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Application of a human error framework to conduct train accident/incident investigations

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Abstract

Accident/incident investigations are an important qualitative approach to understanding and managing transportation safety. To better understand potential safety implications of recently introduced remote control locomotive (RCL) operations in railroad yard switching, researchers investigated six railroad accidents/incidents. To conduct the investigations, researchers first modified the human factors analysis and classification system (HFACS) to optimize its applicability to the railroad industry (HFACS-RR) and then developed accident/incident data collection and analysis tools based on HFACS-RR. A total of 36 probable contributing factors were identified among the six accidents/incidents investigated. Each accident/incident was associated with multiple contributing factors, and, for each accident/incident, active failures and latent conditions were identified. The application of HFACS-RR and a theoretically driven approach to investigating accidents/incidents involving human error ensured that all levels of the system were considered during data collection and analysis phases of the investigation and that investigations were systematic and thorough. Future work is underway to develop a handheld software tool that incorporates these data collection and analysis tools.

Keywords: Accident investigation; Human error; Train accident; Root cause analysis; HFACS

1. Introduction

Safety in the U.S. railroad industry has improved markedly over the last two-and-a-half decades, evidenced by a substantial reduction in accident (e.g., collisions, derailments) and incident (injury) rates (Reinach and Gertler, 2002). However, the train accident and incident rate in railroad yards far exceeds the rates across the entire railroad industry (Reinach and Gertler, 2002). Train accidents include collisions and derailments that involve the operation of on-track equipment and that meet certain reporting thresholds set by the Federal Railroad Administration (FRA, 2003). Train incidents include employee injuries that involve the movement of on-track equipment and that meet certain reporting criteria (FRA, 2003). Human factor-related train accidents make up a significant proportion of all train accidents, including those that occur in switching yards. According to FRA safety data, in 2004, 53% of yard accidents (excluding highway-rail crossing train accidents) were attributed to human factors causes (FRA, 2004). Further, lost workday injuries sustained by railroad employees in yards between 1997 and 1998 (Reinach and Gertler, 2001) showed that about one-third (32%) of these injuries were attributable to human factors causes.

In a recent effort to reduce operating costs and increase safety and efficiency, U.S. Class I freight railroads have begun to implement RCL operations in and around railroad switching yards. A remote control operator (RCO) wears a portable device, usually by means of a vest, and controls the movement of a locomotive while on the ground or riding the locomotive or rail car (see Fig. 1). Typically, two RCOs work together as a crew, although other crew configurations exist. This varies from the traditional crew configuration, where typically one to two switchmen on the ground provide radio or hand instructions to a third crewmember, a locomotive engineer onboard the locomotive who controls its movement.

Although remote control technology has been available for decades, the safety implications of using these devices in U.S. railroad yards and of reducing crew size in yard switching operations remain unknown. Proponents of RCL operations suggest that controlling the locomotive from the ground affords the operator the best vantage point and that the technology reduces or eliminates miscommunication errors between the locomotive engineer onboard the locomotive and a switchman on the ground.

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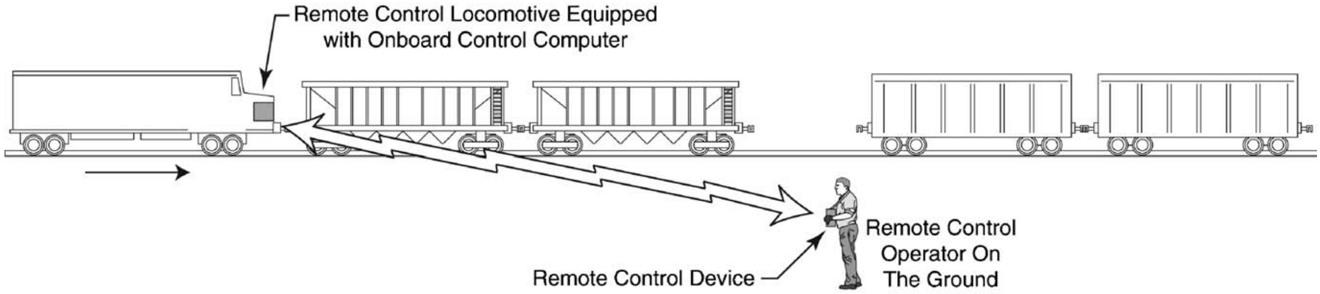

Fig. 1. RCL operation.

Opponents of the technology raise a number of safety concerns, such as inadequately trained and inexperienced operators.

To understand the potential safety implications associated with RCL operations in U.S. freight railroad switching yards, FRA's Office of Research and Development Human Factors Program and Office of Safety launched a multi-study RCL operations research program, including a human-centered investigation and analysis of RCL-involved accidents/incidents in railroad switching yards. This paper describes the results of the human-centered investigation and analysis.

Accident/incident investigations are a qualitative approach to studying industrial and transportation safety, and complement accident/incident database analyses, risk assessments, and other quantitative approaches to system safety. To be effective, accident/incident investigations should be non-punitive and should focus on all levels of the system. However, all too often an operator is blamed for an accident/incident because he or she is associated with the last activity that goes wrong. This approach, referred to as the *bad apple* theory (Dekker, 2002), seeks to fix the problem by blaming the operator. This common but simplistic approach is neither non-punitive nor focused on all levels of the system and typically does little to correct the problem(s).

In fact, human error in industrial environments and transportation systems is much more complicated to decode than simply blaming the operator. As Reason (1997, p. 126) notes, "... human error is a consequence not a cause. Errors ... are shaped and provoked by upstream workplace and organizational factors. Identifying an error is merely the beginning of the search for causes, not the end ... Only by understanding the context that provoked the error can we hope to limit its recurrence." Petersen (2003) refers to these upstream conditions as *traps* that are left for an operator in a workplace that set up the operator to fail, which lead to an accident/incident. Hobbs and Williamson (2003), for example, recently identified the relationship between downstream maintenance operator errors and upstream contributing factors, such as supervision, training, procedures and equipment. Effective accident/incident investigations should be capable of identifying a broad range of factors that may have contributed to an accident/incident, from an operator's action moments before an accident/incident to a senior-level executive decision made years earlier.

The goal of the study was to identify a broad range of contributing factors to accidents/incidents involving RCL operations at all levels of the railroad system. It was desirable, therefore, to select a human error model that incorporated a systems approach to error. This model would be used to provide the theoretical framework for accident/incident data collection and analysis.

A number of human error models and frameworks have been developed over the last two decades to aid in understanding how humans err and how accidents/incidents occur in the larger context of the systems in which these accidents/incidents take place. These include Wickens and Flach's (1988) four-stage information processing model, Rasmussen's (1982) skills-rules-knowledge model of decision making, O'Hare's (2000) "Wheel of Misfortune" taxonomy, Moray's (2000) socio-technical model of error, Edwards' (1972) SHEL model, and Reason's (1990) Generic Error Modeling System (GEMS). The first two models concentrate on the micro, cognitive mechanisms that explain why an operator has erred, typically through some type of omission, commission or violation. The latter four models are macro or systems-based; they focus on the operator and the contextual upstream factors that set up the operator to err.

Both sets of models are valid approaches to understanding human error and how accidents/incidents occur. The application of one approach or the other depends on the goals of the investigation. Whereas the first two models drill down to the cognitive and perceptual processes of the operator who was the closest, physically and temporally, to the accident/incident, the latter four models address the upstream organizational conditions and factors, Petersen's (2003) *traps*, that enabled or facilitated the operator to err, although the models do not penetrate as deeply into the cognitive processes behind how and why operators err.

In addition, a number of human error taxonomies have been developed based on these models. The taxonomies provide a theory driven classification system to allow investigators and researchers to categorize operator errors and accident/incident contributing factors, which in turn enable systematic analyses to be performed. A major benefit of classifying operator errors and contributing factors based on their underlying theoretical nature is in enabling trends to be identified across error forms. For example, a pilot's accidental activation of the wrong button and a miscommunication between pilot and co-pilot may both be linked to the inability to manage one's attention.

A review of models and taxonomies of human error resulted in the identification and selection of HFACS (Wiegmann and

Shappell, 2003). HFACS was developed to provide a theory driven structure to analyze and classify operator errors in naval aviation accidents and mishaps. HFACS is based on Reason's GEMS. Often referred to as the "Swiss cheese model," GEMS depicts errors as arising from holes at four levels of an organization, beginning with the operator and working up through the system to organizational conditions. According to the model, active failures by the operator combine with latent conditions upstream in the organization to lead to an accident. Active factors include operator actions and decisions that occur just before the accident/incident and have traditionally been most often cited as the cause of an accident/incident. Latent factors (decisions or conditions) often exist for years and may never be associated with an accident/incident or identified as a safety issue, unless they are explicitly examined.

HFACS' four levels are unsafe acts, preconditions for unsafe acts, unsafe supervision and organizational influences. Unsafe acts address Reason's active failures, while the three latter levels address Reason's latent factors. For each of the four top-most levels, Wiegmann and Shappell identified a number of second-level categories. Some second-level categories are further broken down, or specified, into third-level categories. Wiegmann and Shappell identify a total of 19 unique categories of contributing factors.

Historically, HFACS has been used mostly to analyze data available from existing accident/incident investigations. However, HFACS was designed to also guide accident/incident investigations to support collection of human factors-related information in the first place. Some federal agencies such as the U.S. Coast Guard and the U.S. Department of Defense have begun to experiment using HFACS to support accident/incident investigations as well as analysis (Wiegmann and Shappell, 2003; A. Carvalhais, personal communication, October 11, 2005). The application of a theoretically driven human error classification system to investigate accidents/incidents has a number of potential benefits. It can:

- Provide a consistent and formal structure to accident/incident investigation data collection and analysis.
- Ensure the investigation is systematic and thorough by ensuring that all levels of the system are considered.
- Counteract heuristics and biases that investigators may bring to investigations.
- Enable comparisons of accident/incident contributing factors across industries that use HFACS to support their investigations and analyses.

HFACS was selected because it could be used to drive accident/incident data collection *and* analysis; it is diagnostic, reliable and comprehensive (Wiegmann and Shappell, 2003); it is based on a widely accepted model (GEMS) of human error in work systems; it has successfully been used in other domains (e.g., air traffic control (Scarborough and Pounds, 2001) and military operations (in Wiegmann and Shappell, 2003)); and it could be applied to the railroad industry due to the generic nature of the terminology.

2. Method

2.1. HFACS-RR

One advantage of HFACS is its use of generic terms and descriptors that are applicable to a range of industries and activities. However, since HFACS was initially developed for the aviation industry, minor changes were made to optimize its relevancy to the railroad industry. The new taxonomy was called HFACS-RR (Fig. 2). Others have made similar alterations to HFACS to suit their particular needs as well, for example, to address air traffic control (HFACS-ATC; Scarborough and Pounds, 2001) or military activities (Canadian Armed Forces or CF-HFACS; in Wiegmann and Shappell, 2003). In all cases, most of the original HFACS categories were retained to preserve the original structure and facilitate comparisons with other HFACS-based accident/incident analyses.

First, the names of the four original top-most HFACS levels were changed to convey neutrality, and a fifth top-most level was added. The five top-most HFACS-RR levels are operator acts, preconditions for operator acts, supervisory factors, organizational factors and (new) outside factors. Outside factors include the regulatory environment and the economic/political/social/legal environment in which railroads operate.

Other changes to the original HFACS taxonomy included:

- Replacing the term "violations" with "contraventions" to avoid stigma and biases associated with violations. Violations in the railroad industry are often associated strictly with operating and safety rules. Contraventions are more general short-cutting and rule-bending and may not necessarily be tied to violating a specific operating rule.
- The addition of a third subcategory under "contraventions" called "acts of sabotage." Acts of sabotage are related to the investigation only as much as the act is in response to a problematic organizational factor that is identified.
- The addition of a new fourth subcategory under organizational factors, called "organizational contravention." This subcategory addresses senior-level and executive management contraventions and short-cutting of (1) existing organizational (i.e., internal) procedures or processes and (2) externally imposed municipal, State, and Federal regulations. This category parallels supervisory contraventions and contraventions of the operators themselves.

Fig. 2 presents the new HFACS-RR taxonomy with these modifications incorporated. The new HFACS-RR taxonomy contains a total of five top-most levels and 23 unique categories of contributing factors.

2.2. Data collection instruments

Several paper-based accident/incident investigation tools were developed based on the HFACS-RR taxonomy and framework. Three sets of interview questionnaires were produced, one each for operators, local officers (supervisors) and upper management. Specific questions were mapped to the different

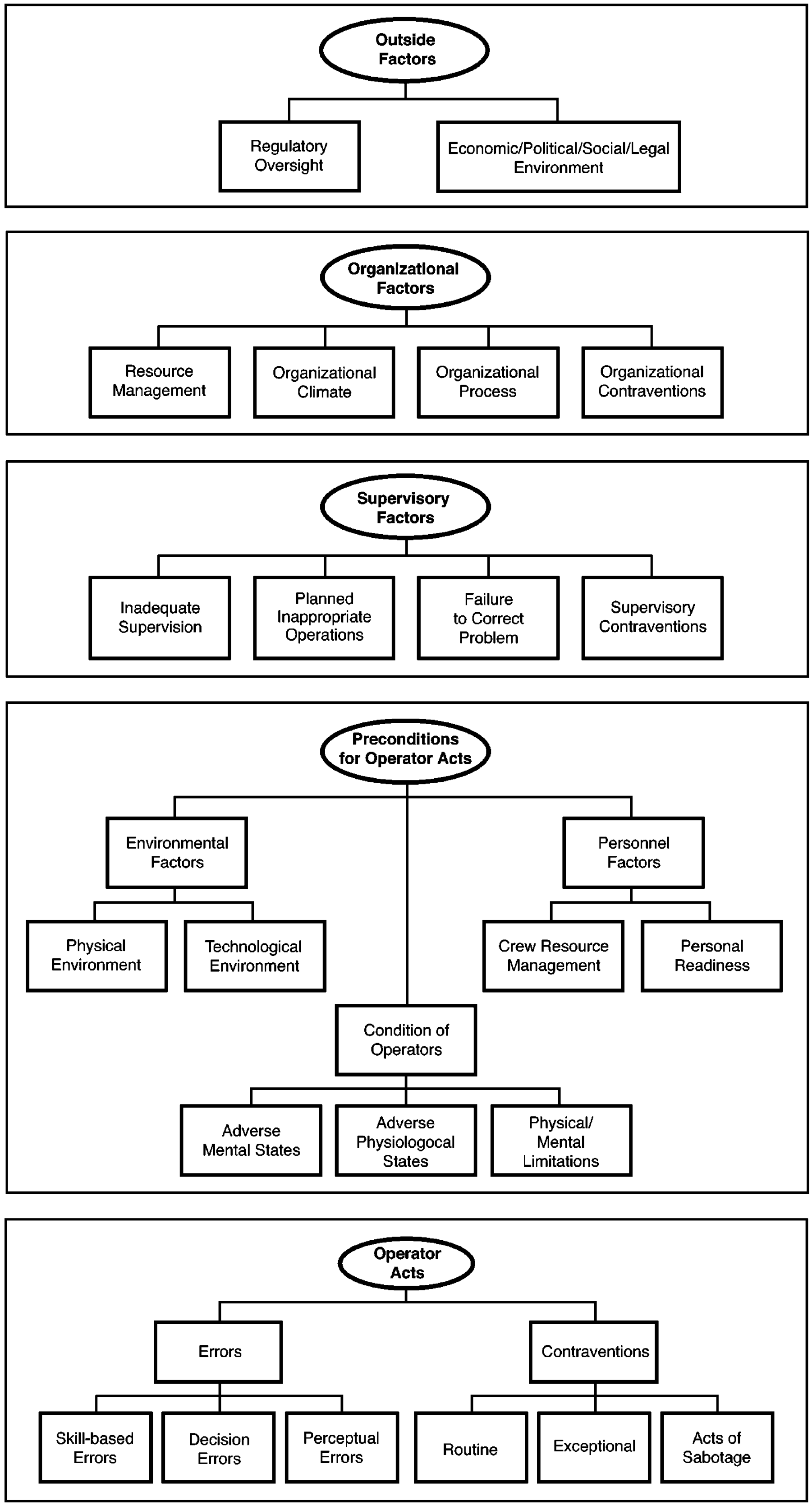

Fig. 2. HFACS-RR taxonomy.

Table 1
Sample interview questions

HFACS-RR level	Interview question
Operator acts	Is there more than one way you could have completed the task? What are they?
Preconditions for operator acts	When did you work during the previous 3 days? What were your other activities during this period? How was your workload on the day of the accident? Were there any time pressures or incentives to work faster? Was this your last move of the day?
Supervisory factors	Do you feel you were adequately prepared to operate remote controlled locomotives in switching yards? Have you ever been encouraged by a supervisor to cut corners or bend rules?
Organizational factors	Do you feel that staffing at this yard is adequate? How would you describe the safety culture at your railroad?
Outside factors	How much communication do you have with the FRA? What is the nature of this communication? How often are FRA inspectors onsite? What types of things do they look at/for? Are there any regulations or other outside influences such as the economy that you feel contributed, perhaps indirectly, to the incident? Please describe.

HFACS-RR levels (see Table 1). The operator questionnaire also included questions related to the operator's sleep habits and work schedule history to facilitate an analysis of operator fatigue. A data collection checklist was developed to help researchers collect relevant information and materials from participating railroads. Candidate data included locomotive or remote control event recorder data, operating and safety rule books and instructions, operator work history data, training records and materials, radio transcripts, equipment diagrams and photographs and initial accident/incident reports. Specific data that were collected depended on the circumstances of the accident/incident.

A flowchart was developed to help researchers consider all possible levels of a system when collecting and analyzing data. The flowchart prompted researchers to first ask or observe whether or not there was involvement at each of the top-most HFACS-RR levels. The flowchart included probing questions to guide the user from each top-most HFACS-RR level to second- and third-level categories of contributing factors, as appropriate. This had the effect of ensuring that all 23 unique categories of contributing factors were considered either directly or indirectly through consideration and dismissal of a higher-level category.

2.3. Procedure

Participating railroads, which included all seven U.S. and Canadian Class I freight railroads (Canadian participation was limited to their U.S. operations) and several regional railroads, were asked to provide data on all FRA reportable train accidents and incidents that occurred in switching yards and that involved RCL operations between May 1 and October 31, 2004. FRA reportable train accidents included collisions and derailments that resulted in US$ 6700 or more in damage, while train incidents included employee injuries that required medical attention beyond first aid treatment (FRA, 2003).

Six accidents/incidents were investigated further using the HFACS-RR-based data collection and analysis tools and framework. Selection criteria and guidelines were established to ensure fair and objective selection of accidents/incidents to investigate, as well as to ensure that those accidents/incidents that were investigated covered a range of RCL operations experiences.

Once an accident/incident was selected for investigation, two researchers worked with the appropriate railroad and labor union to access the accident/incident site, collect materials and information, and interview RCOs and railroad management, separately. Researchers spent 2–3 days onsite collecting interview data and railroad-provided records, logs and reports for each RCL accident/incident. Due to privacy concerns, the researchers did not collect medical-related data. The same two researchers conducted all six investigations using a collaborative approach to data collection and analysis.

All data were de-identified to provide confidentiality to individuals and railroads. During the analysis, a number of decision criteria and heuristics were developed to aid researchers in resolving conflicting information and to ensure consistency in analysis across all six accident/incident investigations. Analysis of each accident/incident case study focused on identifying contributing factors. Each contributing factor was then mapped to a unique HFACS-RR category, based on definitions provided by Wiegmann and Shappell (2003).

An assessment was made in terms of the researchers' confidence in each contributing factor based on the data that supported each finding. The U.S. Navy similarly assigns a level of confidence for each of their naval aviation mishap causal findings (U.S. Navy, 2003). Each contributing factor was considered to be a probable contributing factor or a possible contributing factor. Probable contributing factors were those factors that researchers were reasonably confident contributed, in some way, to the accident/incident. Confidence was based on (1) the degree to which data or information were consistent from one source to the next, (2) verification from a second source and (3) the source of the data (e.g., event recorder data were expected to be more reliable than interviewee recall data). They were also based, although to a lesser extent, on engineering judgment. Possible contributing factors were those factors that appeared to contribute to the accident/incident based solely on interview data or the researchers' understanding of the accident/incident, but these factors lacked additional data to corroborate or support this conclusion. Whether a contributing factor was assessed to be probable or possible was a reflection of researchers' confidence in the conclusion, not the degree of influence that the factor had on the accident/incident. Borrowing from the Navy (U.S. Navy, 2003) again, no effort was made to assess the relative importance of each contributing factor; all factors were considered equal with regard to their contribution to the accident/incident.

As part of the analysis, operator alertness was analyzed to determine whether or not impaired alertness contributed to any of the accidents/incidents. The analysis was based on the sleep, activity, fatigue, and task effectiveness (SAFTE™) model (Hursh et al., 2004). The model can be used to assess the impact of different proposed work schedules, or it can be used for retrospective analysis of alertness-related factors that may have contributed to an accident/incident or error. In this latter mode, information on operator work and sleep schedules prior to the event is entered into the model, and a projection of performance effectiveness and a prediction of the likelihood of a lapse at the time of the event are generated.

A case study documented each accident/incident investigation. Participating railroads and unions had an opportunity to review each accident/incident case study in which they were involved to verify the accuracy of the facts and descriptions of the accidents/incidents and facilities and to ensure that all identifying information had been removed.

3. Results

A total of 67 RCL accidents/incidents were reported during the 6-month period: 29 collisions, 25 derailments and 13 employee injuries not associated with a collision or derailment. Six of these accidents/incidents were further investigated using the data collection and analysis methods developed for this project. A total of 46 contributing factors were identified; of these, 36 were probable contributing factors (78%), while the remaining 10 were deemed possible contributing factors. The remainder of the analyses focuses on the 36 probable contributing factors since they are the most reliable.

Table 2 presents a breakdown of the 36 contributing factors by HFACS-RR level. Each accident/incident had between 2 and 11 contributing factors, and each accident/incident had contributing factors that were associated with between 2 and 4 HFACS-RR levels. Twelve operator acts, nine preconditions for operator acts, six supervisory acts, and nine organizational factors were identified among the six accidents/incidents. In fact, all 36 contributing factors were concentrated among nine unique HFACS-RR categories, as shown in Fig. 3. Numbers indicate how many contributing factors were associated with each HFACS-RR category.

3.1. Operator acts

Three unique categories of operator acts were identified: skill-based errors, decision errors and a routine contravention. Seven *skill-based errors*, four attentional failures (or slips) and three memory lapses, were identified among five of the six accidents/incidents. Attentional failures included an operator's failure to notice rail cars directly ahead of and impeding his path, resulting in the operator's locomotive colliding with the rail cars; an operator's momentary distraction and subsequent loss of attention while dismounting a rail car, resulting in the operator's fall to the ground; an operator's failure to notice the non-operational status of an automated locomotive control system and the same operator's failure to monitor his own locomotive and string of cars after initiating their movement, which resulted in the operator's locomotives traveling out the end of track and derailing. Memory lapses included an operator's failure to recall the correct direction of his locomotive's prior movement, which set up the situation where the locomotive traveled in the opposite direction as intended and collided with another train; an operator's failure to remember to reverse the direction of his locomotive before initiating its movement; and the failure to remember the orientation of a track switch ahead of the locomotive, which resulted in several cars being shoved into an industry building at the end of a short industry track.

Four *decision errors* were observed among four of the six accidents/incidents investigated. They included an operator's poor choice not to communicate information about his locomotive's move onto an unintended track to other yard employees who were affected; an operator's poor choice to initiate the movement of his locomotive without being able to see the locomotive or the string of cars; a poor choice by operators not to monitor the path of the locomotive after overriding an automated locomotive control system and an operator's poor choice to leave a track switch lined for an industry rather than to return the switch to its normal, straight position.

Table 2
Breakdown of accident/incident contributing factors by HFACS-RR level

Accident/incident no.	HFACS-RR level					Total	No. of HFACS-RR levels per accident/incident
	Operator acts	Preconditions for operator acts	Supervisory factors	Organizational factors	Outside factors		
1	2	0	1	1	0	4	3
2	2	3	0	2	0	7	3
3	1	0	4	3	0	8	3
4	1	1	0	0	0	2	2
5	3	1	0	0	0	4	2
6	3	4	1	3	0	11	4
Total	12	9	6	9	0	36	–

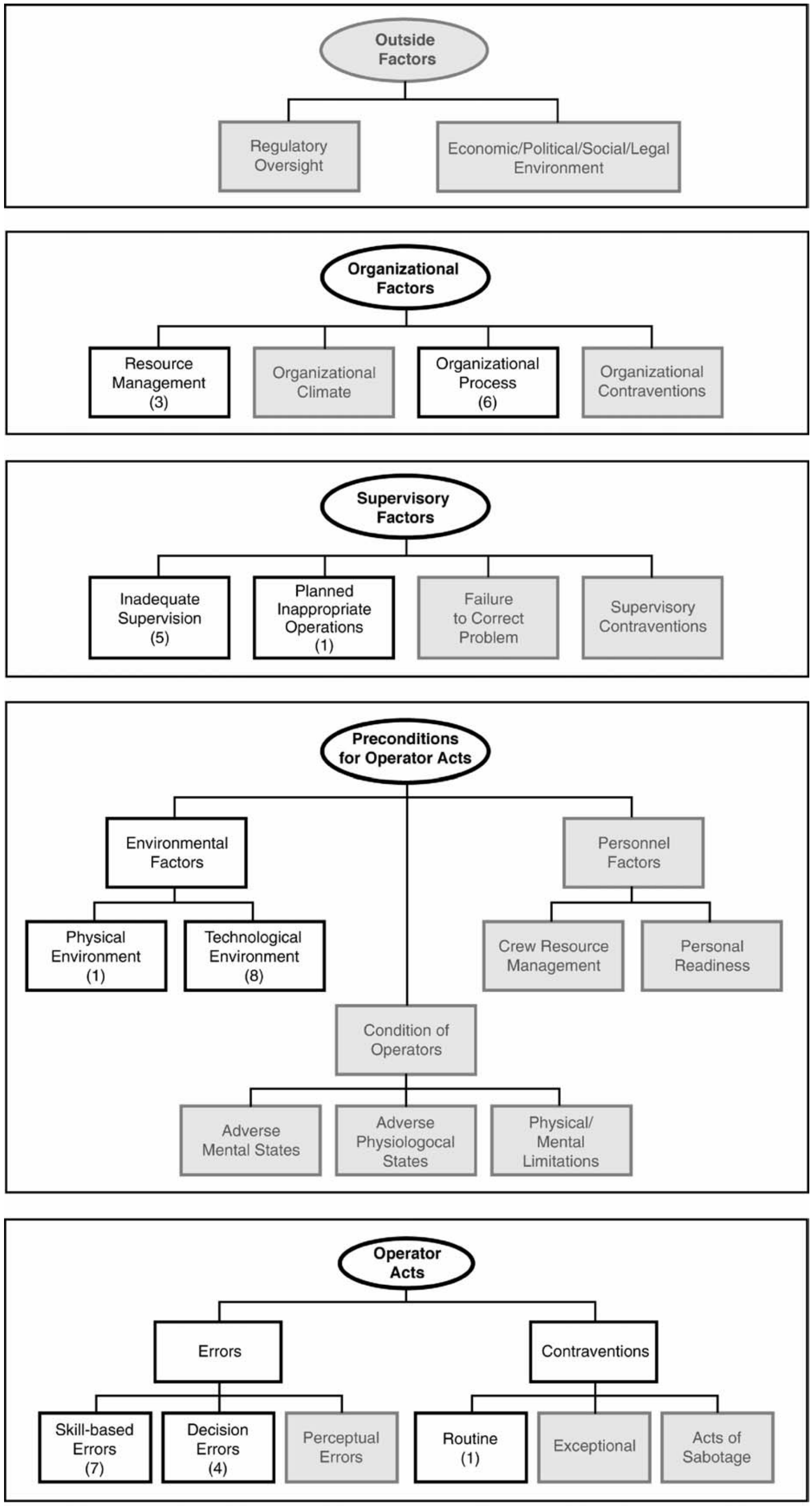

Fig. 3. HFACS-RR classification of probable contributing factors.

One *routine contravention* was observed in one accident/incident. It involved a contravention of a system special instruction (rule) that required an operator to watch ahead of the path of his locomotive or rail cars in certain situations (to "protect the point"). In this case, both operators, who were away from the point of the movement, chose not to follow the rule, out of an apparent desire to save time and/or effort. According to interviews, operators at least occasionally carried out this contravention.

3.2. Preconditions for operator acts

Two unique categories of preconditions for operator acts were identified: the technological environment and the physical environment (both are environmental factors). Eight contributing factors associated with the *technological environment* were observed among four of the six accidents/incidents investigated. They included the portable remote control device itself, which struck a ladder rung and caused a temporary distraction to an operator as he dismounted a car; an inability by the operator to determine which direction was forward for the locomotive (locomotives can travel in both directions, thus it is imperative to know, for a given locomotive, which direction is "forward" and which is "reverse" to command the locomotive to travel in the desired direction); an inability to determine the direction of the locomotive's movement (two separate occasions); an inability to detect a mislined switch ahead of moving on-track equipment and subsequent inability to determine that the locomotive entered an unintended industry track and three factors all associated with an automated locomotive control system referred to as a pullback protection system[1]: a broken wire, an improperly installed cable and the failure of the automated pullback protection system to fail-safe or otherwise inform the operator of a problem with the automated system. All but the first contributing factor was facilitated by the operator's ability to command and control his locomotive from a position other than on or near the locomotive or rail cars. The ability to command and control the locomotive and cars from a location away from the on-track equipment, especially the locomotive, reduces operator situation awareness.

One contributing factor to one of the accidents/incidents that was associated with the *physical environment* was inadequate lighting in the yard. Inadequate lighting made it difficult for the operator to see his locomotive and string of cars from where he was standing, away from the equipment, and contributed to the operator's reduced situation awareness. The operator was standing at the top of a small hill in the early morning hours, waiting for his equipment that he commanded to come toward him in preparation for switching cars at the top of the hill.

3.3. Supervisory factors

Two unique categories of supervisory factors were identified: inadequate supervision and planned inappropriate operations. *Inadequate supervision* was identified five times and was associated with three of the six accidents/incidents investigated. They included a loss of situation awareness by a front-line supervisor (yardmaster) and several training-related factors: inadequate operator classroom training (twice), inadequate on-the-job training and inadequate train-the-trainer training.

Planned inappropriate operations, poor crew pairing, was associated with one accident/incident, where two very inexperienced crewmembers were paired to work together. Both crewmembers lacked important procedural and declarative knowledge necessary to work safely at their particular location.

3.4. Organizational factors

Two unique categories of organizational factors were identified: the organizational process and resource management. *Organizational process* was identified six times and was associated with four accidents/incidents. All six of these contributing factors were associated with inadequate practices and procedures governing RCL operations and the use of the RCL technology, including the automated pullback protection system. They included an unsafe operating practice that required one operator to protect the point by monitoring the path ahead of the movement but that did not require that same operator to control the movement (which led to a reduction in the operator's situation awareness by making his task—to watch ahead for any hazards—passive); an unsafe operating practice that permitted the operator to control his locomotive and string of cars without requiring the operator to be able to see the locomotive or cars at all times; an inadequate procedure specifying the use of an existing video camera to monitor the remote area where the accident/incident occurred and three inadequate practices and procedures governing the use of automated pullback protection systems and track, including what to do when overriding the system.

Resource management was associated with three contributing factors and was involved in two accidents/incidents. These factors included inadequate staffing; installation of an automatic pullback protection system without a critical safety overlay subsystem recommended by the supplier and an inadequate number of locomotives available to meet operational demands, which resulted in delays in the installation of the critical safety overlay subsystems even after the subsystems had been acquired, since the locomotives could not be taken out of revenue service to be outfitted with the new equipment.

3.5. Operator alertness

Since operator alertness analyses were based on estimates of sleep patterns before the accident/incident rather than detailed

[1] The automatic pullback protection system, used with RCL operations, is designed to prevent a cut of cars from traveling beyond a pre-determined location along a track. The system uses a combination of transponders mounted between railroad ties at designated locations along a track and locomotives that are equipped with a radio frequency antenna underneath the locomotive. The onboard antenna energizes and receives a signal from each transponder it passes over. Each transponder authorizes a specific speed; the last transponder instructs the locomotive to stop.

sleep histories or log data, and since it was not possible to obtain corroborating information to verify reduced alertness (e.g., an eyewitness who reported observing an operator asleep or a self-report of dozing off), results of these analyses were treated as possible contributing factors and therefore not reported here.

4. Discussion

Many accident/incident investigation methodologies lack an underlying human error theoretical structure for probing investigators or assisting them in asking relevant questions. One reason is that accident/incident investigation methodologies are, historically, engineering approaches that have been developed with the goal of identifying the causes of mechanical or technological failures rather than human factors failures. Wiegmann and Shappell (2001) and Paradies (1991) have identified a number of barriers to conducting human error accident/incident investigations, such as (1) less sophisticated analysis techniques compared to, for example, those used to assess mechanical and engineering problems, and (2) minimal formal human factors training for investigators.

This study explored the application of a taxonomy of human error to guide human factors-oriented accident/incident investigations in the railroad industry. A modified version of HFACS, HFACS-RR, was developed to help guide the generation of data collection and analysis tools. Two human factors researchers then used these tools to learn more about the safety implications of RCL operations by examining all levels of the railroad system, including the active operator failures and the latent organizational and external conditions and factors. In fact, use of HFACS-RR to guide accident/incident data collection and analysis enabled the capture of both the low-lying fruit of operator acts (Reason's active failures) and the higher-hanging fruit—the preconditions for operator acts, supervisory factors and organizational factors (the latent factors and conditions). Specifically, 12 operator acts (active failures) and 24 preconditions for operator acts, supervisory factors and organizational factors (latent factors and conditions) were identified.

Analysis of the six accidents/incidents found 36 contributing factors associated with nine unique HFACS-RR categories (39% of all unique categories) from 4 of the 5 HFACS-RR levels. The largest single, unique category was the technological environment, which was associated with eight contributing factors. These contributing factors involved RCL technology or the automated pullback protection system associated with the RCL technology. Next, seven skill-based errors, attentional failures and memory lapses, were identified. Poor organizational practices and procedures governing RCL operations and the use of RCL technology, including the automated pullback protection system, were identified six times. Inadequate supervision was identified five times, and four of the five inadequacies were related to some aspect of operator training. Four different poor operator decisions were identified. Poor resource management was associated with three contributing factors, including both staffing and equipment problems. Lastly, a routine contravention of an existing rule, the physical environment (inadequate yard lighting) and planned inappropriate operations (poor crew pairing) were each associated with one contributing factor.

Interestingly, a loss or reduction in operator situation awareness was associated with five of the six accidents/incidents. The reduction in operator situation awareness warrants special attention to minimize its impact on safe yard switching operations. Operation of the locomotive from a remote location can eliminate several types of operator feedback, including visual, aural and kinesthetic cues. These were apparent in each of the five accidents/incidents in which operators lost their awareness of some aspect of the locomotive, its movement, or the track and path ahead of the movement.

There are several areas of low-cost improvement where the railroad industry may reap immediate benefits. These include enhanced training (a supervisory factor) to combat skill-based errors (operator acts) and improved practices and procedures (organizational factors) to mitigate technology-enabled errors (preconditions for operator acts). For example, requiring operators to maintain visual contact of their locomotive and string of cars or requiring operators to protect their point of movement at all times should help operators maintain a high level of situation awareness.

Inadequate staffing and pairing of inexperienced crewmembers, though contributing to only one of the six RCL accidents/incidents, may also warrant attention by the railroad industry. Recently, the railroad industry has been affected by two major economic impacts: a large number of employees are retiring because of a reduction in the permissible retirement age and a significant increase in business. One indication of railroad retirement is the number of employees who began their railroad pension or annuity in a given year. According to Railroad Retirement Board (RRB) data, the number of retired railroad employees increased sharply in 2002 (RRB, n.d.), almost doubling the 2001 retirement figure (6285 in 2001 versus 11,127 in 2002). In response, the railroad industry anticipates hiring up to 80,000 employees over the next several years (AAR, 2004). The result of increased retirements and increased business is a greater demand in moving a larger volume of rail cars with a less experienced crew base. Thus, operator training and experience, combined with appropriate crew pairing, may be a significant safety issue in the railroad industry in the near future.

The use of accident/incident investigation data collection and analysis tools based on the HFACS-RR taxonomy appears to enhance the accident/incident investigation process by ensuring that all levels of an organization, as a system, are at least considered and explored, even if no contributing factors exist at some of these levels. The 36 probable contributing factors that were identified were relatively equally distributed across four of the five top HFACS-RR levels, providing support for a systems approach to accident/incident contribution and providing support for Reason's perspective that Errors ". . . are shaped and provoked by upstream workplace and organizational factors." That is, for each accident/incident, multiple factors, at different levels of a system, appear to contribute to an accident/incident. Table 2 illustrates how different levels of the railroad system contributed to each of the six accidents/incidents examined in this study. Outside factors, the fifth HFACS-RR level, was not adequately explored in this study because of time and budgetary constraints. Generally, as a rule of thumb, the higher up the system or HFACS-RR level, the more resources that are required to identify contributing factors. The absence of contributing factors at this level should not suggest that they did not play a role in at least some of the accidents/incidents that were examined. Their absence reflects only researchers' inability to examine them in this study.

Accident/incident investigations must be consistent and thorough to be most effective. Yet they are, by most accounts, part science and part art. Thus, inevitably, some degree of variability exists across investigative methods and results. Variability depends on a number of factors, including the data collection methods and tools that are used (e.g., Woodcock et al., 2005), the knowledge and experience of the investigators, and the particular accident/incident causation philosophy of the investigator or company (i.e., is the investigation designed to uncover system factors or to find fault?).

Use of the HFACS-RR human error taxonomy and the tools developed based on the taxonomy to guide data collection and analysis appeared to help to combat some of the inherent subjectivity in accident/incident investigation and analysis by ensuring the consistency, objectivity and transparency of the data collection and analysis processes. It also simplified data collection and analysis and made the investigation process consistent from one accident/incident to the next. Instead of considering potential contributing factors for each accident/incident in a subjective or haphazard fashion where opportunity exists to omit a critical factor, or to be inconsistent from one investigation to the next, use of the HFACS-RR-driven data collection and analysis tools required researchers to draw from the same questionnaires and checklist of information as a foundation for data collection and required them to use the same decision flowchart during each accident/incident investigation. The result was that this taxonomy and these tools enabled researchers to systematically probe at least four of the five HFACS-RR levels for each accident/incident.

Another advantage of using the HFACS-RR taxonomy to structure data collection and analysis is that corrective actions can be mapped to each of the unique HFACS-RR categories and subsequently applied systematically to contributing factors from multiple investigations over time. The mapping is based on the fact that different corrective actions are more or less appropriate, or suitable, to different HFACS-RR categories. For example, training is appropriate to address skill-based errors, while improved procedures are appropriate to address deficiencies in organizational process.

Despite the encouraging results, however, the study does have a number of limitations. First, lack of a control group of similar accidents/incidents that were investigated without the tools developed for this study makes it difficult to quantify the benefits of the approach and tools. Second, the fifth HFACS-RR level, outside factors, may have contributed to one or more of the accidents/incidents, but not enough resources existed to flesh out any contributing factors at this level. Third, the results reflect the researchers' best, but limited, understanding, at the time of data collection, of the circumstances that contributed to the accidents/incidents. The participating researchers are well-versed in human factors theory and application, as well as railroad operations, but have never received formal training as investigators nor have they ever worked in a railroad switching yard. Fourth, data collection was limited to information that was volunteered, and certain types of information, such as medical records, were inaccessible to review. Finally, the study was limited to the investigation of six accidents/incidents, a convenience sample representing only a fraction of the accidents/incidents that occur in U.S. railroad yards each year.

There are a number of potential uses of the HFACS-RR tools and methodology both within the railroad industry and beyond. Railroad management, either unilaterally or jointly with railroad labor, could use the tools and process to identify train accident/incident contributing factors beyond the operator; FRA could use to improve their accident/incident investigation process to capture additional human factors issues and other industries and federal agencies could use the tools and process in a similar manner. In fact, some federal agencies, such as the U.S. Coast Guard, are already experimenting with using HFACS as a tool to support their accident investigation process (A. Carvalhais, personal communication, October 11, 2005). The amount of time spent on an investigation, as well as the number of investigators, will vary depending on the resources available and other criteria. What is most important is the use of the tool to make the investigation process more systematic and to expand the focus of accident/incident investigations beyond the operator to begin to address some of the latent conditions that contribute to accidents/incidents.

The HFACS-RR taxonomy and associated data collection and analysis tools are currently being implemented in two other railroad safety studies. In the first study, railroad labor and management have been given the tools and training to conduct their own accident/incident investigations using the same methodology employed in this study. An additional tool that maps 11 corrective actions to specific HFACS-RR categories was also developed for use in this first study. In the second study, a software tool is currently being developed that contains the HFACS-RR data collection and analysis tools. FRA Office of Safety operating practice inspectors will pilot the tool to determine the efficacy of the device.

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References

Association of American Railroads, 2004. Railroads say "You're hired!" April 28, 2004 Press Release. Retrieved August 10, 2005 from http://www.aar.org/ViewContent.asp?Content_ID=2155.

Dekker, S., 2002. The Field Guide to Human Error Investigations. Ashgate Publishing Ltd., Aldershot.

Edwards, E., 1972. Man and machine: systems for safety. In: Proceedings of British Airline Pilots Association Technical Symposium. British Airline Pilots Association, London, UK, pp. 21–36.

Federal Railroad Administration, 2004. Accident causes. Retrieved July 27, 2005. from http://safetydata.fra.dot.gov/officeofsafety.

Federal Railroad Administration, 2003. FRA guide for preparing accident/incident reports. Report No. DOT/FRA/RRS-22. FRA Office of Safety, Washington, DC.

Hobbs, A., Williamson, A., 2003. Associations between errors and contributing factors in aircraft maintenance. Hum. Factors 45 (2), 186–201.

Hursh, S., Redmond, D., Johnson, M., Thorne, D., Belenky, G., Balkin, T., Storm, W., Miller, J., Eddy, D., 2004. Fatigue models for applied research in warfighting. Aviation Space Environ. Med. 75 (3), A44–A56.

Moray, N., 2000. Culture, politics and ergonomics. Ergonomics 43, 858–868.

O'Hare, D., 2000. The "wheel of misfortune": a taxonomic approach to human factors in accident investigation and analysis in aviation and other complex systems. Ergonomics 43 (12), 2001–2019.

Paradies, M., 1991. Root cause analysis and human factors. Hum. Factors Soc. Bull. 34 (8), 1–4.

Petersen, D., 2003. Human error: a closer look at safety's next frontier. Prof. Saf. 48 (12), 25–32.

Railroad Retirement Board, n.d. Section B – Retirement and Survivor Benefits (Table 2). Retrieved March 18, 2005 from http://www.rrb.gov/act/pdf/ST03partb1.pdf.

Rasmussen, J., 1982. Human errors: a taxonomy for describing human malfunction in industrial installations. J. Occup. Accid. 4, 311–333.

Reason, J., 1997. Managing the Risks of Organizational Accidents. Ashgate Publishing Ltd., Aldershot.

Reason, J., 1990. Human Error. Cambridge University Press, New York.

Reinach, S., Gertler, J., 2002. Railroad yard safety: perspectives from labor and management. In: Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting. Human Factors and Ergonomics Society, Santa Monica, CA, pp. 1201–1204.

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

Scarborough, A., Pounds, J., 2001. Retrospective human factors analysis of ATC operational errors. In: Paper Presented at the 11th International Symposium on Aviation Psychology, Columbus, OH.

U.S. Navy, 2003. Opnav instruction 3750.6R change transmittal 2. Retrieved December 22, 2004 from http://www.safetycenter.navy.mil/instructions/aviation/opnav3750/default.htm.

Wickens, C., Flach, J., 1988. Information processing. In: Wiener, E.L., Nagel, D.C. (Eds.), Human Factors in Aviation. Academic, San Diego, CA, pp. 111–155.

Wiegmann, D., Shappell, S., 2001. A human error analysis of commercial aviation accidents using the human factors analysis and classification system (HFACS). Federal Aviation Administration Technical Report No. DOT/FAA/AM-01/3. National Technical Information Service, N Springfield, VA.

Wiegmann, D., Shappell, S., 2003. A Human Error Approach to Aviation Accident Analysis: The Human Factors Analysis and Classification System. Ashgate Publishing Ltd., Aldershot.

Woodcock, K., Drury, C., Smiley, A., Ma, J., 2005. Using simulated investigations for accident investigation studies. Appl. Ergon. 36, 1–12.