulling out cars). The cut of cars now is entering lead E and then F at around 4 mph. The helper then lines the switch for track 19 and then walks down to get into position to line the lead G switch for the next move. The cut enters track 19, still at around 4 mph. The helper looks up and reduced the speed. He then looks back down to his switch list. While thinking about the next move, the helper stops the movement to drop-off the cars. The yard foreman then dismounts the locomotive and pulls the pin to uncouple the locomotive.

Table E-5 presents a breakdown of the task steps involved in the scenario.

Table E-5. Pilot study unfavorable case scenario task breakdown

Task step	Scenario script	HTA lettered tasks
10	The helper, standing at the E switch and in charge of the move, initiates the move up lead A.	Move locomotive (F, G, H, I, J, K)
11	The helper then lines the E lead switch, and walks over to and lines lead F switch.	Line switch (A, B, C, D, E)
12	He then checks his switch list to see what the next move will be.	Check switch list (A)
13	The cut of cars now is entering lead E and then F at around 4 mph.	Maintain locomotive movement (L)
14	The helper then lines the switch for track 19 and then walks down to get into position to line the lead G switch for the next move.	Line switch (A, B, C, D, E) Locate target track (B)
15	The cut enters track 19, still at around 4 mph. The helper looks up and reduces the speed.	Maintain locomotive movement (L)
16	He then looks back down to his switch list.	Check switch list (A)
17	While thinking about the next move, the helper stops the movement to drop off the cars.	Stop locomotive (N)
18	The yard foreman then dismounts the locomotive and pulls the pin to uncouple the locomotive.	Pull pin (T)

For each session, the scenario was examined at a lettered task level, with participants evaluating individual task steps associated with the scenario, such as move locomotive. The assessment team selected the lettered task level for the evaluation because it could help isolate subtasks that may be more or less reliable than others, highlighting areas for further research and investigation. Task step 14 includes two HTA lettered tasks, line switch and locate target track, since they are included in the same task step.

After completing the HEART or APJ exercises, participants were encouraged to provide feedback regarding the applicability of the technique to developing an assessment of human reliability for conventional and RCL operations. In addition, HEART participants were asked to review the GTT and EPC lists, evaluating each item on the list for its applicability to railroad yard operations. Participants were asked to circle the items that were seen as applicable to railroad yard operations, providing the assessment team with a rough measure of applicability for HEART to railroad yard operations.

Upon completion of the session, participants were paid for their time and provided with the opportunity to ask any remaining questions they had.

E.2.3 HEART Procedure

The HEART approach was used in two sessions lasting 2 h each. Although the application of HEART minimally requires an analyst familiar with the domain, the assessment team believed that the assessment would be more reliable and valid if operational SMEs also participated in the evaluation. SMEs were also able to provide feedback regarding the applicability of HEART to railroad yard operations, the accuracy of the scenarios for evaluation, and the assessment process overall.

Eight SMEs participated in the HEART pilot study, with five participants in the first session and three participants in the second session. Participants were first provided with an explanation of the exercise and the general research questions under investigation. The experimenter then provided the participants with a description of the scenario, which included details related to environmental, operational, and personnel characteristics that should be considered during the evaluation process.

The first group of participants were given the favorable case scenario first. It consisted of characteristics believed to produce optimal reliability, such as performing during the day, in good weather, and with a well-trained and alert crew. The second group of participants were given the unfavorable case scenario first. It consisted of characteristics believed to produce poor reliability, such as performing during the night, in bad weather, and with an inexperienced and fatigued crew. For each scenario, the facilitator read through the scenario details and provided participants with a copy of the scenario description for reference. Participants were given the opportunity to ask clarification questions and request more details at any time during the study.

The original intent of the pilot study was to have participants complete assessments with both scenarios (favorable case and unfavorable case). However, only one group of participants was able to perform an evaluation of both scenarios in the time allotted. The other group was only able to evaluate the tasks in the favorable case scenario.

After participants indicated they were familiar with the scenario details, the facilitator started the evaluation procedure by stating the task step (such as line switch or move locomotive) that was to be evaluated. Participants considered the task step and consulted the list of GTT (Appendix

K) to match the step to the GTT most appropriate. If SMEs felt that multiple GTTs were applicable to the task, they wrote the most applicable GTT first, followed by other GTTs.

Participants then consulted the Lists of EPCs (Appendix L) to identify each EPC that they felt applied to the task step and scenario under consideration. Due to the number of EPCs available, this step was the most time-consuming for participants at first, although participants required less time to complete the process as they became more familiar with the EPCs. After recording the GTTs and EPCs associated with the task step under consideration on a form provided to them (see Appendix H), the facilitator introduced the next task step, and the process was repeated.

When all of the task steps had been evaluated, the facilitator asked participants to discuss the strengths and weaknesses associated with the HEART method. Because the method was originally designed as a method to be used by reliability assessors in fields related to process-control, participants were also asked to identify the GTTs and EPCs they felt best applied to railroad yard operations.

E.2.4 APJ Procedure

The APJ approach was used in one session that lasted for 2 h. Five SMEs participated in the study, and they were first provided with an explanation of the exercise and the general research questions under investigation. The facilitator then read through the APJ instructions and described the probability estimates provided on the probability list presented on the APJ probability estimation reference sheet (see Appendix I).

After answering questions and clarifying the procedure, the facilitator provided study participants with a description of the first scenario under evaluation, the same unfavorable case scenario that was presented to HEART participants. The facilitator then introduced the first task step for evaluation (e.g., line switch), and participants considered the performance of the task in the context of the scenario under investigation. Participants recorded their initial reliability (HEP) estimate for the task step on their data collection sheet (see Appendix J).

To facilitate the next step, the Delphi discussion of initial reliability estimates, participants recorded a copy of their reliability estimate on a slip of paper that was handed to the facilitator. The facilitator collected these sheets of paper and led a discussion of the factors that SMEs considered to arrive at their reliability estimate. After listening to and participating in the discussion, some participants chose to revise their estimates, and these new estimates were recorded on the data collection sheet. If participants chose to retain their initial estimate, they simply recorded the same number twice. The facilitator then introduced the next task step for evaluation, and the process was repeated.

After completing the APJ process for the unfavorable case scenario, participants were presented with the same favorable case scenario as was used in the HEART pilot. Participants again followed the APJ procedure and produced reliability estimates for each task under consideration.

After completing this process, participants then followed the APJ procedure to develop an overall reliability estimate for the unfavorable case scenario and an estimate for the favorable case scenario. At the completion of the APJ session, participants were encouraged to provide candid feedback about the APJ process.

E.3 Pilot Study Results

Tables E-6 and E-7 present the results of the HEART assessment for both the favorable case scenario (n=8) and the unfavorable case scenario (n=3). Results support the notion that SMEs can generate estimates for HEART that converge to within 1 OOM. Because the pilot study was conducted as a feasibility exercise, the estimates produced by pilot participants were not subject to rigorous statistical evaluation. Instead, the criterion of acceptable precision was adopted from Kirwan (1996), as used in the main study. This criterion is based on the general practice used by analysts in the HRA field, where "most estimates are within a factor of 10 of the true value" (Kirwan, 1996, p. 362). Because the true values are not known for conventional and RCL operations, acceptable precision was defined as the number of common reliability estimates that fell within 1 OOM of each other.

In the HEART results tables (Tables E-6 and E-7), acceptable precision is depicted in the row labeled common HEPs within 1 OOM. For favorable scenario reliability estimates, a majority of HEART-generated HEPs are within 1 OOM for a majority of the tasks evaluated. In 8 of the 9 tasks, at least half of the participants generated HEPs within 1 OOM of each other. In 6 of the 9 tasks, at least 75 percent of the participants generated HEPs within 1 OOM of each other. Results are similar for unfavorable scenario reliability estimates, with at least two-thirds of participants generating HEPs within 1 OOM of each other for 8 of 9 tasks. The last column in Tables E-6 and E-7 represent the reliability estimate resulting from the sum of each of the assessed tasks. Although the numbers themselves reveal substantial variability, they are all within the 1 OOM for each type of scenario.

Table E-6. Pilot HEART HEPs for favorable case scenario tasks

	Lettered task									
Participant	**Line switch**	**Move loco**	**Maintain loco movement**	**Stop loco**	**Pitch / receive control**	**Move loco**	**Couple cars**	**Pull pin**	**Move loco**	**All sub-tasks**
1	0.09	0.04	0.0004	0.02	0.04	0.2	0.2	0.10	N/R	0.68
2	0.1	0.02	0.02	0.1	0.1	0.02	0.02	0.1	0.1	0.66
3	0.09	0.03	0.09	0.2	0.1	0.6	0.2	0.09	0.2	1.00
4	0.2	0.2	1.0	0.1	1.0	0.7	0.7	0.7	N/R	1.00
5	0.1	0.2	0.6	0.5	0.6	0.2	0.2	0.2	0.7	1.00
6	0.0004	0.0004	0.0007	0.0007	0.00002	0.03	0.0004	0.09	0.0006	0.13
7	0.004	0.3	0.0004	0.01	0.00002	0.3	0.09	0.02	0.3	0.91
8	0.02	0.02	0.02	0.02	0.09	0.09	0.2	0.02	0.003	0.45
Common HEPs within 1 OOM	6 of 8	7 of 8	4 of 8	7 of 8	5 of 8	8 of 8	7 of 8	8 of 8	4 of 6	8 of 8

Table E-7. Pilot HEART HEPs for unfavorable case scenario tasks

	Lettered task									
Participant	**Move loco**	**Line switch**	**Check switch**	**Maintain loco movement**	**Line switch/ locate target track**	**Maintain loco movement**	**Check switch list**	**Stop loco**	**Pull pin**	**All sub-tasks**
6	0.1	0.1	0.2	1.0	1.0	0.6	1.0	0.02	0.1	1.00
7	0.03	0.5	0.5	0.02	1.0	0.1	1.0	0.007	0.05	1.00
8	0.03	0.07	0.1	0.0004	0.03	0.4	0.02	0.4	0.1	1.00
Common HEPs within 1 OOM	3 of 3	3 of 3	3 of 3	0 of 3	2 of 3	3 of 3	2 of 3	2 of 3	2 of 3	3 of 3

Tables E-8 and E-9 present HEPs generated in the APJ session (n=5). The APJ results reveal a similar pattern as the HEART results. For favorable case scenario reliability estimates, a majority of APJ-generated HEPs are within 1 OOM for a majority of the tasks evaluated. In 6 of the 9 tasks, at least 80 percent of the participants generated HEPs within 1 OOM of each other. Results are similar for unfavorable case scenario reliability estimates, with at least 80 percent of participants generating HEPs within 1 OOM of each other for 8 of 9 tasks. Lastly, the all lettered tasks HEPs represent the reliability estimate generated by asking participants to estimate the HEP for the entire scenario, separate from their assessment of each of the subtasks. The favorable scenario estimates are all within 1 OOM, while 4 of the 5 HEPs are within 1 OOM for the unfavorable scenario.

Table E-8. Pilot APJ HEPs (second estimate) for favorable case scenario tasks

	Lettered task									
Participant	**Line switch**	**Move loco**	**Maintain loco movement**	**Stop loco**	**Pitch / receive control**	**Move loco**	**Couple cars**	**Pull pin**	**Move loco**	**All lettered tasks**
9	0.0001	0.01	0.01	0.001	0.05	0.05	0.005	0.1	0.01	0.1
10	0.001	0.005	0.001	0.01	0.001	0.001	0.001	0.001	0.005	0.1
11	0.001	0.05	0.01	0.1	0.0001	0.005	0.0001	0.001	0.05	0.5
12	0.001	0.01	0.005	0.1	0.1	0.005	0.01	0.0005	0.01	0.1
13	0.02	0.01	0.05	0.01	0.1	0.1	0.1	0.01	0.05	0.1
Common HEPs within 1 OOM	4 of 5	5 of 5	5 of 5	4 of 5	3 of 5	4 of 5	3 of 5	3 of 5	5 of 5	5 of 5

Table E-9. Pilot APJ HEPs (second estimate) for unfavorable case scenario tasks

	Lettered task								
Participant	**Move loco**	**Line switch**	**Check switch**	**Maintain loco movement**	**Line switch / locate target track**	**Maintain loco movement**	**Check switch list**	**Stop loco**	**Pull pin**	**All lettered tasks**
9	0.005	0.1	0.05	0.01	0.5	0.005	0.1	0.05	0.005	0.005
10	0.01	0.01	0.005	0.001	0.1	0.005	0.01	0.05	0.0001	0.0005
11	0.005	0.005	0.00005	0.001	0.1	0.001	0.1	0.0001	0.005	0.0005
12	0.1	0.05	0.0005	0.001	0.1	0.005	0.1	0.1	0.05	0.0005
13	0.05	0.05	0.05	0.05	0.5	0.1	0.5	0.1	0.01	0.01
Common HEPs within 1 OOM	4 of 5	4 of 5	3 of 5	5 of 5	5 of 5	4 of 5	5 of 5	4 of 5	4 of 5	4 of 5

The pilot study also generated substantial qualitative feedback from participants. While some participants believed that the HEART approach was too vague for application to railroad yard operations, others stated that HEART seemed a reasonable approach to generating human reliability estimates. While pilot participants stated that some of the words and phrases used to describe HEART GTTs and EPCs were confusing, the assessment team addressed this issue by providing definitions and explanations that were understood by pilot participants. When asked to identify the specific GTTs and EPCs that they believed were applicable to the railroad yard environment, most participants selected at least half of the 8 GTTs available. In fact, individual analysis shows that each participant identified between 2 and 8 GTTs as relevant to the yard switching environment. Similarly, most participants selected at least half of the 39 EPCs available, with a range from 4 to 36 EPCs identified as relevant by each participant.

The HEART and APJ data collectively indicate that the HEART and APJ methods have the potential to yield information in a relatively consistent manner, although substantial variability exists across participants. Some of this variability was believed to be due to the level of granularity of the tasks, which participants from both the HEART and APJ sessions stated was too microscopic for an effective analysis. Many participants stated that it was difficult thinking about tasks at the level of task description used in the assessment. They stated a preference for evaluating an entire scenario, as they think of tasks as whole moves, such as the instructions they might receive from a yardmaster. Because the (lettered) tasks under evaluation were so specific (e.g., pull pin), SMEs felt they were too devoid of context to evaluate effectively. One SME stated that assessing each lettered task was analogous to analyzing the process of pressing a clutch in a manual transmission automobile rather than trying to assess the risk of driving an automobile.

Participants also provided feedback regarding the scenarios developed for the pilot study. Although the favorable case scenario was developed as a baseline that SMEs could use to anchor their reliability ratings for the unfavorable case scenario, participants had a more difficult time evaluating tasks under the favorable case scenario. The favorable case scenario contained few if any negative PSFs, thus affording fewer error-producing opportunities for participants to consider. The unfavorable case scenario was easier for SMEs to evaluate because the negative factors were readily apparent.

Despite the difficulties associated with interpreting the HEART data and the biases that likely influence the APJ approach, these approaches are believed to hold promise because they enable the assessment process to be conducted in a reliable and consistent manner that taps into SMEs existing knowledge of yard operations and experiences. Furthermore, because both HRA methods can be used to evaluate different kinds of scenarios and different levels of task granularity, it is possible to present SMEs with tasks and scenarios at a level of detail that is compatible with their understanding and awareness of yard operations—that is, at the move level. The HRA methods have content validity by enabling scenarios to be described in terms that SMEs readily understand: specific moves performed in the context of the operational railroad yard environment. Lastly, drawing on one method that contains built-in HEP values and relying on SMEs to generate HEPs in a second technique provides a balanced approach to assessing the relative risks of RCL and conventional yard switching operations.

Appendix F.
HEART List of Task Types (GTTs) Used in Main Study

Appendix F contains a listing of the HEART GTTs presented to participants in the experimental study, rearranged based on frequency of response in the pilot study.

Task Type ID	Description
D	A fairly simple task performed rapidly or given scant attention
E	A routine, highly-practiced, rapid task involving relatively low level of skill
C	A complex task requiring high level of comprehension and skill
G	A completely familiar, well-designed, highly practiced routine task, often-repeated and performed by a well-motivated, highly trained individual with time to correct failures but without significant job aids
A	A task that is totally unfamiliar, performed at speed with no idea of likely consequence ** "At speed" means that this task is performed very quickly with little time to think through it or consider the consequences*
F	A task to restore or shift system to original or new state following procedures, with some checking
H	A task that requires a response to a system with an automated support tool providing the operator with accurate information of the current state of the system **For example, a recommendation provided by a computer or feedback from the system that indicates what needs to be done next*
B	A task to shift or restore a system to a new or original state on a single attempt without supervision or procedures
Z	None of the above

Appendix G.
HEART List of Conditions (EPCs) Used in Main Study

Appendix G contains a listing of the HEART EPCs presented to participants in the experimental study, rearranged based on frequency of response in the pilot study.

ID #	**Environment Conditions** **Environment includes both physical conditions, such as weather and yard maintenance, as well as the work climate, such as mental challenges, expectations, pressures, and interaction with other personnel*
2	A poor or hostile environment (the worst possible conditions under which you are still expected to perform duties)
3	Task pacing (either slowing down or speeding up the task), caused by the intervention of others
1	A shortage of time available for error detection and correction
4	Additional team members over and above those necessary to perform task normally and satisfactorily

ID #	**Task Conditions** **Task consists of the individual steps in completing a move*
10	Task performance standards are unclear or confusing
14a	Prolonged inactivity or highly repetitious cycling of low mental workload tasks (for first half-hour) ** This refers to tasks that are boring and uneventful*
14b	Prolonged inactivity or highly repetitious cycling of low mental workload tasks (for each hour thereafter) ** This refers to tasks that are boring and uneventful*
13	An incentive to use other more dangerous procedures
11	A mismatch between perceived and real risk
12	A conflict between immediate and long-term goals

ID #	**Operator Conditions–Experience, Training, and Ability** **Operator is defined as the operating railroader performing the task*
20	Unfamiliarity with a situation which is potentially important but which only occurs infrequently or which is novel
21	Operator inexperience (such as a newly-qualified craftsman, but not an “expert”)
24	A danger that the physical abilities to perform task will be exceeded
25	The need to transfer specific knowledge from task to task without losing (forgetting) that knowledge
23	A need for making decisions which are beyond the capabilities or experience of an operator
22	A mismatch between the educational achievement level of an individual and the requirements of the task
26	Age of personnel performing perceptual tasks ** Perceptual tasks involve reviewing physical information, such as performing a visual inspection or detecting a warning, message, signal, or other cue in the environment that affects completion of this task*

ID #	**Operator Conditions–Other Factors** **Operator is defined as the person performing the task*
34	Low workforce morale
35	Disruption of normal work-sleep cycles
32	High-level emotional stress
30	Little or no intrinsic meaning in a task ** This means that the task is performed with little understanding as to why it is included in the duties to accomplish the job*
33	Evidence of ill-health amongst operatives, especially fever
31	Little opportunity to exercise mind and body outside the immediate confines of the job ** This means that the task is limited or constrained and does not allow the operator to make decisions or physical movements outside of the task description*

ID #	**System Conditions–Feedback, Status, and Alarms** **System includes all equipment and the means of interacting with other parts of the system. For example, vehicles, support tools, and communication technology*
40	Alarms or signals are not easily heard over other noises present in the environment
46	Noticeably unreliable equipment (i.e., faulty gauges, inaccurate feedback, no feedback, etc.)
45	Poor or confusing information conveyed by procedures and person-to-person interaction
43	Poor, ambiguous, or ill-matched system feedback
44	No clear or timely confirmation to the operator of a performed action
41	No means of conveying technical information (position, location, system state) to operators in a form which they can readily understand
42	Information overload, particularly caused by several pieces of information presented at the same time
48	Inconsistency of meaning between displays and procedures
47	No obvious way to keep track of progress during an activity

ID #	**System Conditions–Other Factors** **System includes all equipment and the means of interacting with other parts of the system. For example, vehicles, support tools, and communication technology*
51	A mismatch between an operator’s view of the world and that imagined by a designer ** The designer is the person who designed the system, the equipment, or the standard procedures for using equipment or completing a task. This means that the designer designed the system in a manner that is not consistent with the way things really work or are done.*
52	No obvious means of reversing an unintended action
55	No diversity of information input for veracity checks ** This means that the system does not require the operator to confirm that an action is desired (such as requiring that several actions be performed before the system reacts)*
56	Unclear allocation of function and responsibility ** This means that it is uncertain who performs what tasks, or how much work is required of the equipment and how much is required of the operators to carry out the task*
50	An easily accessible means of suppressing or overriding information or features, such as disabling fail-safes and alarms
53	A need to unlearn a technique and apply one which requires the application of an opposing philosophy
54	Little or no independent checking or testing of output

Appendix H.
HEART Response Sheet Used in Pilot and Main Studies

Please enter the number of each Task Step below. Enter the letter of the Task Type from the List of Task Types. (If you believe that more than one task type is applicable, please list your preferred response first, followed by the additional task types that also apply.)

Next, refer to the List of Conditions and identify the conditions that you feel apply to this task step in the scenario. Enter the ID # of each applicable condition below, and circle the level of impact that you believe this condition has on this task step.

Task Step (#):

Task Type ID *(enter letter)*:

Conditions (ID #)	**Impact on Task**	
#________	Small	Large
#________	Small	Large
#________	Small	Large
#________	Small	Large
#________	Small	Large
#________	Small	Large
#________	Small	Large
#________	Small	Large

Task Step (#):

Task Type ID *(enter letter)*:

Conditions (ID #)	**Impact on Task**	
#________	Small	Large
#________	Small	Large
#________	Small	Large
#________	Small	Large
#________	Small	Large
#________	Small	Large
#________	Small	Large
#________	Small	Large

Task Step (#):

Task Type ID (enter letter):

Conditions (ID #)	**Impact on Task**	
#________	**Small**	**Large**
#________	**Small**	**Large**
#________	**Small**	**Large**
#________	**Small**	**Large**
#________	**Small**	**Large**
#________	**Small**	**Large**
#________	**Small**	**Large**
#________	**Small**	**Large**

Task Step (#):

Task Type ID (enter letter):

Conditions (ID #)	**Impact on Task**	
#________	**Small**	**Large**
#________	**Small**	**Large**
#________	**Small**	**Large**
#________	**Small**	**Large**
#________	**Small**	**Large**
#________	**Small**	**Large**
#________	**Small**	**Large**
#________	**Small**	**Large**

Appendix I.
APJ Probability Estimation Reference Used in Pilot and Main Studies

Please enter the number of each task step in the "Task Step" column of the provided sheet.

Consult the Probability List (Chance of Making a Mistake) below and determine how often an operator might make a mistake performing this task step. Write your estimate of this probability under the first "Chance that an operator may make a mistake" column on the sheet.

After the discussion, write your revised estimate of the probability under the second "Chance that an operator may make a mistake" column. Note that you do not have to revise your estimate after the discussion, and there are no right or wrong answers.

Probability list (chance of making a mistake)

Chance of making a mistake is very high

Probability	Chance
1.0	1 in 1
0.5	1 in 2
0.1	1 in 10
0.05	1 in 20
0.01	1 in 100
0.005	1 in 200
0.001	1 in 1,000
0.0005	1 in 2,000
0.0001	1 in 10,000
0.00005	1 in 20,000
0.00001	1 in 100,000
0.000005	1 in 200,000
0.000001	1 in 1,000,000

Chance of making a mistake is very low

Appendix J.
APJ Response Sheet Used in Pilot and Main Studies

Task step	**Chance that an operator may make a mistake** ***(before discussion)***	**Chance that an operator may make a mistake** ***(after discussion)***

Appendix K.
HEART List of Task Types (GTTs) Used in Pilot Study

Task Type ID	**Description**
A	A task that is totally unfamiliar, performed at speed with no idea of likely consequence ** At speed means that this task is performed very quickly with little time to think through it or consider the consequences*
B	A task to shift or restore a system to a new or original state on a single attempt without supervision or procedures
C	A complex task requiring high level of comprehension and skill
D	A fairly simple task performed rapidly or given scant attention
E	A routine, highly-practiced, rapid task involving relatively low level of skill
F	A task to restore or shift system to original or new state following procedures, with some checking
G	A completely familiar, well-designed, highly practiced routine task, often-repeated and performed by a well-motivated, highly trained individual with time to correct failures but without significant job aids
H	A task that requires a response to a system with an automated support tool providing the operator with accurate information of the current state of the system. ** For example, a recommendation provided by a computer or feedback from the system that indicates what needs to be done next*
Z	None of the above

Appendix L.
HEART List of Conditions (EPCs) Used in Pilot Study

ID #	**Environment Conditions** ** Environment includes both physical conditions such as weather and yard maintenance, as well as the work climate, such as mental challenges, expectations, pressures, and interaction with other personnel*
1	A shortage of time available for error detection and correction
2	A poor or hostile environment (the worst possible conditions under which you are still expected to perform duties)
3	Task pacing (either slowing down or speeding up the task), caused by the intervention of others
4	Additional team members over and above those necessary to perform task normally and satisfactorily

ID #	**Task Conditions** ** Task consists of the individual steps in completing a move*
10	Task performance standards are unclear or confusing
11	A mismatch between perceived and real risk
12	A conflict between immediate and long-term goals
13	An incentive to use other more dangerous procedures
14a	Prolonged inactivity or highly repetitious cycling of low mental workload tasks (for first half-hour) ** This refers to tasks that are boring and uneventful*
14b	Prolonged inactivity or highly repetitious cycling of low mental workload tasks (for each hour thereafter) ** This refers to tasks that are boring and uneventful*

ID #	**Operator Conditions–Experience, Training, and Ability** ** Operator is defined as the operating railroader performing the task*
20	Unfamiliarity with a situation which is potentially important but which only occurs infrequently or which is novel
21	Operator inexperience (such as a newly-qualified craftsman, but not an “expert”)
22	A mismatch between the educational achievement level of an individual and the requirements of the task
23	A need for making decisions which are beyond the capabilities or experience of an operator
24	A danger that the physical abilities to perform task will be exceeded
25	The need to transfer specific knowledge from task to task without losing (forgetting) that knowledge
26	Age of personnel performing perceptual tasks ** Perceptual tasks involve reviewing physical information, such as performing a visual inspection or detecting a warning, message, signal, or other cue in the environment that affects completion of this task*

ID #	**Operator Conditions–Other Factors** ** Operator is defined as the person performing the task*
30	Little or no intrinsic meaning in a task ** This means that the task is performed with little understanding as to why it is included in the duties to accomplish the job*
31	Little opportunity to exercise mind and body outside the immediate confines of the job ** This means that the task is limited or constrained and does not allow the operator to make decisions or physical movements outside of the task description*
32	High-level emotional stress
33	Evidence of ill-health amongst operatives, especially fever
34	Low workforce morale
35	Disruption of normal work-sleep cycles

ID #	**System Conditions–Feedback, Status, and Alarms** ** System includes all equipment and the means of interacting with other parts of the system. For example, vehicles, support tools, and communication technology*
40	Alarms or signals are not easily heard over other noises present in the environment
41	No means of conveying technical information (position, location, system state) to operators in a form which they can readily understand
42	Information overload, particularly caused by several pieces of information presented at the same time
43	Poor, ambiguous, or ill-matched system feedback
44	No clear or timely confirmation to the operator of a performed action
45	Poor or confusing information conveyed by procedures and person-to-person interaction
46	Noticeably unreliable equipment (i.e., faulty gauges, inaccurate feedback, no feedback, etc.)
47	No obvious way to keep track of progress during an activity
48	Inconsistency of meaning between displays and procedures

ID #	**System Conditions–Other Factors** ** System includes all equipment and the means of interacting with other parts of the system. For example, vehicles, support tools, and communication technology*
50	An easily accessible means of suppressing or overriding information or features, such as disabling fail-safes and alarms
51	A mismatch between an operator's view of the world and that imagined by a designer ** The designer is the person who designed the system, the equipment, or the standard procedures for using equipment or completing a task. This means that the designer designed the system in a manner that is not consistent with the way things really work or are done.*
52	No obvious means of reversing an unintended action
53	A need to unlearn a technique and apply one which requires the application of an opposing philosophy
54	Little or no independent checking or testing of output
55	No diversity of information input for veracity checks ** This means that the system does not require the operator to confirm that an action is desired (such as requiring that several actions be performed before the system reacts)*
56	Unclear allocation of function and responsibility ** This means that it is uncertain who performs what tasks, or how much work is required of the equipment and how much is required of the operators to carry out the task*

Abbreviations and Acronyms

ANOVA	analysis of variance
APJ	Absolute Probability Judgment
APOA	assessed proportion of affect
COC	conventionally operated cut (of cars)
CONV	conventional
d	day(s)
EPC	error producing condition
EMR	electromagnetic radiation
FMECA	Failure Modes, Effects and Criticality Analysis
FRA	Federal Railroad Administration
GTT	generic task type
h	hour(s)
HEART	Human Error Assessment and Reduction Technique
HEP	human error probability
HRA	human reliability assessment
HTA	hierarchical task analysis
LWD	lost workday
Loco Engr	locomotive engineer
min	minute(s)
mo	month(s)
MSHA	Mine Safety and Health Administration
OCC	onboard control computer
OJT	on-the-job training
OOM	order of magnitude
PHA	preliminary hazard analysis
PPE	personal protective equipment
PRA	probabilistic risk assessment
PSF	performance shaping factor
PSP	positive stop protection
RCA	root cause analysis

RCD	remote control device
RCE	remote controlled (mine) equipment
RCL	remote control locomotive
RCO	remote control operator
RCO-F	RCO foreman
RCO-H	RCO helper
RCO-P	primary RCO
RCO-S	secondary RCO
RCLS	remote control locomotive system
RCZ	remote control zone
s	second(s)
SME	subject matter expert
SRM	(UK) safety risk model
SOFA	Switching Operations Fatality Analysis
THERP	Technique for Human Error Rate Prediction
UTU	United Transportation Union
yr	year(s)

Glossary of Terms

Arrival tracks: Designated tracks in a railroad yard that are used by inbound trains to leave their trains or cuts of cars in preparation to be classified. Arrival and departure tracks are generally longer than classification (including bowl) tracks.

Assessed proportion of affect (APOA): APOA is used in the HEART technique and refers to the degree to which a particular EPC (and its multiplier) influences a particular GTT. APOA is assigned a range between 0-1, whereby 0 refers to an EPC that has no influence on a particular task, to 1, whereby an EPC has a strong influence.

Blind pull: A pull (pulling of cars with any locomotive) for which the point (leading end) is neither protected nor seen to be on a clear, safe path. RCL operations introduce this new concept in railroading. The rules for RCL operations attempt to eliminate some blind pulls (and sometimes some blind shoves) by establishing an RCZ.

Blind shove: A shove (pushing of cars with any locomotive) for which the point (leading end) is neither protected nor seen to be on a clear, safe path.

Bowl tracks: A set of classification tracks associated with a hump, whereby cars are cut off or uncoupled at the top of a hump and classified into one of a number of bowl tracks. The term bowl refers to the typical concave shape of the tracks whereby the entrance to the bowl tracks from the hump is on a descending grade to allow free rolling cars into the track, and the exit to the tracks is on an ascending grade to make it difficult for free rolling cars to errantly leave the track.

Classification tracks: Tracks used by switching crews to classify or sort cuts of cars based on their next destination. Cars may be classified using a hump or simply by shoving, kicking, and pulling cars into the tracks.

Coded digital radio communication: Radio communication exists between a body-mounted RCD and its electronically mated OCC on an RCL. This communication is coded to select precisely among which OCC and RCDs communication is conducted. Communication is in digital form. Digital data comprise a series of discrete numeric values. The code is a set of rules for interpreting a series of bit patterns for these data. OCCs and RCDs each operate on a unique digital address.

Conventional crew: The crew of a conventional yard locomotive consisting of 2-4 members, who do not use RCL equipment. Crewmembers include:

- Locomotive Engineer: The person who runs a locomotive and handles the attached train or cut of cars.
- Engine Foreman: He is the crewmember in charge of a yard locomotive under the rules. He is sometimes called a yard conductor or yard foreman.
- Helper: A helper is the third (and any fourth) crewmember, also called a switchman, pin puller, or field man.

Conventional operations: This refers to the customary non-RCL operations whereby a locomotive engineer operates a locomotive and is accompanied by other conventional crewmembers. Conventional yard operations refers to conventional operations inside yard limits, generally the acts of running light engines and classifying cars through flat or gravity (hump) switching.

Conventional yard locomotive: A locomotive, usually of the diesel-electric kind, used in yard service and not equipped with RCL equipment.

Cut: Two or more cars coupled, with or without the air brakes operative.

Departure tracks: Tracks that are used in a yard to re-assemble cuts of cars into outbound trains. Arrival and departure tracks are generally longer than classification (including bowl) tracks.

Electronic pullback protection (EPP): A generic label for a system having various proprietary names. It uses GPS and/or tag-readers to provide location of rolling equipment, pull-back protection for an RCL movement, and other functions, such as sounding an RCL horn and bell and activating grade-crossing warnings.

Error producing condition (EPC): EPCs are often another term for PSFs. In the HEART method, Williams (1988) has defined a specific set of relevant EPCs from which the assessor can select. Each EPC has an associated multiplier (from 102 percent to 1700 percent) that reflects the influence each EPC has on GTT reliability in a worst-case scenario.

Event recorder: A device, with appropriate software, for electronically collecting, storing, sorting, and replaying a designated number of hours of locomotive or RCL equipment performance data. Some event recorders enable users to remotely download these data for storage and analysis.

Fail-safe: This term is a referent in design, a planned arrangement of components in a system. This referent means that, if a system or component fails (stops operating, or, at times, operates to a design designation of less effectively, reliably, or tolerably than planned), the item goes to a more restrictive condition. The more restrictive condition in fail-safe design, however, does not necessarily ensure safety to persons, property, or the environment. For example, steam locomotives and tank cars have several (redundant) safety (pressure relief) valves atop the boiler or tank shell. The valves automatically self-actuate by an increase of internal pressure beyond a design maximum. Such safety valves have not ensured that the boiler or tank car shell does not rupture, sometimes in a violent explosion causing a loss.

Fouling, bodily: This relates to a physical area which a human body enters (fouls) on a track on which rolling equipment is or could be present. To foul means to be in the path of, to become interspaced or entangled with, and to collide with or be collided with on-track equipment. The fouling puts a human in danger of injury or death. Sometimes this physical area is called the red zone or zone of danger.

Generator (or alternator) field: A magnetic field in which the generator or alternator armature rotates. Without this field, no electrical power can be produced; hence, a locomotive cannot be powered for movement.

Generator: A rotating machine which changes mechanical energy into electrical energy. The main (traction) generator on a diesel-electric locomotive receives power from the prime mover, a diesel engine which comes in sizes varying from 600 to 6000 hp. The main generator delivers, through connections in a high voltage cabinet, direct-current electrical power to traction motors geared, one each, to the locomotive's axles. Some newer locomotives have an alternator producing alternating current for traction instead of a direct-current main generator.

Generic task type (GTT): HEART consists of nine GTTs, derived and distilled from a number of laboratory studies, that describe a set of tasks that can be carried out as part of an operation. Each GTT is also associated with a nominal unreliability number as well as a range of unreliability values corresponding to 5th percentile and 95th percentile populations. These values are the starting point in calculating an HEP using HEART.

Groundman: A collective term for switchmen, brakemen, conductors, yard foremen, engine foremen, and RCOs.

Human error assessment and reduction technique (HEART; Williams, 1988): One of a number of HRA methods available to risk assessors. HEART is a simple, easy-to-use, quick, and reliable technique for assigning human error probabilities to industrial tasks based on a number of GTT and EPC. Reliability data were derived from a number of laboratory studies of basic human activity.

Human error probability (HEP): HEP is a measure of consistency in human performance or response, and is expressed as the chance that an error will occur over some number of opportunities. HEP can range from 0-1. For instance, a HEP of 0.01 means the possibility of an error is 1 time in 100 opportunities.

Human reliability assessment (HRA): HRA is a category of risk assessment methods that are designed to identify and quantify the risks that human operators contribute to a system or operation. HRA methods can be used alone or in conjunction with other risk assessment techniques. Often, human reliability is measured in terms of HEP.

Hump: A method of classifying cars in a railroad yard whereby cars are shoved up over a hill (the hump or crest) and uncoupled to allow them to roll freely into one of numerous classification tracks on the other side of the hill. These classification tracks are known as bowl tracks. Automatic or manual retarders are used to slow down the free rolling cars as they progress into the designated bowl track for classification.

Kick: A switching move in which cars are shoved by a locomotive/RCL and then uncoupled and allowed to roll freely into a designated track, while the locomotive/RCL decelerates or stops.

Kinesthetic (adj.) kinesthesis (noun): This term refers to the human sensations of movement, tension, and position perceived through nerve-endings in the muscles, tendons, joints, and skin. These kinesthetic receptors of the human body form a feedback loop telling the brain, in part, the extent to which the operator's instructions to a machine or vehicle are being executed in the manner the operator desires. Aircraft pilots, automotive vehicle drivers, boat operators, heavy equipment operators, and locomotive engineers receive such kinesthetic stimulation. Kinesthetic stimuli and their meanings are gradually learned and maintained through experience. Kinesthetic feedback cues onboard a locomotive, but absent on the ground, include acceleration, deceleration, and velocity stasis of the locomotive/cut of cars; variable pressures of slack run-in and run-out; feeling of resistance when starting a heavy train or cut of cars; detection of driving wheel slip and spin on the unit occupied; feeling of picking up the drivers (locking wheels during braking and sliding them flat) on the unit occupied; and so forth.

Live track: A track on which a movement of rolling equipment can be made at any time in either direction.

Locomotive: A unit of rolling equipment capable of producing tractive effort and propelled by any form of energy. An RCL could be a single-unit or a multiple-unit set of locomotives controlled from one RCD. A locomotive may operate with its long hood or short hood forward. Long hood forward means that the locomotive cab is located at the opposite end of the movement, while short hood forward means that the cab is positioned nearest the direction of the movement.

Identification of a locomotive's short hood and long hood

Move: Any action by an operating railroader or railroad officer resulting in a movement. (e.g., "The move he made was to have the locomotive come ahead.")

Movement: Any number of coupled vehicles of rolling equipment on track, in motion or stopped.

Onboard control computer (OCC): A major component of RCL operations. The OCC is mounted in or on a standard yard or road locomotive (often in a compartment in the nose of the locomotive or inside the cab). Depending on which supplier, the OCC either receives from and transmits to, or else receives from, an RCD, via radio communication. Commands manually entered by an RCO on his RCD for radioing to the OCC are converted to electronic signals by the OCC. The OCC communicates these commands to the locomotive through hardwired electrical wires and components. The OCC links to the locomotive's air brake and electric traction controls, as well as other locomotive functions, such as sanding and horn/bell activation. The OCC is also sometimes referred to as a remote control receiver.

Operator: A person who controls a machine or device in any industry, not limited to an RCO.

Ordinal measure: One of four levels of statistical measurement (the four are nominal, ordinal, interval, and ratio). These four measures show different relationships among values of a particular variable of interest. Using ordinal measures, values can be rank-ordered (e.g., better than or less than, more or less), but the distance between two values is unknown (i.e., exactly how much more or less) or does not have any meaning. In other words, an ordinal measure implies a direction in quality, from best to worst or from most to least (or vice versa). It shows the relative position of items with no determination of exact position from other items. An example of an ordinal measure might be where you are asked to indicate how safe you feel dismounting moving equipment is, and you are provided with five answer options: (1) very unsafe, (2) somewhat unsafe, (3) neither safe nor unsafe, (4) somewhat safe, and (5) very safe. Given the ordinal nature of this question, the higher the number, the safer dismounting moving equipment is believed to be. Thus, an answer of 5 is safer than 4, but the precise amount of safer is unknown between the two possible answers.

Participant: A railroad yard employee participating in any part of the HRA and thus providing data regarding conventional or RCL operations. Participants are railroad yard switching operations SMEs.

Performance shaping factor (PSF): PSFs are those conditions, factors, or elements that affect an operator's performance in carrying out job tasks. PSFs include such factors as fatigue, experience, amount and quality of training, and aspects of the work environment (noise, vibration, light/glare). PSF is another term for EPC.

Personal protective equipment (PPE): PPE includes gloves, steel-toed shoes, reflective vests, safety goggles, ear plugs, and other clothing and materials worn on or around the body to protect the individual from harm.

Pitch-and-catch: When two RCOs work together as a crew, they may alternate controlling the RCL and thus the movement depending on the circumstances. This is accomplished by following prescribed procedures to manipulate the RCD. Only one RCD (the A or primary RCO, a.k.a. RCO-P) can control the RCL at one time, except for certain emergency features that are available to the B or secondary RCO (a.k.a. RCO-S). The two RCOs can be located 100 or more car lengths from each other.

Point protection: A railroad operating practice safeguard in which a crewmember (1) takes a position on the leading unit of the rolling equipment or (2) is in some other place (e.g., on the ground), to ensure that the track to be traversed ahead of the movement is clear of persons, physical obstructions, and defects. Point protection means that the point (leading end) of a shoving or pulling movement is either protected or seen to be on a clear, safe path.

Pull: A movement whereby one more locomotives pulls one or more cars coupled to the locomotive/RCL so that the locomotive or RCL is at the leading end (the point) of the movement.

Reliability: The ability of a test instrument to yield consistent results from repeated measurements or observations of the same group over time. Reliability refers to the constancy, or accuracy, between data obtained by repeating the same tests (measurements) on the same phenomenon under highly similar conditions.

Remote control device (RCD): A body-mounted, battery-powered console having controls and visual and audio indicators for radio communication with the OCC on an RCL for the purpose of controlling and monitoring the RCL. RCDs operate as single or paired units. When two RCDs of an RCL crew are used together, often referred to as pitch-and-catch operations, the two units are designated as A and B or Primary and Secondary. Depending upon the supplier, either one-way (transmitting) or two-way (transmitting and receiving) radio communication exists between a body-mounted RCD and its electronically mated OCC on an RCL. The RCD is usually body-mounted by a vest. The RCD must be fastened at all four of its corners to the vest to ensure that the RCD's tilt protection feature can function properly. The rechargeable battery of the RCD has a power life of about 12 h. The RCD is also variously referred to as a radio control transmitter, OCU, or box.

Remote control locomotive (RCL): An RCL is a locomotive controlled by an RCO using an RCD. An RCL may be controlled by an RCO positioned on the ground, on the locomotive, or inside the cab of the RCL.

Remote control locomotive operations (RCL operations): This is a method of operation whereby an RCO controls an RCL by means of an RCD. Only FRA-certified RCOs and employees being trained in RCL operations are permitted to operate RCL equipment. All of a railroad's operating, air brake, train handling, safety, and other rules remain in effect for RCL operations, except when changed by additional RCL rules. Further, new RCL rules may specify or prescribe additional RCL operating practices that must be followed under RCL operations. RCL operations may involve the use of an RCZ as well. RCL operations can be one-person operations (one RCO equipped with an RCD), two-person operations (either two RCOs each with an RCD, see pitch-and-catch; or one RCO and one helper), or more rarely three-person operations (generally two RCOs each with an RCD, and a helper). RCL yard operations refers to RCL operations inside yard limits, generally the acts of running light engines and classifying cars through flat or gravity (hump) switching.

Remote control locomotive system (RCLS): An RCLS includes the technological components used by an RCO to control an RCL from a remote location away from the locomotive or on board the locomotive (e.g., standing on a sill or inside the cab). RCLS components include an RCD, OCC, RCL, and optional repeater. RCOs control the RCLS by means of an RCD mounted on the body of an RCO and an OCC mounted on or in the RCL. A repeater can be an additional item of equipment in an RCLS.

Remote control operator (RCO)[24]: An employee who has received RCO-specific classroom and on-the-job training and has been certified to operate an RCL and associated car(s). Typically, RCOs come from the ranks of groundman (e.g., engine foremen, switchmen) or locomotive engineer.

- RCO-Primary (RCO-P): The operator operating an RCL through an RCD. In RCL operations with only one RCO, then, that person is necessarily the primary RCO. A primary RCO can control all functions of his RCL and can pass the control (pitch) of his RCL to the secondary RCO.
- RCO-Secondary (RCO-S): Is an RCO having an RCD not controlling an RCL. However, emergency functions are still available to this RCO.
- RCO-Foreman (RCO-F): The RCO crewmember in charge of the RCL. Either the primary or secondary RCO can be the RCO-F.
- RCO-Helper (RCO-H): The second (and any third) RCO crewmember is the RCO-H, analogous to a conventional crew's engine foreman's helper or pin puller (and for any

---

[24] The term RCO should not be confused with the term Control Operator—an employee assigned to operate a CTC or interlocking plant or authorized to grant track permits.

third switchman, called field man). Either the primary or secondary RCO can be an RCO-H.

NOTE: The first two labels above refer to who is controlling the specific tactical move of a cut of cars or train, while the latter two labels refer to who, more generally, is in charge of the work being performed.

Remote control zone (RCZ): Point protection is not required in an RCZ activated by an RCL crew, although some carriers' rules stipulate that the RCO is relieved of providing point protection on pulling (RCL on lead end) movements only. Most RCL rules include the requirement that a "Remote Control Area" be published in the timetable, and within this area, an RCZ be verbally activated by an RCL crew. The tracks of an RCZ are designated by appropriate signage in the field and special instructions. If a carrier does not establish an RCZ, then all RCL movements must have point protection. Before activating an RCZ, the RCL crew inspects the tracks of the zone. RCZ tracks must be known to be clear of rolling equipment, persons, improperly lined switches and derails, blue signals, and other objects. Switches, and derails if required to be in the derail position, must also be properly lined and locked. RCZ signs must be displayed only during the period of activation of the zone. The RCO-F must notify the designated control office of the activation of the RCZ. The RCZ is then under the command of this RCO-F. Generally then, railroad operating employees or contractors desiring to work in, or foul, the RCZ request permission of the RCO-F to enter or foul the RCZ. When the RCO-F gives permission for other employees or contractors to enter his RCZ, his RCL crew must provide protection for these employees and contractors.

Repeater (a.k.a. radio repeater station): A repeater is a specially located transceiver receiving and retransmitting radio signals between an RCD and an OCC mounted on an RCL. The repeater extends the range of an RCD when operated in a yard or other area. Without a repeater, the range of an RCD in controlling an RCL is about 1 mi; with a repeater, the range between an RCD and the RCL is about 2 mi.

Risk: Risk is generally defined as the subjective evaluation of the significance of two safety-related factors that are combined, the likelihood that an accident/incident with a negative outcome will occur (e.g., highly likely, highly improbable) and the severity of that outcome (e.g., catastrophic, severe, mild). Likelihood of occurrence and severity can be defined qualitatively, as in the examples provided, or quantitatively (e.g., one death in 1,000,000,000 labor hours). The U.S. Department of Defense, through its system safety Mil-Std-882, provides some guidance in defining risk.

Rolling equipment: Any railroad car, locomotive, or other vehicle capable of moving on its flanged wheels over railroad track. Formerly referred to as rolling stock.

Securing an RCL: When an RCL is left unattended (as during a meal period or at the end of a shift), varying railroad rules require that the RCL be secured (i.e., made inoperative). Tasks in such securing include turning off the RCD, thereby causing a full service application of the air brakes; manually cutting in the independent air brakes and applying them on the RCL; tying down the hand brake; and turning the isolation switch to ISOLATE position, thereby preventing generation of tractive power.

Shove: A movement whereby one or more locomotives or RCLs pushes, or shoves, one or more cars that are coupled to the locomotive/RCL, so that a car is at the leading end (the point) of the movement.

Situation awareness: Refers to an individual being conscious of the full set of circumstances forming the context for his action(s). It includes the gathering, integration, and assessment of information from the operating environment, based on the individual's experiences and knowledge. It also includes projections of this information into the future to develop, sometimes alternative, plans of action. Higher levels of situation awareness are more than simply knowing what is going on around you. They comprise acute perception of and acting on conditions of machine operation and the encroaching factors of human and object interactions. Situation awareness can deteriorate during periods of low workload having little stimulation from the environment, during times of task saturation with rapid flow of stimuli from the environment, with fatigue, and with concern over personal issues.

Slack: The unrestrained free movement in rolling equipment. Slack can run in and run out, a potentially hazardous event, given sufficient force. Run-in is the movement of coupled rolling equipment to a state of compression. Buff is a term used to describe coupler compression forces. Run-out is the movement of coupled rolling equipment to a state of tension. Draft is a term used to describe coupler tension forces. Tension/stretching of coupled rolling equipment is a term describing the opposition of two outward forces, draft, along a single axis.

Snow brake: When activated, this feature keeps a constant, light, independent, air brake pressure against the locomotive wheels. The friction from this pressure results in heat, which prevents buildup of snow and ice on a locomotive's brakes.

Subject matter expert (SME): An SME is anyone with specialized expertise and knowledge of a particular domain. For the purposes of this study, an SME is defined as an expert on RCL yard operations and/or conventional yard operations. An SME can be a professional consultant or a railroad operating employee (including railroad officer).

Tilt protection feature: A feature of an RCD, also called the man-down feature. When an RCD detects a tilt condition in excess of approximately 45° past its vertical axis, this feature is activated. The RCO first receives an audible alarm after about 1 s and has the option of extending the duration of the tilt protection feature (i.e., tilt time extension) by pressing an RCD button. Otherwise, after an additional brief period of time (3-5 s), the air brakes go into emergency application, and the man-down alarm is broadcast. The man-down alarm is an audible alarm broadcast with a synthesized voice, from the locomotive voice-radio over an ordinary yard, two-way, channel. This occurs unless the tilt extension feature is activated. The man-down feature remains activated until an RCO recovers the RCD from the feature. Recovery is that from an emergency brake application. The frequency of the locomotive radio must be tuned to that of the designated office that monitors the man-down distress call. The call contains the locomotive initials and number and indicates that an RCO is down.

Tilt time extension: Tilt time extend extends the allowable tilt time. If the RCO anticipates having to tilt the RCD on his body for more than a few seconds, pushing the time button extends the allowable tilt time up to 60 s (this varies by railroad). This tilt time extension cannot be repeated (i.e., an RCO cannot request a second tilt time extension).

Tilting, to tilt: A new verb in railroading, meaning the RCO leans over, 45° or greater, past the vertical.

To throw an RCO from a unit of rolling equipment: The fall could be to unobstructed ground, against a trackside object such as a switch stand, debris, or adjacent unit of standing or moving rolling equipment, or under the wheels of the unit of rolling equipment being ridden.

Trim: An activity where cars are removed from bowl tracks in a hump yard after they have been classified and moved to departure tracks. This aids in preparing outbound trains and clears bowl tracks for further switching using the hump.

Validity: Validation is a procedure for determining if an assessment instrument or variable measures what it is supposed to measure. Validity refers to the extent to which data relate to a criterion that is an accepted measure of the phenomenon under investigation.

Vigilance feature: The vigilance feature is active only when the RCO-P selects a speed other than stop on the RCD. When the RCO-P does not change the status of any control on his RCD within 50 s (i.e., the RCD does not detect any input from the RCO), the RCD emits an audible warning, which must be reacted to within 10 s by pressing either of the two vigilance buttons on the RCD. This resets the vigilance feature. If the RCO-P does not press the button within an overall duration of 60 (50 + 10) s, a penalty full-service brake application occurs. To operate the RCL, the RCO-P must do a recovery from a full-service application.

Voice-radio: A two-way radio used for spoken communication among members of a crew, between different crews, and between a crew and a supervisor and other person (e.g., yardmaster).