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Approaches to Error Avoidance

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REPORT SUMMARY

This report provides guidance to avoiding errors in switching operations on electric power systems.

Switching safety and reliability are ongoing concerns in the utility industry. Errors in switching can compromise both safety and reliability of the system and personnel. The rate of error occurrence, or decrease in this rate, may be used as one metric of performance of a utility and its control room operators.

This report represents continuation and in some ways the culmination of the research described in EPRI's Field Operation Power Switching Safety (EPRI TR 106465, published in 1996), from which the current Switching Safety Reliability Project has grown. It includes references to the several reports that have been published since then on specific aspects of the switching process and associated error prevention methodologies. The report also looks forward to projected or on-going studies that may shed further light on specific error prevention techniques.

Background

Since 1997, EPRI's Power Switching Safety and Reliability Project has had a steering committee of electric utility subject matter experts to guide the collection and dissemination of information on practices related to safety and reliability of power systems. Information on switching errors, collected previously from utilities participating in this project shows that calculated error rates vary by an order of magnitude among utilities. Therefore, many utilities are in need of information that will aid them in preventing or avoiding switching errors, or decreasing error rates.

This report is the first general and comprehensive work to fill this need.

The report summarizes the state of knowledge on factors affecting human performance and commission of errors, documents a range of approaches to error prevention, identifies specific error prevention techniques employed by participating utilities, and identify candidate "best practices" for error prevention.

Objective

The objective of this research is to provide a job aid or check-list to assist utilities in assessing their own error prevention strategies and identifing opportunities for improvement.

Approach

The report is based on information collected by a literature review and a survey of 24 utilities conducted by telephone and e-mail, a visit to one utility, and examination of documentation as available. The approach was the same as used in previous reports for this project, including *Collecting and Using Near-Miss Information*, EPRI TR 1001956, and Incident Investigation and Reporting, EPRI TR 1002077. The approach included:

- Survey of literature on human error, accident prevention, organizational approaches to promoting high reliability, and other topics related to error causation and reduction.

- Telephone survey and collection of supporting documentation, including program descriptions and training materials where available
- A visit to one utility identified in the survey who had a particularly strong programmatic approach to error prevention in place.

Twenty four (24) utilities supplied information and sample materials for this study. Participating utilities were selected from volunteers at the Annual Switching Safety and Reliability Conference, held in Columbus, OH (2003), or contacts that had been made in conducting previous studies. The majority of participants were current members of EPRI's Substation Operations and Maintenance target or of the Switching Safety and Reliability project.

Key Points

Factors affecting human performance, often called performance shaping factors (PSFs), can be organized under the following four headings:

- Person-related factors
- Task-related factors
- Workplace-related factors
- Cultural and social factors

Most important error avoidance approaches described in the related literature include self-verification, conducting audits to detect error susceptibility before errors occur, and establishing a healthy corporate safety culture.

Many participating utilities employ some forms of error avoidance approaches that were implemented as result of specific incidents.

A set of recommendations and a checklist of errors-avoidance strategies are included in the report.

EPRI Perspective

Safety and reliability have never been more important for a utility. The number of switching errors is an important component of reliability and can be used as a measure of success in assessing progress in eliminating switching errors.

This report is the first general and comprehensive work that is aimed at helping utilities prevent or avoid switching errors, or decrease error rates.

Keywords

Substations
Switching
Safety practices
Power system operation
Power system control

ABSTRACT

Introduction

EPRI's Switching Safety and Reliability project has been focused on ways to increase the safety and reliability of switching operations. This work is a continuation and in some ways the culmination of the research described in EPRI's *Field Operation Power Switching Safety* (EPRI TR 106465, published in 1996), from which the current Switching Safety Reliability Project has grown.

Overview of This Report

This report contains four sections:

Section 1, *Factors Affecting Human Performance*, is intended to provide background information that supports the discussion of specific error reduction or avoidance techniques described in Sections 2 and 3. It provides a brief summary of what is known about a range of factors affecting human performance in general (Performance Shaping Factors). These are divided into four groups: factors having to do with personal, task, workplace, and cultural/social characteristics or "factors" that may affect the likelihood of error. This section also contains brief discussions of human information processing and memory, and the Skill/Rule/Knowledge (SRK) characterization of human performance which may be useful in understanding errors in switching tasks, particularly the most common of all switching errors, operation of the wrong component.

Section 2, *Error Prevention Tools and Techniques*, documents a range of approaches to error prevention described in the literature. The most notable of these are the use of self-verification techniques and audits to detect the conditions that make errors more likely before they contribute to an error or incident. The section includes discussions of safety culture and some of the lessons learned from academic research on high reliability organizations.

Section 3, *Utility Practices Intended to Reduce Errors*, is based on a survey of 24 contributing utilities. The section describes a variety of techniques (some of which may not be widely known or used) employed by participating utilities and believed to be useful in combating a wide range of errors. Many of the techniques (modifications to labeling, procedures, etc) described by participants were adopted in response to incidents they had experienced and are specific to certain very specific situations. The section also contains descriptions of multi-element "programmatic" approaches used by 6 of the 24 utilities surveyed.

Section 4, *Toward Best Practices in Error Avoidance*, identifies candidate "best practices" for error prevention. Rather than specific measures that are intended to reduce a particular type of error, this section focuses on "big-picture" practices intended to support error free performance, identify and correct error likely situations, and help establish or maintain elements of a safety or high reliability culture.

To assist utilities in assessing their own error prevention strategies and identify opportunities for improvement, the recommendations given in Section 4 have been summarized in the checklist on the following pages.

Checklist of Error-Avoidance Strategies

The checklist below is organized in the order in which various techniques are discussed in Section 4. In the References column, the first reference given is to the Section 4 discussion explaining the basis for the recommendation, and additional references are to other sections of the report in which related information is presented. Footnotes identify recommendations that are supported by OSHA, and give the text of the associated requirement from 29CFR1910.269.

Part A: Person-Related Strategies and Techniques

•	*Strategy*	*Reference*
Training		
	1. System operators and field switchpersons receive regular refresher training in switching and clearance procedures	4.2.1; 1.1.2; 2.1.2; 3.2.1; Table 3-1; Table 3-6
	2. System operators and switchpersons receive specific training in error prevention strategies, including recognition of error-likely situations and specific techniques for dealing with them	4.2.1; 2.1.2 Table 3-1; Table 3-6
	3. Utility-specific or industry incidents are used in training system operators and field switchpersons	4.2.1; 2.1.2; Table 3-1; 3.2.1; Table 3-6
	4. Training or information about techniques to mitigate the effects of shift work is provided to system operators and field switchpersons who work rotating shifts	4.2.71; 1.3.3; 2.1.2; Table 3-1; 3.2.1; Table 3-6
	5. System operators participate in the training of field personnel	4.2.1; 3.5.1
Supervision		
	1. Supervisors spend sufficient time with their crews to actively monitor real-time performance[1]	4.2.2; 1.3.4; .1.4; 3.2.3; 3.6.2; 3.6.5
Discipline		
	1. Personnel may be disciplined for deliberately failing to follow procedures even if the failure does not result in an incident	4.2.3; 2.1.5; 3.2.2.
	2. Disciplinary action following an incident is administered only for willful procedural non-compliance and in a manner that is perceived as just	4.2.3; 2.1.5; 2.3.2; 2.4.2; Table 2-10; 3.2.2

[1] 29CFR1910.269(a)(2)(iii) The employer shall determine through regular supervision and through inspections conducted on at least an annual basis, that each employee is complying with the safety-related work practices required by this section.

Part B: Task-Related Strategies and Techniques

•	Strategy	Reference
General		
	1. The entire switching process, from the initial request for switching through filing of paperwork upon completion of the job, is performed in strict accordance with a set of complete, clear, and well understood written procedures	4.3.1; 1.2.2; 2.2.3
	2. Procedures and practices are reviewed and updated on a periodic basis by those who perform them	4.3.1
	3. Revised documents are tested with a sample of intended users prior to issue for use	4.3.1; 3.3.5
•	**Strategy**	**Reference**
Planning Switching		
	1. Written instructions are prepared for all switching operations for removal and restoration of equipment under both normal and abnormal conditions	4.3.2; 1.2.2; 3.3.1
	2. One-lines and other pertinent documents are used in preparing switching and are attached to or referenced in the instructions	4.3.2; 3.3.1
	3. At least one independent person reviews and signs off on each switching instruction	4.3.2; 2.2.1; Table 3-4; 3.3.1
Performing Switching		
	1. Field switchpersons conduct a walk through of the intended switching and verify equipment status before starting to switch [2]	4.3.3; Table 2-6; Table 3-4; 3.3.2
	2. Use of a self-verification technique, such as the Six Steps of Switching or STAR, is required	4.3.3; 2.2.1; 3.3.4
	3. Use of a formal 3-part communication protocol is required	4.3.3; 1.2.3; 3.3.3

2 29CFR1910.269(a)(3) “Existing Conditions.” Existing conditions related to the safety of the work to be performed shall be determined before work on or near electric lines or equipment is started. Such conditions include, but are not limited to, the nominal voltages of lines and equipment, the maximum switching transient voltages, the presence of hazardous induced voltages, the presence and condition of protective grounds and equipment grounding conductors, the condition of poles, environmental conditions relative to safety, and the locations of circuits and equipment, including power and communication lines and fire protective signaling circuits.

Issuing Clearances and Tagging		
	1. Clearance holders inspect the clearance points (with the switchperson if possible) before accepting the clearance	4.3.4; 2.2.1; 3.3.4
	2. Separate tags are hung for each clearance (for SCADA as well as in the field), resulting in multiple tagging of equipment that is common to both clearances [3]	4.3.4; 3.3.4

3 29CFR1910.269(m)(3)(viii) If two or more independent crews will be working on the same lines or equipment, each crew shall independently comply with the requirements in paragraph (m)(3) of this section.

1910.269(m)(3)(ii) All switches, disconnectors, jumpers, taps, and other means through which known sources of electric energy may be supplied to the particular lines and equipment to be deenergized shall be opened. Such means shall be rendered inoperable, unless its design does not so permit, and tagged to indicate that employees are at work.

1910.269(m)(3)(iii) Automatically and remotely controlled switches that could cause the opened disconnecting means to close shall also be tagged at the point of control The automatic or remote control feature shall be rendered inoperable, unless its design does not so permit.

1910.269(m)(3)(iv) Tags shall prohibit operation of the disconnecting means and shall indicate that employees are at work.

Issuing Clearances and Tagging (cont'd)		
	3. Information tags or permanent information labels warning of special conditions or equipment peculiarities are provided on field equipment and SCADA displays	4.3.4; 2.2.3 3.3.4
	4. Tags in the field for a long period of time are inspected periodically and missing or deteriorating tags are replaced	4.3.4
	5. The number and locations of personal protective and other temporary grounds are recorded	4.3.4
	6. Clearance holders inspect the clearance points (with the switchperson if possible) before accepting the clearance	4.3.4; 2.2.1; 3.3.4
	7. Separate tags are hung for each clearance (for SCADA as well as in the field), resulting in multiple tagging of equipment that is common to both clearances [4]	4.3.4; 3.3.4
	8. Information tags or permanent information labels warning of special conditions or equipment peculiarities are provided on field equipment and SCADA displays	4.3.4; 2.2.3 3.3.4
	9. Tags in the field for a long period of time are inspected periodically and missing or deteriorating tags are replaced	4.3.4
	10. The number and locations of personal protective and other temporary grounds are recorded	4.3.4

4 29CFR1910.269(a)(3) "Existing Conditions." Existing conditions related to the safety of the work to be performed shall be determined before work on or near electric lines or equipment is started. Such conditions include, but are not limited to, the nominal voltages of lines and equipment, the maximum switching transient voltages, the presence of hazardous induced voltages, the presence and condition of protective grounds and equipment grounding conductors, the condition of poles, environmental conditions relative to safety, and the locations of circuits and equipment, including power and communication lines and fire protective signaling circuits.

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1910.269(m)(3)(iv) Tags shall prohibit operation of the disconnecting means and shall indicate that employees are at work.

Part C: Workplace Strategies

•	Strategy	Reference
Working Conditions		
	1. Staffing levels are adequate to minimize predictable stress on employees	4.4.1; 1.3.5; 2.1.4 ; 3.4.3
	2. Where rotating shifts are used, the rotation schedule is optimized based on knowledge of circadian rhythms	4.4.1; 1.3.3
	3. Distractions in the work environment are minimized by engineering or procedural controls	4.4.1; 1.3.1
	4. Accessibility, usability, and other human factors engineering issues are considered in the design of facilities and the purchasing of new equipment	4.4.1; 1.3.2; 2.2.2
	5. Maps, drawings, and other job aids are updated in a timely fashion: current revisions are available to all who need them	4.4.1
Audits		
	1. Regular audits are performed to ensure procedural compliance[5]	4.4.2; 2.3.2; 3.4.2; 3.6.1; Table 3-6
	2. Audit findings indicating procedural deficiencies, ambiguities, or misunderstanding are acted upon in a timely fashion	4.4.2; 2.3.2; 3.6.1
	3. Audit findings are posted and tracked	4.4.2; 3.4.2; 3.6.1
	4. Audits have "teeth" in that they influence individual and unit performance evaluations	4.4.2; 3.6.1
Incident Reporting and Investigation		
	1. A system of incident and near miss reporting and investigation is in place	4.4.3; 2.3.1; Table 3-5; Table 3-6
	2. Some form of root cause analysis is performed for incidents and near misses	4.4.3; 2.3.1; Table 3-5; Table 3-6
	3. Reports of incidents and the findings of investigations are widely disseminated, including to senior management and training staffs	4.4.3; 2.1.2; 2.3.1; 3.4.2; Table 3-5; Table 3-6
	4. Actions to correct deficiencies identified through incident investigation are undertaken in a timely fashion	4.4.3; 3.6.6

[5] 29CFR1910.269(a)(2)(iii) The employer shall determine through regular supervision and through inspections conducted on at least an annual basis, that each employee is complying with the safety-related work practices required by this section.

Part D: Cultural Factors

•	Strategy	Reference
	1. System operators and switchpersons are empowered to stop work if they are not confident the switching they are performing is correct	4.5; 3.5.2
	2. System operators and switchpersons are encouraged to take the time needed to perform a job correctly 'by the book' and not to rush. They are empowered to stop or slow the pace of work to compensate for fatigue, overload, or other error-producing conditions	4.5; 3.5.2
	3. Individual responsibility and accountability are encouraged	4.5; 2.4.1; 3.6.3
	4. A "questioning attitude" is encouraged	4.5; 2.4.2; 3.5
	5. Opportunities are provided for face-to-face contact between System Operators and field personnel	4.5; 2.4.1; 3.5.1
	6. Senior management is personally involved with the error reduction efforts, including participation in incident review meetings (including membership and regular participation in the incident review committee if one is established)	4.5; 2.3.4; 3.4.1 ; 3.6.6; Table 3-6
	7. Management communication is frequent, clear , and consistent as to the priorities it accords safety and reliability, and how these priorities relate to other potentially competing priorities such as timeliness, efficiency, utilization of available resources, etc.	4.5; 2.1.4

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INTRODUCTION

Background

EPRI's Switching Safety and Reliability project has from its inception been focused on the prevention of operating errors/incidents and, more generally, on any and all means to increase the safety and reliability of switching operations. This work is a continuation of the original research described in EPRI's *Field Operation Power Switching Safety* (EPRI TR 106465, published in 1996), from which the current Switching Safety Reliability Project has grown. It includes reference to the several reports that have been published since then on specific aspects of the switching process and associated error prevention methodologies. The report also looks forward to projected or on-going studies that may shed further light on specific error prevention techniques.

Project Goals

The goals of the present investigation were to:

- Provide a brief summary of what is known about a range of factors affecting human performance in general and the commission of errors in particular, and to provide access to the literature on human performance and human error.
- Document a range of approaches to error prevention described in the literature.
- Identify specific error prevention techniques employed by participating utilities (with particular emphasis on those that may be useful but may not be widely known or used) as well as any programmatic approaches that they are using. For this report a *"programmatic approach"* is defined as one that incorporates at least two elements in a coordinated fashion under the direction of an identified single authority or individual.
- Based on the convergence of literature-based recommendations and actual utility practice, identify candidate "best practices" for error prevention.
- Provide a job aid or check-list to assist utilities in assessing their own error prevention strategies and identify opportunities for improvement.

Research Approach

The report is based on information collected by a literature review and a survey of utilities conducted by telephone and e-mail, a visit to one utility, and examination of documentation as available. The approach was the same as used in previous reports for this project, including *Collecting and Using Near-Miss Information*, EPRI TR 1001956, and *Incident Investigation and Reporting*, EPRI TR 1002077. The approach included:

- Survey of literature on human error, accident prevention, organizational approaches to promoting high reliability, and other topics related to error causation and reduction.
- Telephone survey and collection of supporting documentation, including program descriptions and training materials where available
- A visit to one utility identified in the survey who had a particularly strong programmatic approach to error prevention in place.

Participants

Twenty four (24) utilities supplied information and sample materials for this study. Participating utilities were selected from volunteers at the Annual Switching Safety and Reliability Conference, held in Columbus, OH (2003), or contacts that had been made in conducting previous studies. The majority of participants were current members of EPRI's Substation Operations and Maintenance target or of the Switching Safety and Reliability project. Participating utilities are listed in Appendix A.

Organization of the Report

This report includes the following sections:

Section 1: Factors affecting Human Performance

Section 2: Error Prevention Tools and Programs

Section 3: Utility Approaches to Error Reduction

Section 4: Toward Best Practices

Appendix A: Participating Utilities and Utility Contact Persons

Appendix B: Questions used in Telephone Survey of Participating Utilities

The table below provides a Reader's Guide to assist readers in locating the sections of the report that are of particular interest to them.

If you are interested in:	Go to:	To learn about:
Why operators make errors in general	Section 1	Factors affecting human performance
A range of possible reasons why an individual operator is making errors	Section 1.1	Personal characteristics and transient states that may dispose an individual to make errors
Why experienced operators make stupid mistakes when they know better	Section 1.6	What skill-based errors are and how they arise
The Skill-Rule-Knowledge (SRK) model of human behavior	Section 1.6	What governs behavior in each of the SRK modes and how this helps in understanding switching errors
Tools, equipment that can improve operator performance	Section 1.2	Engineering characteristics of tasks; design of tools and equipment
General approached to error prevention	Section 2	Error prevention tools and programs
An effective aid to reduce “operated wrong control” errors	Section 2.2.1	Self-verification techniques
Approaches to “tightening-up” the conduct of operations	Section 2.3.2	Organizational audits to detect situations that increase the likelihood of error
Attitudes, beliefs, and habitual practices that aid individuals to avoid errors	Section 2.4	Attributes of High Reliability Organizations and Safety Culture
Techniques other utilities are using to combat errors	Section 3	Utility approaches to error reduction
The role of discipline in preventing errors	Section 3.2.2	Utilities’ use of discipline for errors
Aspects of utility culture believed to contribute to error-free operation	Section 3.5	The importance of face to face communications and empowering operators to resist time pressure
Error prevention programs in use at participant electric utilities	Section 3.6	Features that make an error prevention program different from a collection of good practices
Characteristics of utility Error-prevention programs	Section 3.6.7	Elements common to most error prevention programs
What the authors of this study concluded	Section 4	Recommended practices and the Checksheet in the Executive Summary
Selective implementation of recommendations	Section 4.6	A range of criteria for selecting “fixes” to implement
The challenge of maintaining practices that are effective	Section 4.7	The importance of “*persisting in the face of success*.”

1
FACTORS AFFECTING HUMAN PERFORMANCE

Before embarking on a discussion of ways to prevent errors, it is important first to understand how errors arise. Accordingly this section of the report provides a discussion of the factors that affect human performance with an emphasis on those that affect human error.

Factors affecting human performance are often called performance shaping factors (PSFs). Not surprisingly, there are very many PSFs because, under the right circumstances, almost anything you can think of can affect performance. The grouping of PSFs is somewhat arbitrary, and varies among different sources. In this report they are organized under the following four headings:

- Person-related factors
- Task-related factors
- Workplace-related factors
- Cultural and social factors

This grouping has been adapted from the categories of PSFs presented in Embrey, Kontogiannis, & Green (1994) and Petersen (1996). Even within these sources there are differences. For example, Embrey, *et al.* (1994) group training under task characteristics while Petersen lists it under factors internal to the worker; stress related PSFs are scattered throughout the Embrey, *et al.* lists, but tabled separately by Petersen; etc. The grouping mirrors to some extent the distinctions made by Reason (1997) when he contrasts three models underlying different approaches to safety management: the person model, the engineering model, and the organizational model. The PSFs discussed here have been selected based on their potential relevance to switching operations.

It is worth noting that PSFs vary in their relation to error. While some PSFs have two possible values (e.g., either a task is dynamic or performed step by step), most represent a continuum of qualities. PSFs may also vary in their effects on the task; that is, the PSF may have either a positive or negative effect on performance, depending on how it interacts with the requirements of a specific task.

In this section, the four major groupings of PSFs are first discussed separately in Sections 1.1 through 1.4 respectively. Where an error-prevention technique is a natural corollary of an individual PSF, the technique may be mentioned here, thus anticipating to some extent the discussion of error-prevention strategies in Section 2. Although the applicability of given PSFs to the performance of switching tasks is mentioned from time-to-time, detailed application of the literature findings to switching performance is deferred until the concluding section of the report.

The description of individual factors is followed in Section 1.5 by a brief discussion of interactions among them. Finally, Section 1.6 presents the important integrated approach to understanding the source of human error namely the Skill-Rule-Knowledge information processing model due to James Reason (Reason 1987, 1990, 1997).

The information in this section is based largely on the literature of the field or the experience of other safety-critical industries such as nuclear power, commercial aviation, and petro-chemical industries. Earlier work completed as part of EPRI's Switching Safety and Reliability Project is also cited where applicable. Where no specific literature sources are cited for a given assertion, this is because the information is generally well-known or is scattered through many of the sources mentioned in the bibliography.

1.1 Person-Related Factors

Person-related factors that affect task performance include the individual's knowledge, skills and abilities (KSA's) as they affect the requirements for performing a specific task or job. Additional factors include attitudes and emotional stability, and such transient states as current state of health, fatigue, stress, or impairment, which all relate to the ability to effectively deploy the KSAs in performance of a given job.

In Table 1-1 below, person-related factors are arranged in three groups:

- Individual traits that are stable over time, at least on the time scale of performing a given task
- Knowledge & skills
- Transient states

This grouping is for convenience of discussion. Ultimately all PSFs impact the individual. For example shift rotation is listed in Section 1.3 as a workplace factor, but its effects are manifest in the transient states of the individual such as fatigue (Table 1-1).

Table 1-1
Person-Related PSFs

Individual Traits	Knowledge and Skills	Transient States
Gender Physical condition/health Personality • Risk seeking/risk averse (thrill seeking vs. play-it-safe) • Attitude toward authority • Impulsivity • "Macho" Motivation / work attitude	Knowledge of required tasks and skill in performing them Skill and practice in performing tasks • Frequency • Recency	State of Awareness Alertness • Mental blocks • Task unrelated thoughts • Complacency • Mental Fatigue • Boredom Preoccupations Goals & goal conflicts Stress (mental or bodily tension) Impairment (Illness, Alcohol, Drugs)
Source: Adapted from Petersen (1996); Embrey *et al.* (1994) and Scerbo *et al.* (1998)		

1.1.1 Individual Traits

Individual traits are characteristics that individuals bring to the job. Characteristics that may affect the individual's propensity for error include gender, physical condition and certain personality traits.

Gender

Research conducted by British ergonomist Jeremy Williams (as cited in Reason 1997, p. 146) shows that females tend to be more conscientious and are less likely to take shortcuts when following procedures – a definite asset in switching operations.

Physical Condition/Health

Although most switching activities can be performed by individuals who are not in particularly good physical condition, a reasonable degree of physical fitness aids in resistance to fatigue and stress, and thus may exert an indirect influence on the propensity to error under such conditions.

Personality

Certain aspects of personality may affect performance if they predispose the worker to risk taking, hasty or ill-considered action, or a casual attitude toward the letter of policies and procedures.

Risk Taking

Risk taking is generally considered to be a fairly stable personality trait of individuals, though it is also influenced by group norms. The discussion of risk taking in Embrey, *et al*. (1994, p. 137) notes that not only do individuals vary in their willingness to take a risk, they also vary in their perception of risk. Unfortunately, the correlation is negative: those more willing to take a risk tend to be less likely to have an accurate perception of the level of risk to which they are exposing themselves. Neither of these necessarily leads to error, but either or both of these could increase the likelihood of taking a shortcut, such as not referring to the written order before throwing a switch.

Shortcuts commonly take the form of omitting selected steps that do not appear to the worker to be important to the completion of the task. Although they are violations of procedure, such shortcuts are thought of as harmless by those who take them. The shortcut is itself an error when judged against the standard of performance embodied in the procedure, but it usually has no obvious effect on task outcome. Reason (1997) notes that the principal effect of shortcuts is to reduce the safety margins built into the procedure, which increases either the likelihood of something unwanted happening, or reduces the ability to recover from an error if one is made. For example, in maintenance tasks, shortcuts involving the substitution of fluids can result in the early failure of the component.

Attitude toward Authority

Individuals with a negative attitude toward authority may be less likely to follow procedures, communications protocols, and safety rules scrupulously, all of which may increase the likelihood of error.

Impulsivity

Impulsivity refers to a tendency to act without thinking things through. It is a fairly stable trait of individuals that can predispose to errors and accidents. Its exact opposite, careful deliberation, is required in all aspects of switching operations.

Macho

One personality trait has been identified in the safety literature as particularly dangerous: "Macho." This trait incorporates the undesirable characteristics of all three traits above into one package. Petersen (1996, p. 224-5) notes that this trait is commonly reflected in a refusal to wear safety equipment. It may also lead to an underreporting of near-misses or hazardous conditions, and a reluctance to ask for clarification if instructions are ambiguous, the latter being a condition that often leads to errors.

Motivation/Work Attitudes

Motivation is important to success in all jobs. Error-free performance of switching requires a pattern of verification and reverification of facts that the worker is, for the most part, already sure of. This degree of checking and rechecking virtually everything is unusual and perhaps even dysfunctional in everyday life. Further these activities are only infrequently rewarded with an obvious "catch" of an error in the making. Persisting in double- and triple-checking requires a high degree of motivation.

1.1.2 Knowledge and Skills

Knowledge of required tasks (together with their associated procedural requirements and standards) and skill in performing them are clearly prerequisites for effective performance. So also is the ability to execute the required tasks within whatever constraints are imposed by the environment. It is important to remember that knowledge alone is seldom sufficient for optimal performance. Moreover, both skill and knowledge will decay (or become unavailable) if they are not used. So recency of exposure, or frequency of use of task-specific knowledge, are also important PSFs. Experience also plays a part insofar as experience leads to development of expertise that may result in a task being performed in an "automated" or skill-based mode. (See the discussion of skill-based performance in Section 1.6).

1.1.3 Transient States

Transient states may be especially relevant to the occurrence of slips and lapses, which seem to account for the majority of switching errors. They include factors related to state of awareness, preoccupations, goal conflicts, and stress. Factors that cause temporary impairment were included in Table 1-1 but are not discussed here.

State of Awareness

Various transient factors relate to a person's state of awareness. Scerbo *et al*. (1998) describe several types of reduced or distorted awareness that they call hazardous states of awareness (HSAs). These are unfocused states of mind that can lead to errors in tasks that require operators to work for extended periods of time on routine, habitual activities. The same authors also discuss "lapses" and "slips" as products of states of awareness, but we prefer to think of these as products of inattention rather than states of awareness in their own right.

The HSAs include:

- Mental blocks
- Complacency. The authors give a technical definition specifically related to aviation as "the failure to monitor the actions of a machine or computer." A more general definition from the NASA Aviation Safety Reporting System is "self satisfaction which may result in non-vigilance based on an unjustified assumption of system state." This definition closely corresponds to everyday usage of the term. Unlike the other HSAs, complacency may be a relatively long-lived state.
- Mental Fatigue
- Boredom. Petersen believes boredom is more important in accident causation than fatigue (1996, p. 149)
- Task-unrelated thoughts (TUTs) – these can include preoccupations (see below)

Although the work of Scerbo *et al*. was performed for NASA, and was largely directed at continuous monitoring tasks, the HSAs described may be relevant to the "loss of focus" that is the only explanation given for approximately one-half of all switching errors.

Preoccupations

Preoccupations are thoughts that detract from focus on the task at hand. They may include a fight with one's spouse, thinking about a recent fishing trip, concern about a sick child or a motorcycle-riding coworker who is late. All of us are subject to them at one time or another. Preoccupations are to be distinguished from distractions, which are external events over which management has much more control.

Goals and Goal Conflicts

There are two kinds of goal conflicts, those between conflicting personal goals, such as the conflict between taking the time to do the job “by the book” or hurrying up so you can go home, and those between corporate goals such as reliability/safety vs. productivity. Whereas the resolution of personal goals may be decided in favor of safety/reliability by appropriate attitude or group norms (culture), conflicting corporate goals put the worker in a very uncomfortable position.

Stress

Stress may be defined as an unpleasant state of arousal that can be disruptive to behavior if it is excessive. The most common view of stress is that it arises from a real or perceived mismatch between the requirements of a situation and the resources available to meet them. An exception to this statement is that many people find unchallenging, routine repetitive tasks stressful, and being significantly underloaded or underaroused has similar effects on many kinds of performance.

Common Job-related Sources of Stress

Many job-related stressors clearly fit the requirements/resource mismatch model. Preoccupations and goal conflicts have already been mentioned. Others that are relatively common in utility work include:

- Perceived time pressure: this is perhaps the most frequently cited source of stress among utility workers. Time pressure, whether real or perceived is mentioned in about 15-20% of incident reports where errors are attributed to System Operators.
- Responsibility without the authority or resources to control the results.
- Uncertainty in important matters, for example from ambiguous communications or instructions, or doubts about the personal consequences of a corporate reorganization.

Another obvious source of stress is being in a threatening situation. The threat may be a physical danger, or a threat to employment or self-esteem. Although there are physically dangerous elements in some switching activities, these are usually not stress-inducing because the individual has (or should have) been provided with effective resources for dealing with them, such as training, procedures, personal protective equipment.

Combinations of Stressors

Although there are many situations that can predictably induce stress, to the extent that it is a dysfunctional state of arousal, it exists in the individual rather than the situation. The stress experienced in a given situation is a combination of the effects of all the stressors affecting the individual, both on-the-job factors (potentially controllable by management) and off-the-job factors. That is, the effects of other stressors effectively add to on-the-job stressors. Dealing with an illness, a failing marriage, or a troubled teen can leave a person sufficiently "stressed-out" and that he or she doesn't have many additional resources to cope with on-the-job demands.

Effects of Stress

Stress has many potentially negative effects on task performance:

- At a minimum, stress usually produces the *task-unrelated thoughts (TUTs)* described earlier which can distract from task performance. Concentrating on a task can reduce the sensation of stress, and a small amount of stress can actually enhance task performance.
- Prolonged exposure to significant stress may induce *stress-related illnesses* such as difficulty sleeping or high blood pressure, which, in a positive feedback loop, are themselves additional stressors.
- High levels of stress can *disrupt behavior*. Well-learned skills are least susceptible to disruption, and everyday rule-based behavior somewhat more so.
- Moderate to high (and also abnormally low) levels of stress frequently induce a shift to a *more risky mode of behavior* in an effort to cope. This behavior typically takes the form of cutting corners, omitting parts of procedures that seem to be of low importance. In switching activities this would most likely result in a reduction in the normal amount of rechecking typically employed in the development and execution of switching procedures.
- High levels of stress may result in a number of *distorted patterns of thinking* that are very disruptive to knowledge-based problem solving. Such high levels of stress may be induced in those on the scene at a serious accident, but are generally not encountered in routine utility work. Discussions of such distortions are presented briefly in Embrey *et al.* (1994, pp. 149-151) and in more detail by Reason (1990).

Individuals vary a great deal in their reactions to stressful situations. Some may not feel it as much as others, some may have more resources or more effective coping mechanisms, and, as discussed earlier, some may already be fairly near their limits for reasons unrelated to the present situation. Within a group of individuals whose performance in routine situations is at a similar (and usually high) level, the above factors tend to shift the average level of performance downward, though the performance of some individuals may not be affected at all.

Moderators of Stress Effects

Important moderators of stress include:

- Self confidence (this doesn't even have to be "realistic" – just the attitude helps)
- Adequacy of training, which provides resources (skills) and should be a source of self confidence
- Physical condition
- Experience in similar situations

High or “good” values of the above factors make individuals more able to resist performance decrements associated with stress. Organizations engaged in inherently stressful operations such as fire departments and the military devote a good deal of their time and resources to creating positive levels of such moderators. Military, fire, and police departments engage in frequent training and monitor the physical condition of their members. Experience is provided through training exercises that are simulations of scenarios they may encounter. Airlines and nuclear power plants use simulators to practice emergency procedures and recreate hazardous or unusual situations that have occurred to their own crews or those of other organizations in their industries. Simulators are increasingly used in the training of system operators as a preparation for unusual and high-stress conditions.

1.2 Task-Related Factors

Task characteristics may be described in many ways. One common taxonomy deals with what might be called their surface or engineering characteristics; the other describes the information processing requirements involved in performing them. Interpersonal requirements of tasks are addressed as a separate grouping. Important elements from each area are listed in Table 1-2 and will be discussed in turn. The knowledge and skills needed to perform a given task were identified as Person-related Factors and are not discussed further here.

Table 1-2
Task-Related PSFs

Required Knowledge, Skills, and Abilities

Engineering Characteristics:

- Type (discrete vs. continuous)
- Pacing (internal vs. external)
- Task Frequency/Repetitiveness
- Perceptual requirements
- Physical requirements (speed, strength etc.)
- Requirements of hardware interface

Information processing characteristics

- Task complexity (information load)
    - Long and short term memory load (interpretation, decision-making, calculation requirements)
    - Availability of procedures and job aids
- Environmental information
- Feedback (knowledge of results)
- Concurrent task requirements

Interpersonal Requirements

- Team structure and composition
- Written or oral communications

Source: Adapted from Petersen (1996) and Embrey, Kontogiannis, & Green (1994)

1.2.1 Engineering Characteristics of Tasks

The tasks performed by humans are dictated by what systems are designed to do and the way their components are designed. In theory, tasks are "designed" to support requirements for performance of the overall system; in practice, tasks are largely determined by the requirements of the technology embodied in the system. Human factors engineering seeks to simplify as much as possible the requirements that technology makes on its human operators and maintainers. Nonetheless, task requirements and task design are driven by the technology employed, and the physical characteristics of tasks are – at least in part – a result of the (engineering) design of the controls and displays provided by the technology.

Type

The task may consist of one or more *discrete* actions (e.g., executing a switching procedure) or it may require more or less *continuous* inputs guided and adjusted by some external reference (e.g., driving a car, guiding a power saw). Switching tasks require discrete actions, which are usually easier and require less concentrated attention than continuous tasks.

Pacing

The pacing of the actions performed may be under the direct control of the person performing the task (*internal* pacing), or may be controlled by external cues to which the performer must continually attend and conform his actions (*external* pacing). In general, externally paced tasks are more subject to errors because the individual needs to keep up with the external pacing in addition to performing the required actions.

Switching tasks are internally paced. In fact, switchpersons are generally encouraged to take their time precisely so as to reduce the risk of error (see discussion in Section 3.5.2).

Task Frequency and Repetitiveness

The frequency with which a task is performed is an important factor in the development and maintenance of skill. Very infrequently performed tasks may not be as well understood as those more frequently performed, and thus may require additional "refresher" training to ensure that the required knowledge and skills are available if called on. On the other hand, tasks performed too frequently, especially if they are highly repetitive, encourage the development of an "automatic pilot" mode of performance, which is efficient but may be a liability if some detail of the work to be done changes.

Perceptual Requirements

Task information is conveyed by many sensory modalities. These must be compatible with the perceptual capabilities of the worker. In switching tasks the key modalities are vision and hearing (verbal instructions). Problems arise when required perceptual discriminations exceed the capability of the individual. This can happen through the characteristics of the individual or engineering features of the tools used in task performance. Perceptual characteristics of individuals that may be important in switching include color discrimination (important for interpreting color coding used on many displays, or wires in equipment cabinets) and hearing loss.

- Color codes used on EMS displays and other devices need to be tested for accuracy of discrimination. For example, colors that are easily *discriminated* when presented side by side may not be *recognized* with very high accuracy when presented alone. Also, as display technologies have improved (particularly in resolution) designers have been tempted to increase the information presented by individual displays by making characters and symbols smaller. Human factors engineering guidelines for minimum character dimensions are based on human perceptual abilities, and these, rather than what can be squeezed out of the current technology, must be used to determine the size of display elements.
- High frequency hearing loss is part of the normal aging process, and may make it difficult for individuals to understand verbal instructions, especially if the communication devices are of low quality or subject to interference. Use of a phonetic alphabet (alpha, bravo …) when communicating component nomenclature provides redundancy that offsets the effects of sub-optimal hearing and poor quality devices. Also, it is a characteristic of many forms of hearing loss that the affected individual has greater susceptibility to auditory interference: that is, he or she experiences greater difficulty picking sounds out of background noise. Thus it is important to control noise levels in control centers.

Physical Requirements

The physical requirements for performing switching from the Control Center via EMS or switches mounted on a control panel are fairly minimal. However, significant force may be required to operate lever-operated switches in a switchyard (especially gang switches where three blades are moved by a single lever), and pole- and line-mounted switches on distribution lines.

Other Requirements of Hardware Interface

A substation control house typically contains panels on which are mounted arrays of very similar looking displays and controls with the most critical facts about them, what they display or control, indicated only by labels. On many such panels the design principle appears to have been simply the grouping of similar instruments and controls together, without regard to how they relate to each other, how they are used in actual operations, or how the panel layout relates to the location of the controlled components on the ground or in relevant diagrams. At best such layouts slow task performance by making the desired component more difficult to locate. At worst, closely spaced arrays of identical objects increase the likelihood that a user will inadvertently select and operate the wrong control. Seen in their best light, such layouts require the operator to pay close attention to what he or she is doing (which is expected in any case); at worst, they can also punish the user with an error if he or she does not.

A strong trend in the industry is the use of compact microprocessor-based components equipped with multifunction displays and controls. This has increased both the amount of information available to the operator and the variety of technologies in which competence is required. The operator interfaces on such devices are more complicated than those of the older electro-mechanical devices that they replace. Widespread use of such devices has probably increased the number of opportunities for human error, though we know of no hard data supporting this supposition.

1.2.2 Information Processing Characteristics of Task

A very important aspect of any task is the information processing requirements it imposes on those performing it. It is arguable that essentially all errors may be understood as failures of information processing. A simplified model of information processing is shown in Figure 1-1.

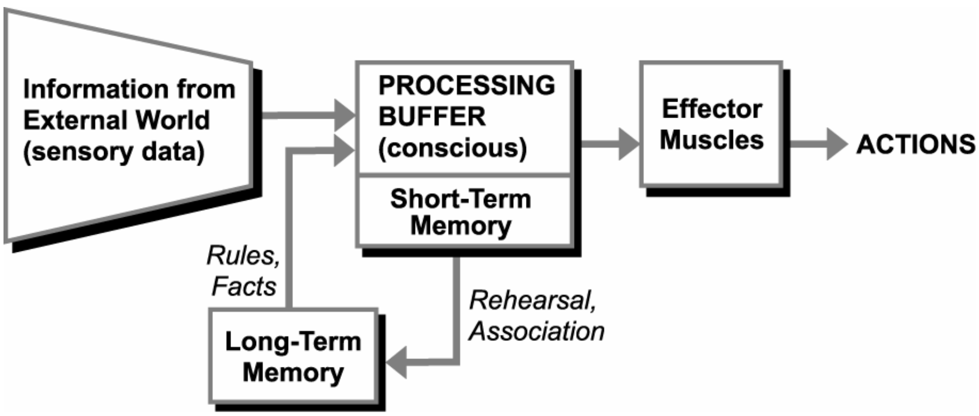


Figure 1-1
Simplified Information Processing Model

Current thinking has the majority of task-related information processing carried out by what in computer terminology would be called a buffer. This processing buffer has been variously identified with conscious awareness and short-term memory. Processing within this buffer is slow, and it has a very limited capacity in terms of the number of objects that it can deal with. The buffer processes sensory data from the external world together with selected rules, facts, etc. that have been stored in long-term memory in order to determine what actions to effect in a given situation. Note that the vast majority of processing is not conscious and what would be called massively parallel. For example, on the input side, you are not aware of the pattern of light and dark on your retina, but the object it represents. On the output side, few of us are aware of the number of muscles involved or the intricate coordination required to grasp an object or say an intelligible word: we just do it.

Using this model, we will discuss task-related factors that affect performance in terms of task complexity; environmental information; feedback; and concurrent task requirements.

Task Complexity (information load)

The complexity or information load of a task may be thought of in terms of the amount of information that must be funneled through the buffer. This information comes from the external world and from long-term memory, which (among other things) provides the rules for processing (making sense of) the external information, e.g., “that indicator light is red, therefore the breaker is closed” and acting on it; “if breaker number is NNN, then open breaker.” This latter rule involves “loading” the required number NNN from memory or a printed instruction and comparing it against the sensory image. In reality, a switchman will probably “load” both components more than once, that is he or she will look back and forth between the instruction and nameplate several times rather than a single glance at each.

Both maintaining information in short-term memory and moving it from short-term memory into long-term memory involve a process of rehearsal, often literally saying it several times to yourself. As explained in more detail in Section 1.6, this process is easily disrupted. Moreover, we will argue that switching tasks are particularly liable to problems resulting from the fallibility of memory because device numbers are very similar and so are especially susceptible to such disruptions.

Numerical calculations are also processing-intensive, involving intermediate products that have to be rehearsed until they can be combined with the result of the next operation.

Support for cognitive aspects of a task involves making information readily available from some source other than memory. The simplest support is paper containing the required information and maybe a pencil for creating our own memory aids. Doing calculations on paper is usually more accurate – and faster – than doing them in your head because the paper “remembers” the intermediate products for you, without so much rehearsal. Doing them on a calculator is faster and more accurate still, however, the calculator does not remember or store intermediate steps and does not facilitate checking of intermediate products.

Procedures are a very important tool in “externalizing” information (thereby reducing the burden on retrieval of rules from long-term memory) as well as in ensuring consistent performance. Other job aids such as diagrams or structured sheets for calculations can reduce the time and effort taken to perform a task and greatly increase the likelihood of getting it right the first time. The availability and quality of such aids can have a substantial impact on performance.

Environmental Information

All tasks are guided by information, either plans of action in the operator’s head or signals from the environment, usually a combination of both. Information present in the environment (labels, written instructions) is always available, and not subject to forgetting or interference. For example, coding the handles of ground switches by size, shape, or color makes them easier to locate than labels alone, and thus facilitates task performance.

Feedback

Except in vary rare cases, the availability of some sort of feedback is essential to successful task performance. Feedback may vary in availability, immediacy, kind, and sensory channel.

Most feedback in switching is visual (e.g., indicator lights) and immediate. Problems arise in discrete tasks when the feedback available is not immediate. For example, if the indicator lights show a change in device status, the operator knows that the intention to throw the switch has been registered, but does not know if the operator action has actually resulted in a change in the status of the device – the indication may be false. The operator may move on to the next task before receiving confirming indication, and so be unaware of the problem on those rare occasions when a device does not engage.

Collection of positive and accurate feedback is so critical that separate confirmation steps are usually explicitly written into switching procedures. Good switching practices generally require multiple sources of confirmation: check the meters as well as the indicator lights, visually confirm that the disconnect opened, and so on.

Concurrent Task Requirements

Most tasks require a large amount of conscious attention. The necessity to perform another task at the same time reduces the attention that is given to each, usually to the detriment of one or the other. So-called loss of focus is often the result of interruptions or preoccupations, attending to which is, in effect, an additional task.

System operators may be involved in directing several sets of switching instructions more or less simultaneously. The trick of multi-tasking is to segment the tasks into small chunks and attend to each component sequentially, but completely. In switching, this is made relatively error-free by the use of written procedures, with checkoff spaces for keeping place.

1.2.3 Interpersonal Requirements of Tasks

The interpersonal requirements of a task can affect performance, particularly where accurate communication of information between two or more parties is required as is the case for switching.

Team Structure and Composition

Although switchpersons frequently work alone in the field, switching tasks have a significant interpersonal component. In switching operations the dispatcher and the switchperson in the field act as a team. For this, effective communication skills are needed. Many utilities try to arrange at least personal acquaintance between dispatchers and field workers on the generally correct assumption that it will foster more effective communication. The benefits of face-to-face communications are discussed further in Section 3.5.

Team structure generally requires that one individual assume a guiding or leadership role to coordinate the activities of other team members. The designated leader usually is the person with the best understanding of the team's goals and overall procedure, and generally is vested with authority to require that the procedures be followed. For switching, this role is always performed by the dispatcher.

In some cases, the degree of task complexity or coordination is such that a team is required to do the job. This is so if the job requires a mix of skills not possessed by a single individual, or if similar skills must be applied more or less simultaneously, or simply if several hands are required. Team composition is effectively determined by task requirements because team members must collectively possess all the skills required to do the job.

Beyond specific technical skills, it is sometimes desirable to have a variety of differing perspectives (i.e., persons of dissimilar training and experience) represented on a team. In general, the less structured the task, the more it may benefit from such diverse perspectives.

Written/Oral Communications

By now, most utilities use written documents to communicate detailed technical information such as switching instructions. This avoids transcription errors and the considerable time required to dictate and verify dictated instructions. However, oral communications are still important for discussing the work, and any unforeseen circumstances or changes that must be made.

Consistent performance is best achieved by use of structured communications, conducted according to a formal protocol. At minimum, this protocol should require use of official nomenclature when referring to locations, equipment, and actions to be performed, and the use of a phonetic alphabet (alpha, bravo, charlie. . .) for conveying device numbers. It is entirely too easy to confuse "M" with "N," especially if the communications devices are subject to static or at the limits of their ranges.

Moreover, oral communications should be "professional" at all times. This includes avoidance of non-task related discussions, and avoiding the use of slang or "local" names, no matter how much we may feel that "everyone" understands them. Moreover, both parties should be alert to how they speak, so as not to discourage free communication of all concerns, no matter how seemingly trivial, by content or tone.

1.3 Workplace-Related Factors

Another important set of influences on human performance has been grouped under the heading "Workplace-Related Factors." They are summarized in Table 1-3 and will be discussed in turn.

Table 1-3
Workplace PSFs

Work Environment • Physical environment (temperature lighting noise vibration general cleanliness) • Distractions
Availability / Adequacy of Equipment, Tools, & Supplies
Work Hours and Other Time-related Factors • Shift work and alertness (quantity and quality of sleep) • Shift schedules (permanent and rotating) • Shift length
Quality of Supervision
Resource Allocation/Staffing
Source: Adapted from Petersen (1996) and Embrey, Kontogiannis, & Green (1994)

1.3.1 Work Environment

Physical Environment

The physical environment may facilitate or hinder task performance. Incident reports occasionally identify inadequate lighting, noise levels that interfere with communications, or sloppy housekeeping resulting in piles of materials that preclude free access to equipment as factors contributing to operator errors. Although these are not factors in a large percentage of incidents, all are correctable.

Distractions

Distractions are characteristics of the workplace that may divert attention from the task at hand. Their presence is to a large extent under management control. For example, work in a process or power plant is often directed from the control room. One of the senior operators' responsibilities is to monitor what is going on, write up work requests, issue work permits, etc. Thus there is often a lot of traffic in the control room. This constitutes a distraction for those operators who are monitoring or controlling the process. To minimize such distractions, the control room may be designed with a separate area for these activities to reduce interference with the operators.

In some dispatch centers, trouble calls are routed directly to the control room. Responding to these may be a part of the operators' job, but it is a distraction from their main tasks. It is also one that is likely to peak just when their other duties do, for example when there are unplanned outages to deal with. In this case, the source of distraction can be eliminated by job redesign or transferring the responsibility for answering trouble calls to someone else, somewhere else.

1.3.2 Availability/Adequacy of Equipment, Tools, and Supplies

Where tools or equipment are required to support task performance, deficiencies in either their availability or adequacy may negatively impact task performance. For example, deficient instrumentation may lead to delays in detecting and correcting a malfunctioning component. In a simple example, elevated equipment in a station is often operated with insulating sticks. If the stick is unavailable, the operation cannot be performed. If the available stick is too short, the operator may have to assume a position where he does not have a good view of what the end of the stick is doing, or set himself up for a fall by trying to use the stick from a stepladder. A more serious concern is the kind of devices used for detecting whether lines or equipment is energized (voltage detectors for live working). Devices that give a numerical readout of detected voltages seem to be involved in fewer incidents than those that give only an auditory indication. More than one utility has adopted the more sophisticated devices after an incident in which a crew failed to hear – or failed to heed – an auditory indication.

1.3.3 Work Hours and Other Time-related Factors

Shift work can affect fatigue and alertness which in turn affect performance as discussed earlier (see Section 1.1.3). In particular, shift work affects circadian rhythms and the worker's ability to obtain the quantity of good-quality sleep required to maintain optimal performance.

Shift Work and Alertness

Circadian Rhythms, Body Temperature and Alertness

The term "circadian rhythm" refers to a daily fluctuation in body temperature and other physiological parameters. The maximum peak-to-trough difference in temperature is about 2-3°F. Circadian rhythms are apparently regulated principally by the light-dark cycle (body temperature is higher during the day and lower at night) and by the timing and content of meals. Circadian rhythms are of interest for two reasons:

Alertness tends to be positively correlated with body temperature. Accident rates for long-haul trucking and other industries engaged in round the clock operations are higher between 1 and 5 AM, which correlates with the low point in the temperature cycle. Performance of simple tasks also tends to correlate positively with body temperature, better when it is high and poorer when it is low. However, performance on some complex, memory intensive tasks is counter-cyclic, better in the early morning hours when the temperature is low (Embry *et al*. 1994, p. 117)

The quality (restfulness) of sleep tends to be better during the low temperature parts of the cycle. That is, for a "day-adapted" worker, sleep taken between 7 and 11 AM does not have the same restorative power as sleep taken between 1 and 5 AM.

Shift work tends to disrupt the normal circadian rhythm, flattening out the temperature cycle (reducing the peak-to-trough difference) and decoupling it from the rhythms of other parameters.

Timing of Meals and Alertness

There is no consensus on the effect of specific content of meals on patterns of alertness. However, the timing of meals while on shift may also be expected to affect performance: a large meal before the early morning low in the circadian rhythm may exacerbate the normal reduction in alertness at this time.

Effects of Sleep Deprivation

The major and best documented ill effects of shift work on performance relate to inadequate sleep. The average adult needs 6 – 8 hours of sleep in 24. Some people can function more or less adequately – not at their best, but adequately – on 4, for relatively short periods of time (days, not months). A worker who misses 2-3 hours of needed sleep in 24 can manage. However, this sleep debt appears to accumulate: by the end of a week of 2-3 hour debts, the individual is seldom maximally alert, and decrements in mental performance become evident, including reduced attention to detail. To some extent this can be compensated for by taking more time to perform a task correctly. An additional consequence of sleep loss is that it lowers mood and motivation and reduces morale and initiative (Krueger, 1994).

Shift workers have difficulty getting enough sleep; their sleep schedule is shifted relative to the society at large, and the sleep and activity cycles of the other members of their immediate family, both of which tend to reduce the hours available for sleeping. In addition, because they must sleep during daylight hours (often in not-completely-dark, and not-completely-quiet environments), it is harder for shift workers to get to sleep during the day, and the sleep that they do get is not of good quality.

Shift work is common in utility work, nearly universal for plant and control center workers, but less common for field workers. Shift work is, on balance, probably not good for you, and probably detrimental to performance as well. It is nonetheless a fact of life in our industry. Its effects can be mitigated by the way the shifts are scheduled.

Shift Schedules

Shift work can be scheduled in a variety of ways:

- **Permanent Shifts**. With “permanent shifts” some employees always work days some always work nights. This is thought to allow the circadian rhythms to adapt, though the permanent night worker still has difficulty getting enough hours of sleep.
- **Rotating Shifts**. This is a more common approach, where each worker works on all three (or two) shifts and rotates among them. The rotation can be either rapid (a few days on each shift) or long (several weeks on each). The long rotations are thought to allow a degree of adaptation (shifting as well as flattening of the circadian rhythms); the short rotations are intended to prevent such shifting. Current wisdom tends to favor the short rotations (Krueger, 1994).

- **Direction.** An additional variable is the "direction" of shift rotation, either "forward" (days, evenings, nights) or "backward" (nights, evenings, days). There is clear evidence that the forward rotation is superior (Krueger, 1994, Tepas, Paley, and Popkin, 1997).

Shift Length

It is reasonable to expect that the length of a shift would affect performance. The 12-hour shift is popular in utility control centers, primarily because it incorporates large blocks of days off. Experience with 12-hour shifts in the nuclear industry and utility control rooms has been generally positive (Baker 1995), although a study of process plant operators on 12-hour shifts quoted in Embrey, *et al.* (1994, p. 115) showed measurable decrements on tests of performance and alertness (NIOSH Fatigue Test Battery) near the end of the shift, even after seven months of adaptation to the schedule. It was not reported that the test results were reflected in job performance, but there were reports of sleep reduction and disruption of other personal activity on the 12-hour workdays. Twelve-hour shifts are likely to have greater effects where the work involves more physical exertion, e.g., line workers, but so far most of them retain the 8-hour shift structure.

1.3.4 Quality of Supervision

The supervisor is the front-line workers' primary interface with the rest of the organization. He or she is often the person charged with scheduling work and with ensuring that the required tools and supplies are available and in good condition. Quality of supervision is important for transmitting policies and procedures; for monitoring adherence to them; and for constantly reinforcing their importance. The supervisor is also usually the channel through which the workers' concerns and suggestions are transmitted up the chain of command. Finally, as an authority figure, the supervisor serves as a role model for his employees. All of these considerations indicate the important effect that the quality of supervision has on task performance. When errors occur, a frequent observation in the incident reports analyzed as part of an earlier study (Beare et al. 2004), is that the required procedures were not followed. Such non-compliance may be a sign that supervision was absent or lax in ensuring that procedures are followed to the letter.

1.3.5 Resource Allocation/Staffing

With the advent of deregulation, most utilities are managed for maximum return on investment. This has led to cost-cutting on a large scale, typically by a combination of deferring infrastructure maintenance and upgrading, reductions in personnel, and an increased emphasis on production: "doing more with less." Logically, these trends might be expected to contribute to an increase in error rates, though indirectly and only after their effects have had a while to accumulate.

Cost cutting has also led to a reduction in personnel in almost every job category, and frequently the most experienced personnel are among the first to go. In addition, the most effective system operators are often siphoned off by newly formed ISOs. Even without the loss of experience, reductions in numbers lead to increased workload and often increased stress on remaining personnel. Both of these are thought to be precursors to error: they do not directly cause errors but weaken the defenses against them, thus making their occurrence more likely.

Inadequate staffing limits the reserve available to cope with unanticipated situations, and routinely results in involuntary overtime. The amount of involuntary overtime is a measure of when "lean staffing" becomes too lean and can be a source of stress on individuals if excessive. Involuntary overtime has been identified as one of the "leading indicators" of human performance in EPRI *"Leading Indicators"* work (to be discussed in Section 2.3).

A very important side effect of inadequate staffing that may affect the likelihood of error is that short-staffing makes it difficult to "free-up" personnel to attend the training necessary to maintain and increase their skills. Training time is generally among the early casualties of inadequate staffing.

1.4 Cultural and Social Factors

Cultural and social factors determine the context in which job performance takes place and thus may affect the likelihood of errors or incidents either directly or indirectly through their impact on other PSFs.

Culture encompasses beliefs, values, and habitual ways of thinking and approaching *all* aspects of doing business. Culture is reflected in stated goals, styles of management (proactive vs. reactive, autocratic vs. consultative), the way employees are treated, openness to new ideas, and others. The concept of "safety culture" and several cultural aspects of high reliability organizations are discussed in greater detail in Section 2.4. In this section we discuss a few specific cultural/social PSFs identified in the literature that may increase or decrease the probability of committing an error. They are listed in Table 1-4.

Table 1-4
Organization and Social Performance Shaping Factors

Organizational Structure and Communications • Changes in authority, responsibility • Management Communications Management Policies • Rewards/Recognition/Benefits Culture: Group identifications/group norms • Action by supervisors, coworkers, and union representatives
Source: Adapted from Petersen (1996) and Embrey, Kontogiannis, & Green (1994).

1.4.1 Organizational Structure and Communications

In the past decade, most utilities have undergone changes in management structure brought about by downsizing, mergers and acquisitions, or the splitting-off of entire areas of operations e.g., forming separate companies for generation, transmission, and distribution.

In addition, the emergence of ISOs has resulted in a situation in which an extra-organizational authority may control a significant part of a utility's day-to-day operations. As a result of both of these trends, lines of authority, responsibility, and communication have generally become more complicated, and may not be as clear as they should be. This lack of clarity about who's in charge may create a situation where errors are more likely to occur.

Communication is one of management's primary tools and an important PSF. The effectiveness with which managers communicate their expectations and reinforce such communications with occasional repetition and visible actions affects employee performance. Although in a sense actions speak louder than words, the words are also necessary, as properly structured communications are less liable to multiple interpretations than are actions alone.

It is also critical that management encourage communication up the chain of command and have multiple channels for receiving feedback from the workforce. One of the advantages of the often-advocated "management by walking around" is that it provides opportunities for line level workers to communicate their concerns directly to more senior management.

1.4.2 Management Policies

Management policies directly affect the performance of the operational level of an organization in numerous ways and may indeed be the key for reducing operating errors. The effects of management policies are discussed in many places in this report. Resource allocation was discussed under Staffing earlier. Here we single out for attention rewards and recognition.

Rewards/Recognition/Benefits

An effective management uses reward and recognition to buttress communications delivered by other means. These are monitored quite closely by employees as indications of what management's true priorities are. Because of this, care must be taken to ensure that their distribution is perceived to be in line with stated goals and policies. For example, it is common practice to tie part of a yearly performance incentive payment to meeting organizational goals, which may include the number of errors reported. This is an effective way of communicating the importance attached to the goal, although it may have the undesired effect of discouraging the reporting of such incidents, thus depriving the organization of the opportunity to learn from them.

1.4.3 Culture: Group Identifications and Group Norms

Group identifications and group norms may influence the probability of error through attitudes associated with group membership, such as risk taking and “macho” described above. Other important group norms are reflected in the reporting of near misses or errors that might otherwise go undetected. Although the drawbacks of “macho” attitude have been discussed, the more positively stated “can-do” attitude may also result in inhibiting communications about problems, or in an individual’s taking on more than he or she can comfortably handle.

Actions by Supervisors, Coworkers, and Union Representatives

The behaviors and attitudes of supervisors and coworkers contribute to what is considered acceptable behavior by the organization or workgroup. Supervisors and/or coworkers may create an atmosphere that encourages either punctilious observation of all procedures or risk taking, encourages or discourages the asking of questions, precision or casualness in communications, etc. A union may act in ways that encourage or discourage the assumption of personal responsibility, or exhibit a distrust of management that inhibits the free flow of communications.

1.5 Combinations of PSFs

The last four sections have, for convenience, discussed PSFs in four discrete groupings.

In fact, there are always multiple PSFs at play in real-world situations. It is generally accepted that PSFs interact, so that the detrimental effect of negative values on two factors is probably larger than the sum of the effects of either one of them alone. “Good” values of some PSFs can also act to offset “poor” values on others. Workers generally try to compensate as best they can for factors that negatively affect performance. Unfortunately the combined effect of negative PSFs sometimes make demands that exceed the resources the operator can devote to them and still perform the task accurately.

In Section 2 we will examine ways in which the PSFs can be managed to minimize the risk of error. In that section we will also discuss error prevention programs that combine many individual elements needed to combat errors. But first, in the section that follows, we provide a fuller description of an integrated model that is the basis for many important insights into how errors occur and how they may be prevented.

1.6 The S-R-K Approach to Understanding Human Error

In the previous sections, we have identified a variety of factors that influence (i.e., increase or decrease) the likelihood that an error will occur. This section represents a fuller examination of the information-processing characteristic of tasks that was described briefly in Section 1.2. We describe first the Skill-Rule-Knowledge (SRK) hierarchy of tasks and apply it to actual task performance. We then describe an error modeling system that relates causes of errors to the SRK hierarchy.

1.6.1 The Skill-Rule-Knowledge (SRK) Hierarchy

The Skill-Rule-Knowledge taxonomy was developed by Jens Rasmussen in the mid 1970s and early 1980s to describe the kinds of tasks or behaviors performed by operators in industrial settings, particularly process plants where the operator's duty is to control an ongoing continuous process that employs complex technology that the operator may not fully understand. Rasmussen's taxonomy was embraced by researchers seeking ways to understand and improve the performance of nuclear plant operators in the wake of the Three Mile Island accident in 1979, and has diffused from there into the training departments of many utilities.

Three Levels of Performance

As summarized by Reason (1990, p. 43), Rasmussen's model describes three levels or mechanisms of human performance:

- **Skill-based**: At the skill-based level, human performance is governed by stored patterns of preprogrammed instructions present as analogue structures in a time-space domain.

  Driving is an example of a very well practiced skill-based behavior. Steering and maintaining a set following distance from the car ahead require appropriately timed actions that must be well coordinated with the external environment that is ever-changing. Although it is a very complicated behavior, driving exhibits an important characteristic of skill-based behavior: it can be done successfully without a great deal of conscious attention. This is not to say that attention is not required, but rather that it is done automatically and the appropriate behaviors are evoked without being consciously intended, so long as everything proceeds in a routine way through familiar territory. You can drive home on "automatic pilot," but you can't traverse an unfamiliar route that way.

- **Rule-based:** The rule-based level of performance is applicable to tackling familiar problems in which solutions are governed by stored rules (referred to as productions) of the type:

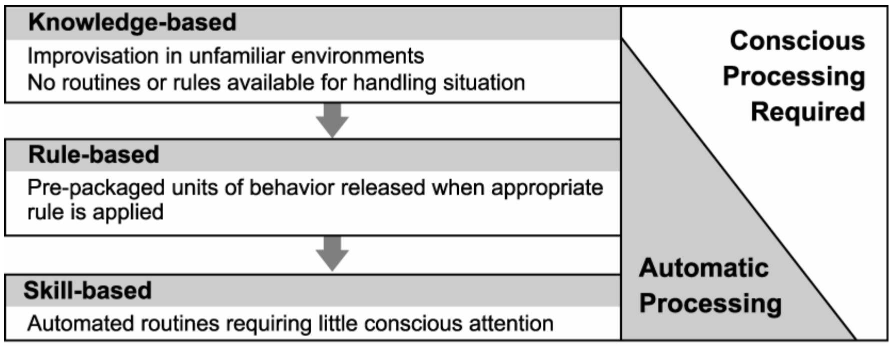
  "if (state), then (diagnosis)," or

  "if (state), then (remedial action)"

  Here errors are typically associated with the misclassification of situations leading to the application of the wrong rule or with the incorrect recall of procedures.

- **Knowledge-based:** The knowledge-based level comes into play in novel situations for which actions must be planned on-line, using conscious analytical processes and stored knowledge. Errors at this level arise from resource limitations ("bounded rationality") and incomplete or incorrect knowledge. With increasing expertise the primary focus of control moves from the knowledge-based toward the skill-based levels; but all three levels can co-exist at any one time. (Reason, 1990, p. 43)

The three levels of information processing differ in the amount of conscious processing required, as illustrated in Figure 1-2 below.



Source: Adapted from Figure 2.4 of Embrey, Kontogiannis, & Green (1994, p. 71). Copyright 1994 by the American Institute of Chemical Engineers and reproduced by permission of AIChE.

Figure 1-2
Conscious and Automatic Information Processing at Different Levels of Performance

The detailed execution of skill-based behavior is largely unconscious, controlled by automated routines that require little conscious attention. Where sets of several routines are required, they become linked or melded together through the process of repetition. Conscious attention is applied to check on the progress of the unconscious routines, and redirect them if necessary. This conscious attention is especially critical in cases where the usual (most frequent) linkage is inappropriate. This is illustrated by an experience most of us have had while driving. The same street that takes me to church also leads to my children's school, except I turn off a block earlier to go to the school. If I am preoccupied with some problem while driving to church, I will frequently begin to turn off toward the school. I have in effect forgotten to override the usual linkage. This kind of mistake is called a "slip." An important characteristic of such slips is that they are usually detected almost immediately.

At the other extreme, knowledge-based behavior requires a high level of conscious attention. The person must improvise his or her response to unfamiliar environments or situations, without the benefit of rules or routines. Knowledge-based behavior tends to be slow because a lot of information must be shuffled in and out of the limited capacity buffer of conscious attention. It is also perceived as difficult.

Rule-based behavior lies in the middle, requiring a mix of conscious effort and unconscious responses.

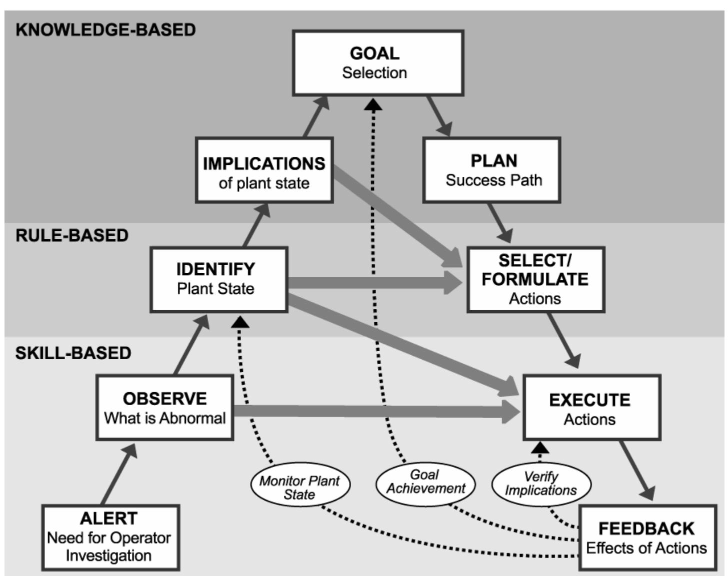
Effect of Practice on Level of Performance

Practice allows control of performance to be moved down to lower levels. At first a well-trained but novice practitioner has much knowledge, and is often supplied with the most commonly used rules. As the person gains experience, he or she begins to fit his knowledge into the supplied rules, and perhaps to develop additional rules of his or her own. The application of rules rather than operating from first principles makes diagnosis easier and much more rapid. This process changes problem "solving" to problem "recognition," where each recognized problem is associated with a set of rules for its resolution. As we gain experience in using the rules, the process becomes more automated, requiring less conscious processing. Eventually, with enough practice, we do not have to consciously recall the rule and syllogistically deduce IF X THEN Y. We simply recognize that X means Y. The same thing happens on the response side with appropriate practice: when we recognize Y, we know immediately that we should do Z. Eventually we may get to the point where perception of X simply evokes the response Z, without having to "think about it" at all, although most real-world tasks probably do not evolve to this point.

As stated in Section 2.2.2, information processing is critically dependent on memory. Human memory is both very powerful and very fallible. Although long-term memory is limitless, short term memory uses a rather small "buffer" that is also used by conscious attention. Delegating control of an activity to a lower level in the SRK hierarchy of processing frees up this scarce resource, and has the advantage of greatly increasing the speed at which information can be processed.

Shifting Between Levels within a Given Task

Rasmussen makes the point that there is constant shifting from one level of performance to another, as shown in Figure 1-3. This so-called "stepladder model" illustrates how levels of processing can move "up the ladder" to knowledge-based processing and then down again to the skilled routines with which actions are executed.



Source: Adapted from Figure 2.7 of Embrey, Kontogiannis, & Green (1994, p. 77), Copyright 1994 by the American Institute of Chemical Engineers and reproduced by permission of AIChE.

Figure 1-3
Rasmussen's "Stepladder" Model of Levels of Performance

Frequent and entirely legitimate "shortcuts" are indicated by the heavy arrows in the figure. In practice, the shortcuts are used more frequently than the full processing cycle. For example, response to a typical event moves from detection of some condition triggering investigation (an *alert*) to *observation* (a skill-based activity) to an *identification* of plant state, where the plant state is usually identified by application of rules if the IF-THEN type. For the well-trained operator with an extensive repertoire of rules (or a set of symptom-based procedures in which the rules are codified) identification of plant state frequently leads to *selection* of one or a sequence of actions, again selected by application of an IF-THEN rule. This is indicated by the heavy arrow in the figure connecting the "identify" and "select" boxes.

For unfamiliar problems, when the available symptoms do not match any of the available rules, the operator moves into the knowledge-based problem solving mode where he or she determines what the observations imply vis-à-vis the probable state of the process. The *implications* may be associated with a set of recovery actions (the heavy arrow from "implications" to "select actions"); if not, the operator may have to determine the appropriate *goal* in the situation and create a generalized *plan* for achieving it. The plan is then resolved into a set of (rule based) actions from those available (to accomplish X do Y and Z). The *actions* (starting pumps, shutting down some systems, etc.) involving skill-based routines are then executed in sequence.

Task Performance in Practice

In practice, the majority of performance involves only the two lower levels, rule-based and skill-based. Rapid shifting between these two levels is probably the rule. We believe switching is planned at the rule-based level, and performed largely at the skill-based level. None of this is to say that those who plan and execute switching lack knowledge, but that they possess a set of rules that is adequate to deal with switching activities and there is rarely any need to revert to first principles.

Knowledge-based processing is used primarily for problem solving where the symptoms do not map easily onto a set of IF-THEN rules. Although being "knowledgeable" is a desirable trait in an operator, knowledge-based processing is undesirable in real time operations. It is slow, "effortful," resource limited, and its products are apt to be incorrect, at least on the first iteration. Because of these limitations, knowledge-based processing is usually undertaken only after attempts to fit the problem into a familiar frame for which rules exist have failed.

Recourse to knowledge-based problem solving is seldom necessary in practical situations. When we speak of a "skilled" operator or practitioner, we mean one who possesses a large set of accurate rules that come readily to mind, and is able to select and apply the appropriate rule rapidly and relatively effortlessly. The skilled operator knows what to attend to and has appropriate rules for dealing with any situation he or she is likely to encounter.

The true "expert" possesses an even larger set of these rules and also has an appreciation of when a situation is sufficiently different that the usual rules do not apply. That is, the expert knows when it is appropriate to move into the knowledge-based problem solving mode rather than force-fitting the situation to one of the rules he or she has available. The expert is likely to possess a more detailed and accurate model of the system and the processes by which it and its parts operate, thus making him or her more effective than the skilled operator once in the knowledge-based mode.

1.6.2 The Generic Error Modeling System (GEMS)

In his 1990 book *Human Error*, James Reason describes his Generic Error Modeling System (GEMS), which relates causes of errors to Rasmussen's Skill-Rule-Knowledge hierarchy. GEMS adds failure paths and common failure modes to the SRK model.

Error Types at Each Level of Performance

The GEMS model relates the common kinds of errors observed to the Rasmussen Skill, Rule, and Knowledge categories, as shown in Table 1-5 below.

Table 1-5
Errors in Skill-, Rule-, and Knowledge-Based Tasks

Performance Level	Error Type	Error Causes
Skill-based	Slips and lapses	Omission of required attentional checks due to forgetting, preoccupation, or distraction
Rule-Based	Rule-based mistakes	Selection of an inappropriate rule
Knowledge-based	Knowledge-based mistakes	Lack of knowledge, focus on wrong aspect of the problem, excessive mental processing demands, etc.
Source: Based on Reason (1990, Table 3-1) and Embrey, *et al*. (1994)		

In previous studies we have noted that the majority of errors in planning switching and in executing it, whether in the field or via SCADA, seem to be slips and lapses, rather than rule-based mistakes (application of an incorrect rule). Although the planning of switching is mostly performed at the rule-based level, the majority of the kinds of errors observed – omitted steps, incorrect device numbers – look much more like slips and lapses than the results of using the wrong rule.

Table 1-6 below shows selected characteristics of different types of errors, including:

- Activity Type (routine or problem-solving)
- Control (automatic or conscious)
- Focus of attention (directed or distracted)
- Error form (predictable or variable)
- Ease of detection (easy or difficult)

For each error type the nature of the task activity and typical errors are described:

Table 1-6
Selected Characteristics of Common Error Types

	Skill-Based Slips	Rule-Based Mistakes	Knowledge-Based Mistakes
Activity Performed	routine actions	problem solving	
Cognitive Control	mainly automatic processes (schemata)	(rules)	resource-limited conscious processes
Focus of Attention	on something other than present task	directed at problem-related issues	
Error Forms (kinds of errors made)	largely predictable 'strong-but wrong' error forms (actions)	(rules)	variable
Error Detection	usually fairly rapid	hard, and often only achieved with help from others	

Source: Adapted from Reason, 1987, 1990.

Skill-Based Slips

For tasks performed at the skill-based level of performance, errors arise mostly during routine, well-practiced actions. Control of the actions is in a mostly automatic mode, that is to say proceeding with only occasional checks by conscious attention. These errors are thought to occur because a required conscious check on the progress of the process was omitted, perhaps because the operator was distracted or otherwise not focused on the task at hand.

The kinds of error ("error forms" in the table's left hand column) are predictable, to wit: the intended behavior may be executed on a wrong (i.e., unintended) object (a slip) or simply not done at all (a lapse). Both of these are much more common than an unintended behavior being executed on the intended object. Detection of slips and lapses by the person who made them is very likely, and usually occurs within seconds, then attention is returned to the task.

Because of their importance for switching, a more detailed discussion of how skill-based errors arise is provided later in this section.

Rule-Based Mistakes

For tasks performed at the rule-based level, errors may occur during routine tasks but occur most frequently when the person is engaged in some form of interpretation or problem solving activity (such as planning switching) where application of this mode of processing is most efficient. Control of the task is usually automatic in the sense that the appropriate rule is recognized or simply applied without a conscious effort to determine which is appropriate. Errors occur when an inappropriate rule is applied.

For rule-based errors the attention of the person was usually directed at the task at hand, though he or she may have attended to some aspect of it that evoked the inappropriate rule rather than the correct one, or simply not known or been able to recall the correct rule. These errors are predictable in the sense that it is fairly easy to deduce after the fact what features of the situation led to the selection of the rule used, or that the rule used was the most frequently or recently used one.

More often than not it is difficult for the person who made the error to detect it because he or she is likely to repeat the same mental processing that led to the incorrect choice in the first place. However, rule-based mistakes are usually picked up fairly quickly by a second person reviewing the work or performing it independently

Knowledge-Based Mistakes

Knowledge-based errors usually occur during some sort of problem solving activity of sufficient novelty or complexity to require that this mode of processing be used. The person's attention is focused on the problem at hand, though perhaps not on the most salient or diagnostic aspect of it; if the person knew those, he or she would probably revert to some other mode of processing. The variety of errors in this mode is very large, and difficult to predict. Again it is usually very difficult for the person who made the error to detect that an error has been made.

How Skill-Based Errors arise

As we have stated, the physical actions required for real-world tasks are performed mostly at the skill-based level. Processing at this level is largely automatic, requiring little conscious attention. Such tasks are handled as a series of chained schema, which may be thought of as (usually) short programs or subroutines that are activated from a larger routine that coordinates the individual subroutines. The calling routine itself may be consciously created (at the rule-based level of processing) or it too may be largely automatic if the task is sufficiently well practiced.

The schema responsible for actually performing the actions required have several interesting properties that may lead to skill-based errors:

- **Failure of required checks**. The schemata for executing a task are related to one another by the higher-level, initiating routine in conjunction with environmental cues. The calling routine usually has several "attentional," that is, conscious, checks on how well the program is running, i.e., whether it is still on the expected course to the intended goal state. However, the chain of schemata can and often *will* run to its end even if these checks are omitted. The omission of such "attentional checks" is believed to be the cause of most errors that would be classified as slips, which includes many switching errors.
- **Selection of wrong routine.** Schemata may be activated by both the programmed intention and by environmental cues. It is possible for environmental cues (e.g., the presence of an object that is the usual subject or target of the behavior) to activate the wrong routine, especially if that routine is very familiar and has been recently performed. This can become a problem when a well practiced routine has been (or should be) altered slightly, so the familiar stimuli will result in a slightly different response.

- **Application of intended routine to wrong target.** Similarly the correct routine may be activated but the schemata may be applied to an incorrect object. In switching “operated wrong control” is the most common kind of error; many of these errors can plausibly be explained as failure to act on the correct target. The conscious verification of the appropriate target is especially important in switching because most switches look alike, so any one is an appropriate target as far as the “operate switch” schemata is concerned.

- **Minimal processing of environmental cues**. The processing of environmental cues is often determined by one or two of their most obvious characteristic, i.e., by the characteristics that require the least processing or effort to identify. This minimum processing is very efficient in the use of cognitive resources (it probably aided survival for our ancestors living in a world of large predators). But it is practically guaranteed to lead to errors in switching because all labels are designed to be nearly identical, with the critical information differentiating correct from incorrect conveyed by one or two characters. Thus a consciously adopted strategy of complete processing is required for switching activities.

- **Incorrect selection of schemata based on recency or frequency.** Like conscious rules, schemata are products of memory, and exhibit two characteristics of associative memory, namely recency and frequency effects. This means that in the absence of conscious direction to the contrary, if there are several possible schemata that may perform the desired action, the most recently executed or the most frequently executed is likely to be invoked. This becomes a problem when, for example, switches do not operate in the same way as the majority of others, or do not exhibit the expected relation to other cues (what human factors engineers called “violation of stereotype”).

- **Incorrect target selection due to memory decay or interference.** To characterize the majority of switching errors as slips and lapses is to agree with the common assessment that they are the result of “loss of focus.” However, errors can also arise when the object of action is forgotten or inaccurately remembered. Errors in which the numeric label of the correct control differed from that of the control actually operated by a single digit are fairly common.

    Memory decay. Although many memories seem permanent, newly learned material is retained in short term memory, and moved into long-term memory, through a process that involves rehearsal i.e., repeating the item to yourself (this has been called subvocalization, though some of us move our lips). This is especially true for abstract information such as switch numbers, as opposed to sensory or emotionally-loaded material. If not rehearsed, the material will decay very rapidly. Many activities associated with switching, such as reviewing instructions with the dispatcher and checking them against a one-line diagram, aid in the necessary rehearsal.

    Forgetting the target of an action schemata may let the schemata fasten on its most frequent object, and run to completion if not consciously suspended. Fortunately, we are often aware that we have forgotten something we “knew” a moment ago. However, memory is also subject to many kinds of distortion, of which we are often *not* aware. These distortions may be induced by characteristics which are nearly unavoidable in the environment in which switching is performed. The most important of these sources of distortion is interference.

Memory interference. Although many switch numbers seem to be easily remembered, especially if you understand what is to be accomplished, switching is performed in an environment filled with very similar stimuli (other control numbers) whose processing is likely to interfere with maintaining an accurate memory.

The laboratory procedure for demonstrating memory interference is to have a subject learn a list of words or symbols (letters, pictographs) to some criterion, then have him or her read a second list, and then to test for recall of the first list. The test can be done in a number of ways. The subject can be asked to write down as many of the first list as possible, or he can be shown a third list and asked to simply identify those items that were also on the first list. When this is done two results are common: some of the items on the first list are simply forgotten (neither reproduced nor recognized in the third list) and some of the items from the second list appear as intrusions, i.e., are produced or identified as belonging to the first list. People are, in general, much less aware that a memory has become distorted, as opposed to “forgotten” outright.

Reading a set of labels to identify the control you are looking for is very similar to the laboratory procedure for inducing interference (i.e. there is a correct or target item and a large number of similar distracter items), and likely to produce the same result. If you are trying to rehearse a switch number and read the number engraved on a label, you are applying the same limited attentional resources to the processing of both, and the two sets of symbols are likely to interfere with one another. Reliance on memory rather than checking the instructions in this situation is especially likely to result in an error.

2
ERROR PREVENTION TOOLS AND PROGRAMS

This section presents information about error prevention tools, strategies, and programs that are used in a variety of industries. The literature presents us with a range of possibilities, varying from very specific error prevention techniques to broadly-based programs and strategies. Error prevention techniques are sometimes referred to as “barriers.” A barrier is any tool or method that will either prevent an error from occurring or, if an error does occur, prevent it from having adverse consequences. Humans are fallible and errors will occur. What we have to strive for is an environment where individual errors or failures will not have catastrophic consequences.

We start in Sections 2.1 and 2.2 by describing error-prevention strategies that specifically address person- and task-related PSFs respectively. Workplace-related factors are normally addressed in the context of holistic organizational strategies and programs. For this reason, after brief mention of some specific workplace-related strategies Section 2.3 briefly goes on to describes integrated approaches to error prevention that have been used successfully by different organizations and industries. Some of these programs include a socio-cultural dimension in their approach to error prevention. Because of its emerging importance Section 2.4 focuses specifically on recent studies that describe cultural characteristics needed by organizations to manage complex, hazardous operations successfully. Finally, Section 2.5 summarizes the different approaches and offers some preliminary suggestions for combining them in an effective error prevention program.

2.1 Person-Related Tools/Strategies

Person-centered approaches to error prevention attempt to ensure that individual workers and the work team are equipped for effective, safe, and error free performance. Table 2-1 summarizes these approaches which include selection and training activities, supervision, and discipline.

Table 2-1
Person-related Methods for Achieving Error Management Goals

Error management goal	Methods to achieve the goal
Minimize the error liability of the individual or team.	• Selection (for required abilities and traits) • Training (for required knowledge/skill, error prevention techniques, and adapting to shift work) • Supervision (for coaching/reinforcing appropriate behaviors and recognition/mitigation of transient states) • Avoidance of goal conflicts • Discipline (for enforcing appropriate behavior)

2.1.1 Selection

All workers are selected for the positions they occupy within an organization. Selection criteria usually include educational and experience requirements. The selection process may also include some assessment of the degree to which the applicants possess the physical and mental abilities required for the job, and an assessment of their temperamental suitability for the work.

Ability, aptitude, and temperamental requirements are usually derived from an analysis of traits possessed by outstanding performers. When these have been identified, objective evaluations of job candidates can be based on testing for specific abilities and an assessment of pertinent cognitive and personality factors. Table 2-2 summarizes the qualities to look for in a system operator as developed by one psychological consultant based on studies of the traits of successful system operators (Williamson, 2003).

Table 2-2
Profile of Successful System Operators

- Above average intelligence measured by verbal and math scores
- Skill in critical thinking and analytical reasoning
- Interest in and desire to apply technical knowledge (how things work) and data analysis
- Interest in reading and documentation
- Enjoyment working with visual representations such as maps and diagrams
- Extroverted, positive outlook
- Enjoyment working in a team environment
- Effective communicators
- Decisive and results oriented
- High level of tolerance for frustration and stress of fast-paced environment

Adapted from G.A. Williamson, "Success Factors in System Operator Selection" presented at the EPRI 7th Annual Power Switching Safety and Reliability Conference, Columbus, Ohio, October 2003.

2.1.2 Training

Training as a technique to mitigate errors includes not only training for task performance but training in error avoidance techniques and training to handle the problems associated with shift work.

Training for Task Performance

Insofar as errors may arise as a result of inadequate employee skills or knowledge, training in the tasks to be performed, together with a formal process of evaluation, should be 'givens' among error prevention measures. Moreover, training using high fidelity simulators has the additional benefit of developing confidence in the ability to do the job which is an effective antidote to stress.

Training in the knowledge and skill needed to perform a given set of tasks is not a once-only requirement. Knowledge that is not used will "decay:" that is, it will become unavailable or become muddled when details and sequences are lost, or parts of other training intrude. Thus infrequently applied knowledge or skills must be refreshed periodically. Refresher training of frequently practiced skills is also valuable since it provides an opportunity to detect and correct any bad habits or shortcuts that may have crept into the performance of routine tasks.

Training to Recognize Error-Likely Situations

Training programs that help employees to recognize error-likely situations offer additional opportunities to reduce or prevent errors. A partial list of such situations is shown in Table 2-3 below.

Such training programs inform employees about performance shaping factors, including human limitations, and ways in which they can to some degree be accommodated. Training to recognize error-likely situations is a component of programmatic approaches to performance enhancement such as INPO's Human Performance Enhancement System.

Table 2-3
Error-Likely Situations

<u>Person-Related</u> • Complacency -- reduction in vigilance • Tired/fatigued • Uncomfortable location/posture required	**<u>Workplace-Related</u>** • Task interruption • Time pressure/hurried
<u>Task-Related</u> • Routine but critical tasks • Repetitive/boring task • Departure from a well-established routine • Performing two or more tasks simultaneously • Unexpected encounter with a system or component interlock • Insufficient indications of status • Steps of a procedure near the end of a sequence of actions • Task with a large number of discrete steps • Reading a label -- especially for components, cabinets, and doors • Vague procedures • Procedure step with a large amount of embedded information • Transfer problems: old cue, new responses	**<u>Time Related</u>** • First day of work after several days off • Midnight shift
Source: Adapted from *Self Checking.* Good Practice OE-908, INPO 92-010. Institute of Nuclear Power Operations, 1992.	

If error-likely situations are detected, additional steps to prevent errors from occurring can be taken. Training about error-likely situations should also include training in monitoring the status of yourself and coworkers for signs of impairment such as fatigue, preoccupation, haste, or goal conflicts that are frequent precursors of slips and lapses. (See US Coast Guard, 1998). Training in how to recognize situations in which performance (your own or your coworker's) may be degraded and what actions to take can make a valuable contribution to error prevention.

Training to Avoid Errors

A substantial portion of the errors in the execution of switching tasks appears to be simple slips and lapses, the short-lived mental states that Reason (1997, p. 129) refers to as "…the last and least manageable links in the [error] chain." Techniques that may offer increased resistance to this type of error include the use of self-checking routines such as STAR or the "six steps of switching" (see Section 2.2). On-going training to reinforce these techniques is an important contributor to error prevention.

Training in Lessons Learned

Lessons learned from incidents and near misses are an important training resource and when suitably presented can help employees to avoid future errors. Reports of incidents at the utility itself are the richest resource, but genericized incidents, when appropriately presented, can also be used to assure that such an event would not happen here. EPRI's incident-based training modules (in progress) were designed for just this purpose. The nuclear and commercial aviation industries routinely include simulations of incidents that have occurred elsewhere in the industry as part of their required training.

Training to Ameliorate the Effects of Shift Work

The potentially harmful effects of shift work were discussed as a workplace PSF in Section 1. Employees should be provided with training on the effects of circadian rhythms and, more specifically, on ways to enhance the quality and quantity of sleep so that they can optimize their performance when working rotating shifts.

The military and the airlines have developed detailed and effective recommendations for improving the sleep of shift workers. Application of a few simple rules such as ensuring that the place where the shift worker sleeps during the day is quiet and, above all, *dark* can help improve the quantity of sleep obtained. Modifications in the content and timing of meals may also improve the quantity and quality of sleep.

A simple strategy that may have some impact on the quality of daytime sleep is to avoid bright sunlight between getting off shift and going home to sleep. Using sunglasses during the morning commute home reduces the effect of bright light in making one less sleepy. Taking caffeine before leaving for home may interfere with the ability to get to sleep once at home. Although alcohol may indeed make it easier to get to sleep, significant alcohol consumption tends to reduce the quality of sleep that is obtained.

The author of an NRC study of the performance effects of a simulated 12-hour control room shift recommended that an effective training program in sleep would be a useful addition to any shift schedule that involves successive blocks of night shifts (Baker, 1995). The recommended sleep strategy is described as "anchor sleep" (Minors and Waterhouse 1981, as quoted in Baker, 1995, p. 119). In this pattern, workers take a large portion of their sleep during daytime hours even on their days off, maintaining the rhythm established when working nights. This strategy is useful where there are successive blocks of night work broken by days off. This is not a natural sleeping pattern: workers typically revert to their habitual sleep patterns on their days off, mostly to achieve synchrony with the normal social activities of their families, who are not shift workers.

Another strategy mentioned by Baker for coping with progressive 8-hour shift rotation is to go to bed and get up later as the day of transition from the evening shift to the night shift approaches, thus allowing a sort of pre-adaptation to the sleep pattern enforced by the night shift. He again notes that workers seldom spontaneously adopt this strategy.

2.1.3 Supervision

Traditional safety management techniques (e.g., Thomen, 1991) focus on increasing safety awareness, training the desired safety behaviors, and constantly reinforcing them through active supervision. Thomen envisions a supervisor who is more or less continually present on the worksite and spends much of his time actually *supervising* – conveying management expectations to his workers, directing, consulting, evaluating, and coaching.

Whether on the site or tucked away back at the office, each worker's relations with this primary management representative can significantly impact employees' attitudes and motivation in performing their duties. If the supervisor is perceived as honest, fair, concerned, and conscientious, his or her influence on subordinates' attitudes and motivation will be positive; if not, it is likely to be negative.

Supervision also has an important part to play in monitoring those transient states that may pre-dispose an employee to make an error. For example, a supervisor who knows that an employee is pre-occupied with a sick child may temporarily assign the individual some less demanding or non-safety-critical tasks.

2.1.4 Avoidance of Goal Conflicts

As mentioned in Section 1, goal conflicts are of two kinds, those that arise between institutional goals and those that arise between the goals of the individual worker. The former should simply be avoided. A typical example is the continuing conflict that managers face between efficiency/productivity and the sometimes seemingly inefficient demands of safety and reliability.

No utility manager would admit to knowingly subordinating safety or reliability to productivity. However, it is common that safety and reliability are simply assumed as overriding goals, while there is a steady stream of communication, both verbal and by actions, about productivity. This mismatch may create the impression of a conflict in the minds of workers. Managers should take care to make it clear, and to frequently reiterate, the way in which they expect any such conflicts to be settled.

Managers also need to ensure that policies about such things as staffing do not inadvertently create such conflicts. A lean organization is desirable from a bottom-line perspective, but it has fewer reserves to deal with variations in workload or emergencies. Excessive overtime may leave individuals stressed out, such that the employee feels he has to choose between taking whatever time is needed to do the job right or spending needed time with his family.

Conflicts between the goals of individuals are more difficult to avoid but perceptive supervisors may be able to recognize their existence and assist employees to resolve them or seek professional help.

2.1.5 Discipline

In Table 2-1 we have categorized discipline as a person-related method for addressing person-related PSFs such as procedure compliance. Because disciplinary policies are made at a high level and are usually company-wide, discipline could also be considered as an aspect of organizational culture, which is discussed in Section 2.4. Utility disciplinary practices are discussed at greater length in Section 3.2.2.

Reason notes that threats of punishment seldom work to prevent errors, though they may have some effect on deliberate violations of procedures, because violations are a product of choice, and the prospect of punishment if discovered changes the payoff matrix associated with that choice.

Thomen (1991) discusses discipline as an aid to learning rather than as punishment for misdeeds. Here, we are not talking about discipline for committing errors after they have occurred, we are talking about discipline for not following procedures intended to prevent them, *regardless* of whether the action contributed to an error (although such behaviors are usually only recognized in the aftermath of an error). This makes sense in cases where the failure to follow procedure was in some sense willful, as in not taking the switching order to the yard to perform the switching.

2.2 Task-Related Approaches

The goals of task-related error-prevention tools and strategies are to:

- reduce the error vulnerability of particular tasks or task elements (i.e., task characteristics)
- enhance error detection
- identify task elements in which errors are most likely

The approaches described in this section are summarized in Table 2-4.

Table 2-4
Task-related Approaches to Error Prevention

Error Management Goal	Methods to Achieve Goal
Reduce the error vulnerability of particular tasks or task elements (i.e., task characteristics)	• Task or job design - 2nd party checking - Self verification techniques - Exploiting delays between action and effect
Enhance error detection	• Equipment design - Design of controls and displays - Use of interlocks on critical controls - Confirmation requirement - Validation routines
Identify task elements in which errors are most likely	• Availability and adequacy of information - Written procedures - On-line manuals - Special purpose labeling - Provision of adequate feedback - Identification of failure points

2.2.1 Task or Job Design

Changes in the way that a task is performed may contribute to a reduction in errors. Aspects of task design addressed here include use of 2nd party review or checking, self-verification techniques, and methods for exploiting delays between an action and its effect.

2nd Party Checking

Second-party checking involves a second person independently checking the work of the first ***after*** it is completed, and with essentially zero interaction between the two workers. Non-interaction is important to the integrity of the process because any interaction compromises the independence: in a collaborative effort, the two may focus on the wrong parts of the problem, be subject to the same distractions, buy into the other’s interpretation of an indistinct symbol on a print, etc. Second-party checking is usual practice in the preparation of switching instructions and is occasionally employed in field switching for critical customers such as nuclear power plants, or preparing new substations for connection to the grid. Although independent review is not effective for the final irrevocable action of energizing a block of equipment, it can be employed before to verify the correctness of switching before a clearance is issued. Many utilities have the clearance holder verify the clearance points before accepting the clearance. It may also be appropriate for verifying the correctness of switching performed for restoration before the equipment is energized, and is a common practice when preparing to place new substations in service.

Self-Verification Routines

Self-verification routines have been used successfully in the nuclear industry (INPO, 1992) and adopted for switching tasks by many utilities.

STAR

The steps in INPO's self checking routine STAR (Stop Think Act Review) are shown in Figure 2-1 below.

STAR

1. Stop:	Pause and think before beginning; be organized, focus concentration and enhance attention to the details of the task at hand.
2. Think:	Locate the correct components, procedures, tools, and people. Verify instructions, equipment locations, and time limits. Anticipate the expected response when the task is performed.
3. Act:	Confirm the correct unit, train, and component and perform the task carefully and safely.
4. Review:	Observe and verify that the task was performed correctly, that the actual response is as expected, and that the component/ system is in the desired configuration to support intended plant operations.

Source: *Self Checking.* Good Practice OE-908, INPO 92-010. Institute of Nuclear Power Operations, 1992.

Figure 2-1
Steps in STAR Self-Checking Routine

The basic four steps of STAR have been expanded by various utilities: for example, Figure 2-2 shows an excerpt from a pocket card carried by personnel at a nuclear power plant.

Self Verification must be performed before, during, and after an action is taken to ensure proper work performance.

a. Stop - think about the task. Are you prepared?
b. Locate - physically locate the device.
c. Touch - place hand on device but do not operate.
d. Verify - compare label and address to work document.
e. Anticipate - consider intended response to intended action.
f. Manipulate - perform action.
g. Observe - be alert for unexpected response.

Source: Beare & Taylor, 1996, p. 5-5.

Figure 2-2
Expanded Version of STAR: Excerpt from Pocket Card

The Six Steps of Switching

The "'Six Steps of Switching" practiced by some utilities (see Figure 2-3) is a concise and easily remembered statement of desired practice. It provides an explicit self-verification procedure focused on switching operations, whether performed in the field or at a computer console. Further, it is an easily observable "point of operation drill" whose use can be required and monitored by management (observability allows unobtrusive monitoring of performance by instructors and supervisors). A variation on “six steps” that included a reminder to record the time of the action was proposed by Beare and Taylor (1996, p. 5-5).

“The Six Steps of Switching" Self-Verification Routine

1. Carry the switching order with you while switching.
2. Touch the device name plate to verify its/your location.
3. Recheck the switching order for right location and right sequence.
4. Verify anticipated device position.
5. Perform required action on device.
6. Verify desired device position.

Figure 2-3
Six Steps of Switching

Conditions for Success

As noted by Beare and Taylor (1996), formalized self-verification techniques have been applied to the execution of switching operations by many utilities. Where utilities have a routine such as “six steps,” a very frequent finding in switching error investigations is that the routine was not executed prior to operating the incorrect switch. In any given incident situational factors such as preoccupation, distraction, or a reliance on memory (“I checked the order a minute ago”) may be to blame. Whatever the reason, the number of incident reports containing an annotation that it was not done suggests that such routines are effective *if used*. But the frequency of such annotations suggests that there are problems in ensuring they are used consistently. See *Job and Task Analysis to Identify Failure Points in Switching Operations*, (EPRI 1008692, 2004).

INPO (1992) notes that successful self-verification programs include the following elements:

- A simple, readily understood, and easily remembered self-verification technique that is incorporated into a broad range of station activities.
- Initial and continuing training to communicate the principles and techniques of self-verification, as well as reinforcement of these techniques during training.
- Active support of the program by line managers and supervisors, including reinforcing the proper use of self-verification through on-the-job coaching

Exploiting Delays between Action and Effect to Intercept Errors

Errors are frequently reversible without additional consequence if there is some delay between the performance of the action and its effect on the system.

Switching errors typically become consequential only when they misdirect the flow of energy. A great deal of switching is performed on de-energized equipment to establish the visible breaks in a circuit for a clearance or the configuration required to reenergize equipment after work has been completed. This creates a delay between the commission of an error and its consequences. The delay provides an opportunity to conduct a second review of conditions established by the switching so that errors can be discovered and corrected before their consequences are felt. Although strictly speaking this does nothing to prevent errors, it can do a lot to prevent their consequences, which is what we are really striving for.

2.2.2 Design of Tools and Equipment

Human Factors Engineering or ergonomics addresses, among other things, the design of controls and displays. "Good" human factors reduce extraneous demands for attention so the operator can focus on the task. Poor attention to human factors can result in designs that actually induce errors.

A major problem with man-made environments is that they are perceptually impoverished. Our mental processing evolved in a world rich with redundancy, in which important objects were distinguished by variation on several dimensions. Engineers, on the other hand, prefer simplicity over redundancy, uniformity over variety. Thus we have rows of control panels that look alike, often distinguished only by one or two characters on a label. And these panels contain rows of identical switches, again distinguished only by one or two characters on a label.

Human factors interventions that can reduce the likelihood for the more common kinds of errors include design of controls and displays; use of interlocks; requirement to confirm operation; and use of equipment with validation routines.

Design of Controls and Displays

Simple engineering enhancements to control panels and devices can provide additional information and reduce the likelihood of operating the wrong control. Detailed discussion of the principles of display design is beyond the scope of the present report, but excellent guidance is available from EPRI and other sources. See, for example, "*Display Design for Dispatch Control Centers in Electric Utilities,* EPRI EL-4960, 1987.

Some standard human factors engineering practices applicable to the layout of controls on hard-wired panels in substations include:

- **Appropriate spacing of controls.** Some groupings of switches may be so dense that even looking back to the instructions may result in returning the hand to a neighboring (and incorrect) switch, even though the appropriate verification was done. This is a human factors deficiency relating to the design of the control panel, but it is likely to be overlooked if all panels are designed in the same way.

- **Control and display grouping**. Grouping related controls together aids the operator to rapidly locate the desired control. Grouping should be based on some logical connection between controls, not just similarity of function. For example, from a user's point of view, it makes sense to locate the controls for motor-operated disconnects next to that for the associated breaker, rather than to place all breaker controls together, then all disconnects. Similarly, mounting associated displays close to the control facilitates the monitoring of feedback. An example would be locating volt and amp meters above the control for the breaker.
- **Providing mimics**. A mimic is a representation of a circuit (or piping in the case of a steam plant) with controls mounted on the representation just as the components appear in a circuit diagram. It is a very powerful form of grouping because the mimic shows the relation between the individual controls and the flow of energy within the overall system of which they are a part.
- **"Color padding."** This refers to distinguishing groups of related components by the color of the panel background. The technique has been used extensively in nuclear power plants to compensate for failure to group displays in close proximity and obvious spatial relation to their associated controls.
- **Demarcation of groups of controls**. This can be done by outlining groups of related controls.
- **Color or shape coding of controls**. Color coding of control handles aids the operator to rapidly select the desired class of control. Shape coding provides additional tactile cues, and is especially useful where controls having different functions are very closely grouped. For example, the control handles for breakers, MODS, and grounds switches can be fitted with handles of differing shape and feel. Shape and feel can then provide additional cues that the operator is on the correct switch, or a last-minute warning that he or she has grasped an incorrect one.

All of these techniques increase the amount of information available in the environment (Norman, 1988). They can also enhance efficiency by making it easier to locate the desired control or instrumentation.

Use of Interlocks on Critical Controls

Interlocks prevent the operation of equipment unless certain specified conditions are met, e.g., they can be used to block operation of a disconnect if the associated breaker is closed. They are a time-tested and very effective way of preventing certain kinds of inadvertent operations, such as closing a grounding switch on an energized line. The widespread use of interlocks may help explain the very high ratio of "opened-wrong-breaker" incidents to others such as opening or closing disconnects under load. The tags on many SCADA systems now function as interlocks, preventing operation of the tagged equipment unless the tag is removed.

Requirement for Confirmation of Key Operations

A common design feature of SCADA and other computerized systems is to require that a second action be made to confirm the intention to operate a control. This is standard human factors engineering practice where the action about to be performed is irreversible: deleting a file, launching a missile, closing a switch. The routine is: Select, Operate, Confirm. In the interest of efficiency, the designers have made the confirmation easy, a single button push.

Unfortunately, the confirm action can become habitual: operators push whatever key is required to signal confirmation without reviewing the action a second time. This is efficient because 99+% of the time the initial selection was correct. But its constant practice results in it being over learned, so that it becomes automatic. In fact it arguably *became* automatic because it was done conscientiously at first, but because of low reward in terms of errors avoided it became more and more pro-forma. The operator in effect short-circuited his own conscious processing by the invariant chaining of the Operate and Confirm schemata, so that they eventually melded into one. Then the second push became literally “automatic,” with no intervening thought.

One way to break this pattern is to make it require more conscious attention, for example by requiring the control number be typed in. This of course is also less efficient, the more so because an error in typing the number will delay the process even more. Other ways to make it less automatic are to institute a brief delay in which the system will not accept the confirmation, or randomly vary the key to be pressed for confirmation. These again slow things down, which is antithetical to the mind of the technicians who design such systems and is not popular with the users. But such techniques can disrupt the automatic pilot action, and give the user a second chance to confirm that he or she has acted on the desired object, which is the intention behind the operate-confirm sequence as originally implemented.

Equipment with Validation or Error-detection Routines

Many kinds of microprocessor-based equipment contain data validation routines. In their simplest form these may simply limit the input of values to those corresponding to the range of the parameters entered. However, the principle has been applied to systems that aid in the development of switching. A system developed by one utility will present a warning to an operator who schedules the opening of a disconnect before steps to de-energize the circuit have been implemented.

2.2.3 Availability and Adequacy of Information

At the conclusion of his chapter entitled “A Practical Guide to Error Management,” Reason states that “Errors arise from informational problems. They are best tackled by improving the available information – either in the person’s head or in the workplace.” (Reason 1997, p. 154) Training to improve the individual’s knowledge and skill has already been addressed. So called “cognitive engineering” approaches strive to determine the information the operator needs to make decisions and guide action, and to give it to him or her *externally* in a form that is readily usable.

Written procedures, manuals, diagrams, station operating instructions, flowcharts, decision trees, and some special-purpose labels may be viewed as external (and more reliable) forms of memory. For example a flowchart is a way of presenting a set of rules, and so on. Unlike the memory of things learned in training, such externalized knowledge does not decay, or become unavailable, or mixed up with similar knowledge.

Checklists have an important place-keeping function and are one of the most effective cognitive support tools. However, their effectiveness is dependent on the operator checking off or signing off each step immediately after (and only after) it is completed. If he or she checks off several steps at once, or checks a step off when beginning the task rather than when it is completed, the effectiveness is drastically reduced.

Support for rule-based diagnostic behaviors or decision making is sometimes provided in the form of decision trees, flowcharts, etc, which are often used to summarize material presented in complex written procedures.

Written Procedures

Where reliable performance is required, written procedures are used to structure the activities and often to direct them in minute detail. Written procedures that clearly delineate how a task is performed and whose use is reinforced by supervision reduce the probability of error, foster its early detection, or both.

Many documents provide guidance for writing of procedures and other operating documents. Some guiding considerations are shown in Table 2-5 below.

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Table 2-5
Considerations Relating to Procedures

Considerations Relating to Procedures
• Involving operators in writing the procedures helps get commitment to follow them. • Procedures should describe how to do the task, not why each step is performed the way it is. • Procedures must be kept up to date: this requires a good document control system that ensures outdated /superceded procedures & other technical material is replaced with the latest revision. (Nowadays procedures are usually posted on company's intranet and the controlled copy is the electronic version; no printed document can be regarded as a control copy.) • Procedures should be easy to revise, and a system for doing so in place. • Procedures should provide graphics where necessary for understanding. • Instructions should be written in the active tense. • Complex sentences should be avoided. • Procedures should be written to the reading level appropriate to the least skilled user. • To encourage their use, procedures should be well indexed so appropriate procedure or section is easy to find. • Procedures should be easy to carry to site of work, durable, and easy to use on the job. • Where possible, procedures should contain steps that give some feedback to verify that the intended result is obtained. • Procedures should be validated by trial use. • It should be easier to obtain and follow the correct procedure than to improvise: easy availability is critical to ensuring use. • Procedures of the same type should be written in a standard format across the whole organization (this again contributes to ease of use).
Source: Adapted from Embrey, Kontogiannis, & Green (1994), p. 353-4. Copyright 1994 by the American Institute of Chemical Engineers, and reproduced by permission of AIChE.

Authoritative and detailed guidelines for writing step by step operating procedures are available in various Nuclear Regulatory Commission guidelines for emergency operating procedures in nuclear power plants from the late 1980s and early '90s, and DOE –STD-1029-92, *DOE Writers Guide for Technical Procedures* (1998). In addition, The FAA's *Human Performance Considerations in the Use and Design of Aircraft Checklists* (FAA, 1995) contains an informative discussion of factors that affect the legibility of documents with emphasis on the typographic features (e.g., font, case of lettering, line spacing, and character size) of the formats used for presenting switching instructions. An excellent source of information on procedure writing is found in Wieringa, Moore, and Barnes, *Procedure Writing, Principles and Practices*, 1998, whose authors are responsible for much of the guidance published by the NRC.

Comprehensive, if rather high level, guidelines for designing a consistent system of operating documents, including design considerations for documents that are intended to be presented electronically are presented in the 2000 NASA/FAA document, *Developing Operating Documents: A Manual of Guidelines -- E-Version* (NASA/FAA, 2000), which contains many examples from aviation-related documents.

User Manuals and Help Features for Computerized Devices

Many objects provide information about how they operate by various visible features of their design. These features are an example of what Norman (1988) calls "knowledge in the world," or externalized knowledge in our terminology. Modern multifunctional electronic components do this to a much smaller degree than older, single-function mechanical equipment. Therefore they require more "knowledge in the head" for their successful operation, or more knowledge explicitly externalized in procedures and manuals. Ensuring the ready availability of such materials is thus very important with this type of equipment. If these devices are operated from a computer workstation, the provision of on-line manuals and user-friendly help features are recommended.

Special-Purpose Labels

Additional labeling – typically warnings to avoid certain actions, or in some cases to indicate the expected status (e.g., normally open) – can be used to convey information that may be important to the operation of some controls. For example, if a line is a radial feed it may be desirable to include a label on the breaker control to this effect, rather than relying on some other method such as a numbering convention that assigns special identifiers to radial lines. Tags are of course the quintessential special purpose label.

In general, if there is something unusual about a component that may influence the decision to operate it or not - or the success of that operation - the information should be provided on a label. For example, most switches may be turned to a desired position and left in that position. However, some may require that the control be held against spring tension until a motor driven mechanism has moved the component into position. If this control looks like others that are much more numerous but do not function the same way, a placard that advises the operator to hold the control until the indicator light comes on will prevent "partial" operation.

Many EMSs have the capability to present warning labels indicated by a special symbol on the display. This technique is appropriate for use with all equipment operated through a computer display.

Feedback

Feedback enables the worker to verify that the process that is being performed or directed is on course or has achieved its desired ends. Provision and appropriate use of feedback is a vital component of correct performance. For this reason seeking feedback is usually built into a sequence of instructions in the familiar "open-check open-lock open" sequence. Likewise the operator switching via SCADA receives feedback not only from the indicated switch status, but from confirmation of the expected MW or voltage values upon completion of switching. Such feedback is also available to the operator switching from a control panel.

Because switching processes are essentially binary (the switch is either open or closed) and the feedback provided is after the action, attention to feedback does not serve so much to prevent errors as to aid in their rapid detection. Attention to feedback is also useful in detecting equipment malfunctions.

2.2.4 Evaluating the Likelihood of Error or Violations Associated with Tasks

If the specific tasks or task elements within a given process that are most prone to errors are identified, it may be possible to concentrate attention and resources on error prevention measures addressed specifically to correct the error-prone features.

Failure Points in Switching

Linking errors to a formal task analysis is a common human factors engineering technique for identifying problematic parts of the process or deficiencies in the procedures by which it is performed. A study completed by this Project (Beare and Lutterodt, 2004) used "human errors" described in 169 utility incident reports collected from eight utilities to identify the tasks that were being – or should have been – performed when the errors occurred. The objective of the study was to identify those tasks in the switching process in which "human errors" appear to occur most frequently. The task analysis data used for the study was originally published in *Generic Job and Task Analysis – Handling Planned Outages and Hot Line Work* (EPRI Report #1001789, 2002) and amended in the *Generic Job and Task Analysis Database Version 2.0, EPRI software #1011661, 2005)* to be published by EPRI in 2005. The switching tasks in which most errors occurred are listed in Table 2-6.

Table 2-6
Switching Task in which Most Errors Occur

1. Selection of controls to be operated by operators in the field or Control Center when performing switching via SCADA.
   - Operation of the wrong equipment by operators in the field is by far the most common error.
2. Review of equipment status by operators in the field prior to beginning or resuming a job (referred to in the Job Task Analysis (JTA) as conducting a site review of existing conditions).
   - Failure to perform these inspections is cited in many of the incident reports. While this task is primarily intended to familiarize the operator with the equipment to be operated, an important function is to detect pre-existing conditions that are unexpected or abnormal.
3. Updating of all pertinent records when signing off a job.
4. Thorough review of all pertinent records before *resuming* a job, meaning in this case reviewing the records of switching performed for isolation prior to beginning the restoration-to-service phase of a scheduled outage.

The following additional observations were made in the course of reviewing the incident reports:

- Modifications to a pre-approved plan while the job is in progress appeared to be a relatively common source of incidents for some utilities. The most common problem seemed to be failure to adequately document such changes and communicate them at turnover.
- In spite of a near-universal requirement to stop everything and contact the dispatcher if an error is discovered (or more generally if anything is not as expected), field operators very frequently attempted to correct an error before reporting it.
- Many of the incidents examined in this study reinforce the value of using self verification techniques discussed earlier, specifically the "six steps of switching" and pre-switching walkdowns.

2.3 Strategies Applicable at the Workplace and Organizational Levels

In this section we discuss error prevention strategies that address a combination of workplace and organizational factors. Studies of man-made disasters have shown conclusively that the characteristics of the workplace and its parent organization either aid the worker to prevent errors, or set the stage not only for the errors of the worker but also for their consequences, whether it be the containment or cascading of their effects.

Some of the specific workplace PSFs that were identified in Section 1 have already been addressed in the context of person- or task-related strategies. For example, while supervision and discipline may be considered to be organizational strategies they impact the individual performer directly and were discussed along with other person-related PSFs in Section 2.1. Again, the ways in which shifts are managed is an important workplace strategy that has already been discussed at some length in Section 1.3 and again in relation to training in Section 2.1.

At a more general level, the goals of workplace/organization-level strategies are to:

- Make latent conditions more visible to those who operate and manage the system
- Discover, assess and eliminate error-producing factors within the workplace and organization.

These goals may be addressed – reactively – through an organization's approach to incident investigation and reporting (see 2.3.1) and – proactively – through systems for identifying error-likely conditions in the workplace and organization before errors occur (see 2.3.2). One important approach to error/accident prevention combines these two components with others in a Continuous Safety Management Process for the organization. This is described in 2.3.4.

2.3.1 Incident Investigation and Reporting

Systems for reporting errors, accidents, and near misses are central to most approaches to error reduction. Reporting should be followed by a through investigation that goes beyond laying blame on the individuals and uses root cause analyses (RCA) to identify as many correctable contributing factors as possible. The information developed should be widely disseminated and management should take visible steps to address the causes of the incident. These processes are a critical part of any attempt to understand and manage errors, but since they have been the subject of two recent reports in this series *Collecting and Using Near-Miss Information: Enhancing Switching Safety and Reliability*, EPRI Technology Report 1001956, 2001, and *Incident Investigation and Reporting*, EPRI Technical Report 1002077, 2003. They will not be elaborated upon here.

2.3.2 Systems for Auditing Workplace and Organizational Factors

Auditing is a way of proactively identifying conditions that may contribute to errors or accidents before they are brought to attention by an undesirable incident. Many such systems exist. Three that are thought to be highly successful are described in Reason (1997 Chapter 7, pp. 132-146). Because these approaches are very similar in both conception and detail, only one of them, Tripod Delta, is discussed here. A similar approach, being developed by EPRI for use in nuclear power plants, known as "Leading Indicators," is also described in this section.

Tripod Delta

Tripod Delta is an approach to safety auditing that focuses on workplace and organizational PSFs but also includes personal and task-related factors.

Tripod Delta was created for offshore oil exploration and production operations by a team of academic researchers from the Universities of Leiden and Manchester[6]. It was intended to be a *proactive* approach to incident *prevention*, rather than (and as a complement to) the reactive approach that investigates incidents and seeks to remedy their immediate and underlying causes, which was already in place in the company for which the technique was first developed.

The original focus for the development of Tripod Delta was the prevention of lost time injuries (LTIs) rather than errors *per se*, and the tasks and conditions considered were specific to a highly specialized and uniquely hazardous industry. The technique has since been adapted to use in a variety of other industries.

Underlying Model

The model relies on the concept that incidents result from the combination of personal behaviors (unsafe acts) and particular hazards, both of which are influenced by local situational factors and "upstream" organizational factors. Although current versions use the more descriptive term Basic Risk Factors (BRFs), these situational and organizational factors were called General Failure Types (GFTs) in the original version of the system as described in Reason (1997, pp. 132-133).

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[6] An extensive list of downloadable reports on various aspects of Tripod Delta is available through the Tripod Consultancy at www.tripodsolutions.net.

The essential element of the philosophy behind Tripod Delta is that:

> "Unsafe acts, Lost Time Incidents (LTIs) and accidents are born from the union of . . . General Failure Types and local triggering factors. . . . But only one of these parents is knowable in advance and thus potentially correctable before it causes harm: namely, GFTs or the latent conditions associated with specific organizational processes. . . . LTIs are like mosquitoes. It is pointless trying to deal with them one by one. Others simply appear in their place. The only long-term solution is to drain the swamps in which they breed—that is, the General Failure Types. . . . [Therefore] Effective safety management depends upon the regular measurement and selective remediation of the GFTs." (Reason 1997, pp. 132-133).

The Tripod Delta approach seeks to reduce accidents, incidents, and losses by reducing the hazards (and error/violation inducing factors) produced by the BRFs and the upstream organizational factors associated with them. Because the BRFs give rise to the hazards, the most important management action is to measure and control the BRFs and upstream organizational factors.

Basic Risk Factors Most Likely to Contribute to Unsafe Acts

From a review of accident records and incident investigations in a number of companies, the Tripod Delta researchers identified 11 BRFs that were considered most likely to contribute to unsafe acts or other safety deficiencies. The BRFs, which fall into three categories (Generic, Technology or Site-Specific, and Mitigation), are listed in Table 2-7 below.

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Table 2-7
Basic Risk Factors Evaluated by Tripod Delta

Basic Risk Factor (BRF)	Definition
Generic BRFs	
Procedures	Insufficient quality or availability of procedures, guidelines, instructions and manuals (specifications, 'paperwork', use in practice)
Training	No or insufficient competence or experience among employees (not sufficiently suited / inadequately trained)
Communication	No or ineffective communication between the various sites, departments, or employees of a company or with the official bodies
Incompatible goals	Situations in which the employee must choose between optimal working methods according to the established rules on the one hand, and the pursuit of production, financial, social or individual goals on the other.
Organization	Shortcomings in the organization's structure, philosophy, processes, or management strategies, resulting in ineffective management of the company
Technology or Site-Specific BRFs	
Design	Ergonomically poor design of tools or equipment
Hardware	Poor condition, suitability, or availability of materials , tools, equipment and components
Maintenance management	Non- or inadequate management and performance of Maintenance tasks and repairs
Housekeeping	No or insufficient attention to keeping the work areas clean or tidied up
Error enforcing conditions	Unsuitable physical conditions and other influences that have a disadvantageous effect on human functioning
Mitigation BRF	
Defenses	No or insufficient protection of people, material and environment against the consequences of an operational disturbance that may occur
Source: Modified from Groenenweg, 2000, p 10.	

The list of Basic Risk Factors above is a selective list of elements of the socio-technical system rather than a list of deficiencies. Some of them have been identified earlier as person- or task-related PSFs for which specific prevention strategies have been suggested. Only two are self-evidently negative. However, each of the others may exhibit certain characteristic deficiencies (see Reason's discussion for more details) which can contribute to errors and accidents.

Each BRF has many readily-observable surface aspects, and a tail of "upstream influences" or "specific organizational processes" that ultimately relate to how the parent organization – not just "safety" – is managed: goals, standards, accountability, resource allocation, etc. The status of the BRFs gives an indication of the health of these upstream factors, most of which are not directly observed, but are reflected in things that can be observed in the workplace.

Evaluating Basic Risk Factors

To evaluate the status of BRFs, groups of experts (often line supervisors) first identify a large number of observable indications or symptoms for each. Each should be easily observable on the job site or easily determined from records available onsite. These are stored in a database in the Tripod Delta software. To conduct an evaluation, 20 observables (25 in more recent versions) for each BRF are drawn at random from the database to produce a 220-item checklist (275 items in more recent versions using 25 observables) that can be answered Yes or No, present or absent. The checklist is then completed by a person very familiar with the workplace and the tasks performed in it, often a supervisor.

Responding to the Risk Profile

When a checklist is completed, the data are entered into the Tripod Delta software, which produces a “graphic profile” (a series of bar graphs). Management is expected to evaluate these and tackle the two or three that show the most deficiencies. Unlike an incident investigation, the process does not produce a list of concrete action items, but rather a list of things that should be examined for possible action items. The object is to focus on improving the processes associated with that BRF rather than to correct individual deficiencies, which are not identified on the profile, though they are identified in reports. Feedback on progress may be obtained by comparing the profiles from successive rounds of observation.

Regularly-scheduled Tripod evaluations encourage more or less continual examination of the basic processes of the organization. The process also contributes to the development of the *questioning attitude* and *learning culture* that are central components of a safety culture. (See Section 2.4.)

Leading Indicators of Human Performance

An idea developed by Reason and others is that a long period without a significant event is usually interpreted as an indication that “We’re OK, everything is under control.” When everything is under control, there are no near-misses to expose weakness in training, there is no incentive to review procedures or processes, people become complacent, and management focuses on the problem *du jour*. But in fact defenses are probably growing weaker.

In the nuclear industry, the very success of the reactive approach – incident reporting, investigation, and root cause analysis, followed by corrective actions – has led to a new problem: fewer events means fewer learning opportunities; fewer chances to discover weaknesses and correct things in a strictly reactive mode. Moreover, since “events” are much rarer, there simply isn’t enough data to gage the current and likely future state of safety performance.

Overview of the Leading Indicator Project

Very much aware of Reason's comments on the possible deterioration of safety when everything appears under control, the NRC has implemented a new performance-based oversight process that relies less on the occurrence of major events and more on day-to day performance, as reflected in a number of indicators which are essentially measures of process rather than outcome.

The EPRI Leading Indicators project is a joint effort between EPRI's Nuclear Power target and the US Department of Energy's Nuclear Energy Plant Optimization (NEPO) Program. This work is directly related to NRC-sponsored work on "organizational factors" begun in the early 1990s; the Safety Culture concept advanced by the International Atomic Energy Agency (see more on Safety Culture in Section 2.4); and the work by Reason and other investigators, particularly their appreciation of the importance of latent conditions in contributing to high-consequence organizational accidents.

The premise of the work is that there are aspects of the policies, systems, and culture created by management that can either foster or fail to support more reliable human performance. The leading indicators are intended to be measures of those management actions required to support effective and nearly error-free plant operations. They are "leading" in the sense of economic leading indicators: the degree to which they are present is supposedly indicative of the future state of the quality of human performance at a particular plant, and thus its expected safety performance.

The "Leading Indicators" approach is like Tripod-Delta in that it looks at signs of the effectiveness of the overall socio-technical system. It is intended as an additional component in a system of strategies that also included an effective incident investigation program and INPO's Human Performance Enhancement system, rather than a substitute for those elements.

Identifying Leading Indicators

To identify potential leading indicators, the EPRI project team surveyed models of organizational influences on safety performance in the chemical, aviation, and transportation industries. From a review of the models, seven themes common to multiple models were identified. Each participating plant then identified a set of "issues" related to each theme, that is, a list of different aspects of the quality described by the theme.

The themes and related issues as defined by the research team are given below. The listing is somewhat arbitrary, because the issues identified often have aspects related to more than one theme.

- **Management Commitment:** whether human performance matters are visibly important to senior management as evidenced by resource allocation and the existence of management systems sensitive to human performance issues.
- **Awareness:** Collection, reporting, analysis, and dissemination of data relating to safety, the condition of plant systems and processes, emergency preparedness, also the uses to which the

data collected was put (i.e., whether such information prompts corrective actions where appropriate).

- **Preparedness:** Consideration of both commercial and safety hazards; includes training for crisis response.
- **Flexibility:** Adaptability of management structure and cross-training of first line supervisors.
- **Just Culture:** A clear distinction between unavoidable errors and unacceptable actions that may result in discipline; a disciplinary system that is perceived as fair and does not inhibit the reporting of errors and near misses
- **Learning Culture:** avoidance of "band-aids" and "work-arounds" as a normal way of life; responses to human performance problems; review and modification of organizational structure or processes in response to some event; the frequency with which the same or similar human performance problems keep recurring; how change is managed; whether whistle blowers or bearers of bad news are welcomed or punished.
- **Opacity:** The extent to which management and technical staffs are aware of the current integrity of the system's defenses; how the strengths and weaknesses of the human are understood and catered to in the working environment; how the organization creates the requisite variety in its policy and project groups; how the organization combats the process of "forgetting to be afraid."

Teams consisting of managers, engineers, and operators at each of the three nuclear power plants in the EPRI study identified what its team considered to be the issues of local importance associated with each theme and developed its own observable and quantitative performance indicators for them. In practice, the same indicator may provide evidence related to more than one theme. For example, observation of field activities by management can be an indicator of top-level commitment, as well as a measure of awareness; self-identification of problems is a sign of a just culture that encourages and rewards open communications, but is also a critical component of a learning culture, etc.

The "leading indicators" work is ongoing, with pilot projects at three nuclear plants. More details on the various measures and their quantification can be obtained from three EPRI reports (Wreathall 1999 & 2001, and Wreathall *et al*. 2000).

Conditions for Success

The successful application of the audit systems discussed above requires a commitment to follow up and do something about the findings:

> "It should be emphasized that the success of techniques like Tripod-Delta . . . depends crucially upon the assessors seeing their ratings being acted upon by management. Management need to keep the workforce informed of remedial progress at all times. If nothing is seen to be done, then there is no incentive to give assessments, and the system dies." (Reason 1997, p. 141)

2.3.3 An Integrated Error and Process Safety Management System

Embrey *et al*.'s book *Guidelines for Preventing Human Error in Process Safety* presents a great deal of information about approaches that have been found useful for understanding, predicting and controlling errors in a number of industries. In the final chapter of the book, the authors describe two approaches for addressing the problem.

- The first is to avoid as far as possible all known error-inducing or error-allowing properties when designing a process or facility (or an organization). Although this may be the "best" approach, few organizations have the luxury of following it, but must work within the constraints of existing equipment and facilities.
- The second approach, which we focus on here, is to design a program incorporating a variety of reactive and proactive techniques that can be implemented in existing facilities, within the existing organizational framework.

Many of Embrey *et al*.'s suggestions and examples are specific to the chemical industry and are intended to fit within ongoing initiatives conducted by their industry sponsor, the American Institute of Chemical Engineers' Center for Chemical Process Safety. However at a high level, the program they propose can be generalized to any technology and any organization.

The process they propose for planning and implementing an ongoing program tailored to the needs of an existing facility or organization is outlined in Table 2-8. Note that the first stage is obtaining senior management commitment. The literature and utility experience both suggest that this is a pre-condition for any successful error-prevention program, but one that too often does not receive the required emphasis.

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Table 2-8
Process for Designing an Error Prevention Program

Stage 1 – Obtain senior management commitment to support the program

Stage 2 – Evaluate the current situation: identify existing concerns and perceived problems

- Identify current problem areas
- Evaluate systems currently in place to control errors (or those that should contribute to error control), including:
  - Training policies
  - Procedures
  - Work organization (shift work, overtime)
  - Human machine interfaces (displays and alarms)
  - Communication systems and practices
  - Work control systems (e.g., work permits, clearance procedures)

Stage 3 – Set up a program development and control committee:

- Include representatives of all groups that will be affected
- Train committee on systems approach to error reduction

Stage 4 – Develop a program strategy including:

- Interventions to address problem areas identified in baseline assessments
- A program of data collection & root cause analysis for incidents
- Programs to create an appropriate culture to support error management system (safety culture elements)
- Policies needed to support the new system e.g., standards for training, procedures, communications etc. and mechanisms to ensure feedback to/from management

Stage 5 – Launch program, including the following elements:

- Highly visible senior management support
- Publicity
- Explanation of goals and methods,
- Some way to quickly establish credibility (e.g., a few local success stories such as corrections of some of the problems identified in stage 4)

Stage 6 – Implement program:

- Complete interventions identified and begun in stage 4
- Set up the proactive systems
- Identify critical tasks where efforts may produce the greatest rewards
- Predict possible errors and their consequences (a common practice in the chemical and nuclear industries)
- Audit PSFs
- Implement error reduction measures as appropriate
- Set up the reactive systems: data collection and RCA
- Develop culture to support error management program: open communications and emphasis on problem solving rather than blame. This requires a sustained effort over along period of time and a continuing educational effort.

Stage 7 – Evaluation and improvement:

- Monitor effectiveness (progress) through discussions with employees: look for better understanding of error mechanisms, error-likely PSFs, more open communications, especially reporting of near-misses, note changes in conditions such as housekeeping, better labeling (& more willingness to identify sub optimal conditions), improved procedures, etc.
- Track & trend incidents and near misses for reductions in frequency that may be attributed to the process.

Stage 8 – Maintenance and ownership:

- The program needs to provide tangible benefits to its stake holders
- Ownership is promoted if contributors see changes in work conditions as a result of their contributions

Source: Adapted from Embrey, Kontogiannis, & Green (1994), p. 345-363.

2.3.4 DuPont's Continuous Safety Management Process

J. R. Thomen's book *Leadership in Safety Management* (1991) describes the safety approach used by E.I DuPont Company, which has been recognized as a leader in industrial safety for many decades. The goal of the safety management process closely parallels the goal of an error management program, namely safe, reliable, error-free performance.

The program is summarized in the diagram shown in Figure 2-4 below.

From Proceedings of Switching Safety and Reliability Conference, held in Atlanta in September 2001.

Figure 2-4
DuPont's Safety Management Program

Central Safety Committee (CSC)

Central to the process is the *Central Safety Committee*, indicated in the shape of a key at the center of the figure. All safety activities within a unit are coordinated by this committee. The committee is chaired by the most senior manager on site, and composed of his or her immediate subordinates, that is, the top management. This composition allows the committee to function as a decision making body rather than a problem solving body reporting to management. Subcommittees reporting to the central committee may be used to develop recommendations concerning particular processes.

The major CSC functions are:

1. Incident investigation

2. Management safety audits

3. Coordination of the work both of standing committees for process oversight and maintenance, and of ad-hoc committees convened for addressing specific problems.

4. Safety communications

CSC has a "safety professional" in a staff (supporting service) role. However the safety professional is not responsible for achieving safety: the top management is. Both incident investigation and management safety audits require the direct personal involvement of managers.

Safety Processes

The processes, which are controlled and monitored by the central committee, form an on-going or continuous cycle for managing safety as shown in the figure.

- **Safety Policy.** Safety policy describes management attitude toward responsibility for safety and typically describes the range of sanctions that may be employed for violations of the policy and the work practices in which it is embodied.

- **Management Safety Audits**. The audit is a very structured activity in which management (in teams of two) observes employees in the field (on the job), reaches conclusions about the safety behavior of the employees, enters into a discussion with the observed employees regarding this judgment and then subsequently and anonymously reports the type of observed behaviors needing improvement.

  Thomen (p. 212 ff) provides detailed guidance on how to conduct an audit in a non-threatening way. The proposed techniques claim to "induce" behavioral changes that flow from the employees' own recognition of the need to improve rather than to impose safety from above.

- **Standards of Performance**. Standards of performance include rules, operating procedures, design criteria and the like. They specify the employee behavior required to avoid injury and/or damage to the environment or facilities.

- **Awareness Programs**. Awareness programs include education activities, publicity, goal-setting and participation techniques. They are coordinated by the safety professionals on the staff of the Central Safety Committee and are designed to serve both educational and motivational functions.

- **Process Hazard Reviews**. A Process Hazard Review is a formal evaluation conducted routinely in the chemical industry to identify the hazards associated with the process (e.g., runaway reactions if chemicals are combined too quickly) and how these interact with the design features of the facility. Identified hazards can then be counteracted by specific work procedures or modifications to the physical plant if necessary. For our purposes, process hazard reviews may be likened to the study conducted to identify Failure Points in Switching or to the identification of Basic Risk Factors in the Tripod Delta methodology.

- **Injury/Incident Investigations**. In spite of Safety Audits, Standards of Performance, Awareness Programs, and Process Hazard Reviews, incidents continue to occur. These circumstances need to be investigated to determine what actions to take to improve the effectiveness of the safety management process. The goal of the investigation is to discover ways to improve the process so that similar incidents can be avoided in the future.

  Three other processes not shown in the figure above are considered critical to the success of the DuPont approach.

- **Communications.** Thomen (p. 73) emphasizes that effective communication requires verbal, face to face interaction. This requires that managers at each level become personally involved with communicating the message. Crew safety meetings are generally the last link in the chain of top-down communications, and a vital first link in bottom-up communications.

- **Discipline**. A progressive discipline system whose goal is to educate in the company ways is described in great detail in the book. Thomen emphasizes that discipline should come from the supervisors at all times (although with management concurrence for decision-making leave and termination).

- **Culture**. Thomen makes clear that safety is an important part of the culture at DuPont. Safety is pervasive and integrated into all aspects of operation, from facility and equipment design to product-out-the-door. Safety is understood as a continuous and ongoing process rather than a problem amenable to one-time or short-term fixes.

2.4 Cultural Factors

This section discusses approaches to error prevention based on broad characteristics of the organization that we can describe using the term “culture.” Culture describes a set of shared attitudes, beliefs, and habitual practices: “the way we do things around here.” Because the actions of individuals are ultimately responsible for errors or their avoidance, the culture can either facilitate or act to thwart efforts at error management. Some of these characteristics were already identified in the approaches described in Section 2.3. Here we explore two ideas that have been developed in recent literature: High Reliability Organizations (HROs) and Safety Culture. These approaches overlap in many areas; in particular, several ideas from the HRO research have been incorporated into current descriptions of safety culture.

2.4.1 High Reliability Organizations

In the late 1980s a group of management professors at Berkeley became interested in the unique characteristics of what they called "high reliability organizations" (HROs): organizations that were able to function effectively in fast-paced, very hazardous environments with a safety record much better than one might expect, given the hazards of their operating environments or the technologies they managed. These organizations included fire-fighting crews, flight deck operations on U.S. Navy aircraft carriers, nuclear submarines, air traffic controllers, and high-performing nuclear power plants.

Major themes emerging from this research are outlined below. Many of them are "cultural" in nature, that is they are related more to a general way of viewing the world and approaching the conduct of business (hazardous operations in particular) than to particular procedures addressed to a specific process. Indeed, in the literature on HROs, "A strong organizational culture, and implementation of norms that reinforce that culture—is an important risk mitigation measure" (Grabowski & Roberts, 1997). Some elements of the HRO culture are described below.

Continual Awareness of Danger

- A distinctive characteristic of HROs is a continual focus on the possibility of failure and the means of averting it. (Weick, Sutcliffe, and Obstfeld, 1999) This has been described as "a continual nagging suspicion that things are *not* under control that an unpleasant surprise awaits just around the corner" (Weick, 1987, Weick et. al., 1999).
- The operators of HRO systems resemble commercial pilots in maintaining that reliably safe operation depends on treating their operational environment not only as inherently 'risky', in the sense of embodying the possibility for error, but also as an actively hostile one in which error will seek out the complacent (Rochlin, 1993, p. 1553).

Valuing Technical Expertise

- HROs place a strong emphasis on training.
- Decision making in complex systems requires application of the concept of requisite variety.

> "When technical systems have more variety than a single individual can comprehend, one of the few ways humans can match this variety is by networks and teams of divergent individuals. A team of divergent individuals has more variety than a team of homogeneous individuals. In problems of high reliability, the fact of divergence may be more crucial than the substance of divergence. Whether team members differ in occupational specialties, past experience, gender, conceptual skills, or personality may be less important than the fact that they do differ and look for different things when they size up a problem. If people look for different things, when their observations are pooled they collectively see more than any one of them alone would see." (Weick, 2001, p. 115-16)

- HRO culture allows acting outside the normal "chain of command," with hierarchical authority deferring to technical competence in problem solving.

Individual Responsibility

- HRO culture emphasizes individual responsibility. Organizations that have fewer accidents are those that teach their people to recognize and respond to a variety of problems and empower them to act. Every problem belongs to every operator until he or she fixes it or finds someone who can (Roberts & Bea, 2001).

Continuous Learning

- HROs analyze incidents and near misses, both their own and others, and try to learn as much as possible from them.
- HROs aggressively seek to know what they don't know (Roberts & Bea, 2001 p. 72).

Questioning Attitude

- HROs know that odd things can occur and want their people to be on the lookout for these odd or unusual things instead of assuming that they don't matter or are not important (Roberts & Bea, 2001 p. 72).

Continuous and Open Communication

- Attention to interfaces in the system is important. (Grabowski & Roberts, 1997).
- The necessity for good communications (about ongoing activities and possible risks) cannot be overemphasized.
- There is a preference for face-to-face communications in HROs.

> "Requisite variety is enhanced by face to face communications for two reasons. First, it makes easier to assess and build trust and trustworthiness. Second, face to face contact makes it easier to get more complete data once trust and trustworthiness have been established. Since people are the medium through which reliability is accomplished, signals relevant to reliability flow through them. When those people are both trusted and dealt with face to face, more information is conveyed, which should produce earlier detection of potential errors." (Weick, 2001, p. 117)

As will be seen, many aspects HROs are also a component of safety culture, as discussed below.

2.4.2 Safety Culture

The idea of an identifiable *Safety Culture* gained currency following the publication of a report of the same name by the International Nuclear Safety Advisory Group of the International Atomic Energy Agency (1991). The concept has since been elaborated by Reason and other authors.

IAEA Definition/Explanation

Safety culture is defined in the International Atomic Energy Agency publication *"Safety Culture"* (1991) as:

> ". . . that assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, (nuclear plant) safety issues receive the attention warranted by their significance. ... Safety culture is attitudinal as well as structural, relates both to organizations and individuals, and concerns the requirement to match all safety issues with appropriate perceptions and actions." Source: IAEA (1991, p. 1).

Organizations possessing a safety culture support it with various institutional programs. However, a key contribution of the IAEA document was the identification of the attitudes and behaviors that such a culture inculcates into its individual workers at all levels. This is the critical component because error avoidance is ultimately the task of the individuals actually planning and performing the work.

For the IAEA, the key elements of the safety culture for front-line operating personnel are described as follows:

> "The response of all those who strive for excellence in matters affecting safety is characterized by a *questioning attitude* plus a *rigorous and prudent approach* plus *communication*. . . [these] are all aspects of an effective Safety Culture in individuals. The product contributes to a high level of safety and generates a personal pride in dealing with important tasks in a professional manner." (pp. 13-14)

The specific behaviors identified in the quotation above as defining characteristics of the "safety culture" are widely regarded as desirable in all aspects of power system operations. A list of specific behaviors associated with the "questioning attitude," "rigorous and prudent approach," and "communication" is given in Table 2.9 below.

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Table 2.9
Characteristics of Safety Culture at Level of First Line Operations

Individuals approach all jobs with **a questioning attitude**: - Do I need any assistance? - What can go wrong? - What could be the consequences of failure or error? - What should be done to prevent failure? - What do I do if a fault occurs? Individuals adopt **a rigorous and prudent approach** to their assigned tasks. This involves: - Understanding the work procedures - Complying with the procedures - Being alert for the unexpected - Stopping and thinking if a problem arises - Seeking help if necessary - Devoting attention to orderliness, timeliness, and housekeeping - Proceeding with deliberate care - Forgoing shortcuts Individuals recognize that **a communicative approach** is essential to safety. This involves: - Obtaining useful information from others - Transmitting information to others - Reporting on and documenting results of work, both routine and unusual - Suggesting new safety initiatives.

Note that the first two elements above, a questioning attitude and a rigorous and prudent approach, have been incorporated into the STAR process described in Section 2.2.

Essential Elements in Current Concept of a Safety Culture

The idea of a safety culture has evolved over the years to include many of the ideas from the work on HROs by the Berkeley group. Reason (1997 pp. 195-196) outlines contemporary thinking on the essential elements of a safety culture. They include:

- It is a *culture rather than a program***,** that is to say it is a habitual way of thinking and approaching all aspects of doing business. This is not to say it cannot be instituted deliberately (and such implementation managed by milestones) but it is not a separate line item in anyone's budget, and it has no conclusion: it is a process, not a product. It is – must be – ongoing, always in the background. Reason notes that "Such an ideal is hard to achieve in the real world, but it is nonetheless a goal worth striving for."
- It requires an ongoing appreciation on the part of people at all levels of the many ways things can go wrong: "*not forgetting to be afraid*."
- It is an "*informed culture* – one in which those who manage and operate the system have current knowledge about the human, technical, organizational and environmental factors that

determine the safety of the system as a whole. In most important respects, an informed culture *is* a safety culture."

- One of the principal requirements for an informed culture is a *safety information system* that collects, analyzes and disseminates information from incidents and near misses. But because these are usually few (and hopefully decreasing in number), it also requires ongoing proactive checks on the system's more indirect vital signs. [Tripod Delta and the EPRI's Leading Indicators work are attempts to identify and measure such "vital signs."]
- Because an informed culture depends on the willing participation of the workforce, it is necessary to engineer a *reporting culture* – a climate in which people are prepared to report their errors and near misses.
- An effective reporting culture depends, in turn, on how the organization handles blame and punishment. . . . What is needed is a just culture, an atmosphere of trust in which people are encouraged, even rewarded, for providing essential safety-related information–but in which they are also clear about where the line must be drawn between acceptable and unacceptable behavior.
- High-reliability organizations have evolved a culture that confers the ability to reconfigure themselves in the face of high-tempo operations or certain kinds of danger. They possess a *flexible culture* . . . that in many cases involves shifting from the conventional hierarchical mode [of decision making] to a flatter professional structure, where control passes to task experts on the spot, and then reverts back to the traditional bureaucratic mode once the emergency has passed. Such adaptability is an essential feature of the crisis-prepared organization and, as before, depends crucially on respect–in this case, respect for the skills, experience and abilities of the workforce and, most particularly, the first line supervisors.
- But respect must be earned, and this requires a *major training investment* on the part of the organization (a theme echoed by the Berkeley group).
- Finally, an organization must possess a *learning culture* – the willingness and the competence to draw the right conclusions from its safety information system, and the will to implement major reforms when their need is indicated.

Reason's description above appears to leave out one of the major components of the IAEA description of a safety culture, one that was also emphasized by the Berkeley group in their examination of high-reliability organizations: *a questioning attitude* on the part of workers at all levels. This idea can, however, be subsumed under the general headings of *informed culture* and *learning culture*.

Reason devotes Chapter 9 of his book to describing how the various components of a safety culture can be put into place. Similar guidance from the medical domain is found in the chapter on creating and sustaining a culture of safety in *Keeping Patients Safe: Transforming the Work Environment of Nurses* published by the National Academy of Sciences' Institute of Medicine in 2003.

The "prescription" for implementing a safety culture within and compatible with the existing cultures in medicine is presented in Table 2.10 below. If it largely parallels Reason's (1997) discussion, it is because the Institute of Medicine work is very recent and draws on the work of some of the leading researchers in the field of human error and techniques to combat it, most notably James Reason and David Woods. The emphasis on changing the “shame and blame” culture, reflects the fact that this attitude seems to be especially prevalent in medicine, and provides a strong disincentive for reporting errors and acknowledging and discussing problems of any kind. And of course this constellation of attitudes makes discovering underlying problems difficult, and fixing them unlikely.

Table 2.10
Prescription for Developing a Safety Culture

A Prescription for a Safety Culture for Nurses

- Obtain management commitment for long-term support of efforts to create a safety culture, including:
  - Creation of a system for reporting and tracking errors and near misses
  - Acceptance of wide dissemination and open discussion of incident reports
  - Change in the “shame and blame” attitude toward errors and those who report them
  - Acceptance of a generally non-punitive response to reported errors
  - Commitment to implement changes to established practices where warranted
- Train all nursing staff on the objectives and components of the safety culture effort, including refresher training at appropriate intervals
- Abandon the culture of blame which discourages reporting of mishaps (this will take a long time)
- Change the institutional response to reported errors from one of automatically blaming and perhaps disciplining the person involved to one that is perceived by the staff to be fair and just, with blame and punishment reserved for only conscious violations of established practices, rather than “honest mistakes”
- Encourage free and open communication about errors, near-misses, and error likely situations
- Provide rewards & incentives for safety-promoting behavior, such as proposed improvements to procedures
- Create a confidential or “de-identified” error reporting system for systematic collection of errors and near misses
- Encourage reporting of near-misses as well as errors
- Perform analyses of reported errors and near-misses (including root cause analyses) and feed the results of the analyses back to the staff
- Demonstrate organizational learning from errors and near misses by instituting changes to practices as revealed by analyses of the errors and near misses reported
- Use the results of the reporting and analysis system to measure progress in the implementation of the above characteristics, and (eventually) the reduction of errors. (The number of errors reported may be expected to increase as the reporting culture takes hold, before there is measurable decrease in the number of actual errors.)

Source: Adapted from *Keeping Patients Safe: Transforming the Work Environment of Nurses,* 2003, National Academy of Sciences' Institute of Medicine.

Reason points out that much of what we are attempting to create in a safety culture is a mindset or attitude on the part of individual workers: possessing all the parts does not necessarily mean that it works as intended.

> "… it is worth pointing out that if you are convinced that your organization has a good safety culture, you are almost certainly mistaken. Like a state of grace, a safety culture is something that is striven for but rarely attained. As in religion, the process is more important than the product. The virtue—and the reward—lies in the struggle rather than the outcome." (Reason 1997, p. 220)

2.5 Combining the Approaches Described in this Chapter

In the preceding sections of this chapter we have described four groups of methods for reducing the likelihood that an error will occur, or for interdicting the effects of those that do occur before they affect a customer or the integrity of the electrical system. In this section, we address the question of how a company should select from or combine the numerous approaches that have been described in establishing its own approach to error prevention. We will use the concept of "Defense in Depth" as embodied in the "Multiple Barrier" or "Swiss Cheese" model as one approach to the problem of establishing an error prevention strategy and will briefly explore the inter-relationships and relative effectiveness of the different approaches that have been described.

These questions will be taken up again in the final section of the report when we incorporate the results of the utility survey (Chapter 3) with the literature review, which has been the subject of Chapters 1 and 2, in arriving at a set of recommended practices.

2.5.1 The Four Groups of Methods

To review briefly the four groups of methods:

- **Person-centered** methods include training in task proficiency. Individuals may also be trained to recognize error-likely situations, and to recognize when they themselves (or their co-workers or subordinates) are becoming more liable to err because of perceived time pressure, fatigue, preoccupation, distraction, or other mental state, and to take appropriate precautions.

  In our discussion we also included effective supervision and use of discipline as person-centered methods.

- **Task-centered** methods include task design, including the use of self-verification techniques, aspects of equipment design, and the provision of appropriate procedures and job aids.

- **Workplace and organizational level** methods include – in addition to specific measures like optimizing shift rotation and minimizing distractions in the work environment – incident and near miss investigation, and organizational audits. Comprehensive audit methods such as Tripod Delta and EPRI's Leading Indicators project are designed to identify specific error-likely conditions as well as latent conditions that pre-dispose an organization to poor performance. Also included in Section 2.3 were programmatic approaches that encompass person-, task-, and workplace-as part of an integrated system.

- **Cultural level** methods include practices associated with creating and maintaining a safety culture or a high reliability (HRO) organization. Although "culture" involves a common set of attitudes and beliefs, both safety culture and HROs also embody specific concrete practices that may be (and in fact frequently are) applied in the switching domain.

Given the number of different tools and techniques that have been suggested, the reader may well ask how any one organization can do it all. And if it is impossible or impractical to implement every strategy, how can the organization select from the plethora of tools and techniques that have been suggested?

2.5.2 Defense in Depth

The concept of "Defense in Depth" is based on the premise that multiple "barriers" to error are more likely to be effective in preventing an error – or its adverse consequence – than one or two isolated initiatives. A popular model used to portray this concept, sometimes referred to as the "Swiss cheese" model (see Reason 1990, p. 208), represents each technique as a barrier that has limitations or "holes." All the holes have to be lined up for an incident to occur (see figure 2-5). The likelihood of the holes lining up diminishes as the number of barriers increases.

The model shows that the likelihood of a potential error penetrating all the defenses to become an actual incident is a function of the number of barriers and the number and sizes of the holes in each. More importantly, the graphic suggests that reliability may be increased in two ways, by increasing the number of barriers, or by reducing the number and size of the holes in those already in place, or some combination of both approaches.

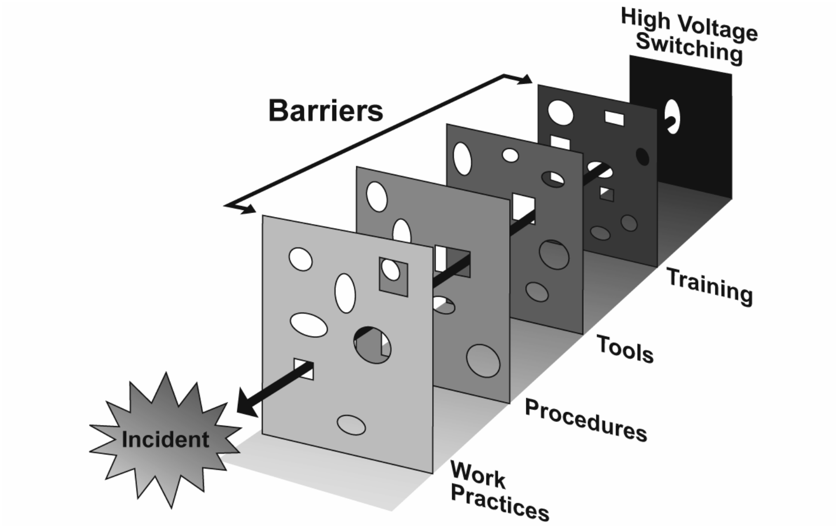

Figure 2-5
“Swiss Cheese” Model: Showing the Effect of Multiple Imperfect Barriers

On closer examination, it becomes apparent that not all of the methods that have been described bear the same relationship to error – or incident – prevention. At the workplace or organizational level, the essential role of audits and error or near-miss investigations is to allow an organization to identify the number and size of the holes in its existing barriers, i.e., whether they are adequate and working effectively, and to guide appropriate corrective action.

Similarly, an organization’s culture can either discourage or facilitate the discovery of weaknesses in the system, and the workforce’s acceptance of safety-or reliability-enhancing changes (e.g., additional barriers). An organization that honestly values and encourages a questioning attitude and the free flow of information (especially about actual or potential problems) is better able to detect and correct error-producing conditions before they can affect the system. Thus a safety or high reliability organization (HRO) culture acts to reduce the size of the holes in the barriers that must be breached before an incident occurs. Programmatic approaches can assist in the selection of tools and techniques by organizing them into a coherent system, with appropriate management support and oversight, thus reducing the likelihood that the holes will be in alignment. One of the added benefits of an announced ‘program’ is that it is a signal of the seriousness with which management regards errors. Such programs are likely to be more effective if they include the active *personal* participation of senior management through, for example, the presence of senior managers on review committees.

2.5.3 How Much is Enough?

In practical terms, we are still left with the question of what a company should do. What are the relative merits of the different barriers – and the supporting systems and processes – and how many are needed?

James Reason, whose work has been cited extensively in relation to understanding the psychological mechanisms at work in the commission of errors (Section 1) and the different approaches to error reduction (this section) has some useful insights into the relative usefulness of the various approaches. In addressing the question of accidents resulting from system failure, he writes:

> "While it is clear that the present situation *[that is, awareness of extra-individual contributing factors to errors and their subsequent consequences*] represents a significant improvement over knee-jerk 'human error' attributions [*that is, blaming the person*], some concerns need to be expressed about the theoretical and practical utility of this ever-spreading quest for contributing factors. We seem to have reached, or even exceeded, the point of diminishing returns, particularly when it comes to risk management. We (…) need to find some workable middle ground that acknowledges both the psychological and the contextual influences on human performance . . ." (Reason 1997, p. 235)

The 'ever-spreading quest for contributing factors' to which he refers are the successively more indirect influences of the workplace, the organizational practices that create and maintain it, and the more recent focus on the culture of the organization in which the workplace and practices exist.

Reason believes the biggest payoff is likely to be realized by focusing attention on workplace and task-related factors: "Workplaces and organizations are easier to manage than the minds of individual workers. You cannot change the human condition, but you can change the conditions under which people work" (Reason, 1997, p. 223). However, although we cannot improve human mental processes, we can make people aware of the characteristics and limitations of such processes, and the situations in which they are likely to get us into trouble. Similarly, we cannot improve human memory but we can provide tools – such as detailed procedures, use of warning labels, and others - that help to avoid dependence on memory. And we can design tasks using self-verification and 2^{nd} party oversight, to provide checks on the performance of the "core" tasks that directly affect the electrical system.

Weick, *et al*. also explore the issue of what steps it is realistic and feasible for an organization to take, particularly in relation to the multiple initiatives needed to assure a high reliability organization:

> "Perhaps the key question for practice is, does it make sense for mainstream organizations to invest time, energy, and human resources in process of high reliability in order to prevent mistakes of relatively minor consequence? The answer is more straightforward for HROs driven by failure avoidance and the prospect of catastrophe than it is for traditional efficiency-oriented organizations driven by success and the prospect of a weak bottom line. . . .
>
> "The piece that is missing from this neat picture is that it is not just safety that costs money. Learning does too. And this is where the pragmatics of reliability and efficiency begin to blend. If we view safety as a process of search and learning [reference in original omitted], then the costs of building an infrastructure that induces mindfulness, can be viewed as an investment in both learning and safety. Investments in safety are defined as investments in mindfulness that mean greater familiarity with the system, an enlarged response repertoire, and clearer accountability, all of which can create competitive advantage [reference omitted]. . . . Furthermore, to encourage mindfulness is

> to tap into intrinsic motivation and increase performance-enhancing perceptions of efficacy and control [reference omitted].
>
> "But whether a high reliability approach leads to sufficient returns in the form of avoided disasters or enhanced performance to justify its implementation, remains an empirical question, difficult to assess and perhaps ultimately unknowable. The choice by mainstream organizations to pursue high reliability organizing … may ultimately be an issue of identity and appropriateness (who do we want to be and how do we want to go about our business), rather than of reality and consequentiality. . ." (Weick, Sutcliffe, and Obstfeld 1999, pp. 113-114)

The answer to these questions as they apply specifically to switching error may become clearer after the next section has reported approaches to error avoidance or reliability enhancement that utilities are currently using or planning to implement.

3
UTILITY APPROACHES TO ERROR REDUCTION

Section 2 described lessons about error prevention to be learned from the literature of the subject and discussed the potential application of these lessons to the performance of high voltage switching. This section reports the results of a survey to identify practices that are used by utilities to reduce the probability of switching errors, and thus improve switching safety and reliability. Many of the practices cited have been introduced in response to error investigations by the utilities.

3.1 About the Survey

3.1.1 Methodology

The study consisted of a telephone survey of 24 utilities (see Appendix A). The survey asked a series of open-ended questions about practices intended or thought to contribute to reliability or error avoidance. The respondent for each utility was also contacted with a series of follow-up questions. A copy of the survey questions is presented as Appendix B. In addition to the telephone interviews, the author sat in on a training session at one of the utilities that had a programmatic approach to error prevention in place, and collected supporting documentation, including samples of training materials.

3.1.2 The Participants

The surveyed utilities were drawn from past and current members of the Switching Safety and Reliability Project, and those who had representatives attend one of the project's annual conferences. This sample is far from random, and should not be considered as representing a cross section of North American utilities.

Eleven of the 24 utilities contacted felt that errors (or, more accurately, the frequency with which they occurred) were not a conspicuous problem on their system, though many said that even one error was undesirable. Four reported that they experienced a number of errors, but that they did not think the number especially high in light of the number of switching operations performed. Three acknowledged that errors were considered a significant problem for them. One of these noted that the bulk of their errors was due to inadvertent relay operations caused by the work of protection and control personnel rather than switching errors in the more common sense.

3.1.3 Interpretation of the Data: A Caveat

It should be noted that the effectiveness of the various methods and strategies that are reported here is not proven. Utilities described procedures, practices, and programs that they had instituted to reduce errors or that they felt were effective in maintaining a low error rate. But for the majority of the practices reported in this section, there is no quantitative measure of effectiveness. This is in part because many of the practices are recently instituted and in part because any individual method cannot be isolated from the constellation of methods used by a given utility to assure safety and reliability. This may be particularly true if it is a long-standing practice that contributes to the good record reported by 11 of the utilities.

However, all those interviewed were obviously concerned with the problem of errors, and many of the practices were instituted in response to errors that occurred on the respondents' systems. For example, the respondent from at least one of the 11 utilities that reported errors are not a conspicuous concern attributed a general decline in switching errors since mid-to-late 1990s to efforts to take errors more seriously, as well as to several concrete measures instituted to understand and prevent them.

The weight given to practices reported here should reflect the limitations inherent in this study. Nonetheless, concurrence by different participants in use of a given practice is, at the very least, an indication that the practice is worthy of consideration, particularly if it is a practice that is endorsed by the literature in the field.

3.1.4 Organization of the Section and Naming Conventions

The remainder of this section organizes the results of the study around person, task, workplace/ organizational, cultural, and programmatic approaches to error reduction, respectively, thus facilitating reference to the discussion of the literature findings that was presented in Section 2.

Individual utilities contacted in the survey are identified by a randomly assigned number from 1 to 24. Generic job titles are used throughout: the titles system operator (SO) and dispatcher are used synonymously for the person that directs switching from the Control Center. The title "field operator" is used for any of a number of job titles authorized to perform switching in substations or other locations in the field. The acronym CC is frequently used for Control Center. The majority of respondents are involved primarily with scheduled switching to facilitate outages. Some respondents are from organizations that also operate a bulk power system and conduct operational switching to manage emergent system conditions in addition to outage-related switching.

3.2 Person-Related Approaches

In Section 2, we described training, supervision, and discipline as person-centered approaches to error avoidance. Utility practices in each of these areas are reported here, with particular emphasis on their presumed contribution to error reduction.

3.2.1 Training

When asked about their approaches to error avoidance, the majority of respondents felt that adequate training was an important contributor to their relatively low error rates. However, only a few who offered this opinion seemed to be doing anything out of the ordinary. Of particular interest for this study are:

- Frequency of refresher training on switching and tagging procedures
- Specific techniques used in refresher training
- Use of operating errors and lessons learned in training sessions
- Training sessions to recognize and avoid error-likely situations
- Provision of training or information to minimize adverse effects of shift work

Table 3-1 summarizes the number of participants (out of 24 in the study) who were using different forms of training as part of their error prevention strategies.

Table 3-1
Use of Training as an Error Prevention Technique

Training Activity	Utilities Reporting
Regularly scheduled refresher training for field personnel	13
Use of incidents and lessons-learned in training (includes those who discuss incidents in safety or other meetings as well as those who incorporate discussion of incidents in scheduled training activities)	22
Training to recognize error-likely situations*	11
Training or provision of self-study materials for adapting to shift work (applies to SOs only)	13
Notes: *System Operators are more likely to receive this training than are field operators.	

Frequency of Refresher Training on Switching and Tagging Procedures

Regularly scheduled refresher training for field operators is provided by 13 of the 24 respondents (leaving 11 who do not provide such training sessions). An alternative to refresher training is providing training as needed for new equipment or procedure changes: for example, Utility 17 now uses this approach, although they are considering going back to periodic refresher sessions. At Utility 14, introduction of the new Tagging and Clearance procedure involved training virtually all craft people in the company.

For those that did have regularly scheduled refresher training, the sessions ranged from two hours to three days presented at one- or two- year intervals with the longer sessions covering a range of topics in addition to switching.

All utilities provided ongoing training for their system operators, though how much of this was devoted to switching and tagging procedures or to the explicit topic of error prevention was not clear.[7]

Techniques Used in Refresher Training

Several respondents thought that certain aspects of their training programs were at least helpful in error avoidance. For example, three reported that switching training and refreshers for field personnel were conducted using live equipment, as opposed to only classroom review of Switching & Tagging procedures.

- Utility 11 uses live substation equipment for hands-on training. Training is conducted in small groups of 4 or 5 operators.
- Utility 16's refresher training for field switchpersons is ½ classroom review of Switching & Tagging procedures and ½ hands-on with real equipment at a retired substation set up for training. This was instituted about 2-3 years ago, largely on the initiative of a supervisor who felt the hands-on work was required for realistic training. This utility does testing as part of the recertification of switchpersons, and reported that some operators have failed the hands-on part of such tests.

Other note-worthy approaches to training that were reported included:

- Utility 16 has its system operators assist instructors from Safety & Training in providing the training. The SOs provide added realism, and are able to explain why things are done the way they are. Trainees have commented that it is helpful to have the face to face contact with the dispatch organization in that it helps build mutual confidence.
- At Utility 19 while one of the class performs switching, the other students observe and complete a critique sheet. Afterwards, they discuss their observations with the person who was observed before the instructor's critique. This peer review process is a way to maintain interest and involvement in classes that are covering material that is decidedly "old hat" to most of the attendees.
- Utility 7 is seeking a way to bring home the impact of errors in training. One of the ways in which they are trying to do this is to program the simulator used for SO training to force the operators to make errors. This effort was in its initial stages when the survey was conducted.

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[7] Much of this training is probably in response to NERC requirements which do not explicitly include switching and tagging.

Use of Operating Errors and Lessons Learned in Training Sessions

Twenty-two of the respondents stated that they used reports of errors in training at least occasionally, or made special presentations about significant incidents. In many cases this meant simply that errors were discussed with field crews or system operators at regular scheduled safety meetings. However, many have also incorporated such materials into scheduled training classes. For example,

- Utility 3 uses lessons learned from incident investigations in requalification classes for field operators. They have been doing it for about three years. The practice was instituted at the request of the field operators.
- Utility 6 has been using lessons learned in SO training for about 2 years. SOs at this utility have training sessions every 7 weeks. Lessons learned are used in training sessions as soon after the incident as possible.
- Utility 19 uses their own errors in switching classes, and has also used some from the incident-based training modules prepared by the Switching Safety and Reliability Project[8]. They focus class discussions on how the errors could have been prevented. Interestingly, although the utility conducts detailed investigations and distributes reports, they have found that field people often do not know about particular errors. (This finding may reflect a weakness of the distribute-to-the-local-manager approach to the dissemination of incident reports.)

Training to Recognize and Avoid Error-likely Situations

Eleven of the respondents reported using materials specifically related to the causes and prevention of errors (e.g., materials from INPO or the reports from the Switching Safety and Reliability Project) in training.

Training of Operators in Techniques to Help Minimize the Adverse Effects of Shift Work

About one half (13) of the survey participants stated that their System Operators had been given instruction or provided information on techniques for adapting to shift work. Specific practices mentioned by participants include:

- Utilities 4, 6, and 7 have provided their operators with specific training in adapting to shift work.
- Utility 5 will send an operator to such training if he or she requests it.
- Utility 19 gives refresher training classes on adapting to shift work based on materials available from the Department of Energy.

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[8] A series of Incident-Based Training Modules is in preparation. Each module is based on an actual utility incident and has been “genericized” to remove specific names and locations. The modules will be published by the Switching Safety and Reliability Project in 2005.

- Utility 18 has recently received “train the trainer” instruction in presenting classes on adapting to shift work from a leading company in the field.

In addition, at least eight have subscribed to Circadian Technologies’ shift worker newsletter or shift worker calendars that contain helpful tips, though one dropped their subscription because of lack of interest.

3.2.2 Use of Discipline

There are two ways in which discipline may affect the occurrence of operating errors:

- When used as a tool to enforce compliance with established practices independent of an incident
- When used to “punish” personnel responsible for operating errors

Table 3-2 summarizes how participants in the study reported using discipline in response to switching errors.

Table 3-2
Use of Discipline for Switching Errors

Approach to Use of Discipline for Switching Errors[1,2]:	Utilities Reporting
Never use discipline for errors	4
Seldom use discipline for errors	16
Frequently use discipline for errors	4

Notes:

1. All respondents reported that their company had some version of a “progressive discipline” policy. They varied in how frequently it was invoked for “honest mistakes,” with the majority saying that discipline would be used for only deliberate violations of established work rules/practices, or for multiple repeated errors.
2. In many companies (we do not know the exact proportion) certain safety violations (e.g., use of PPE or fall protection) are always subject to discipline.

Enforcement of Procedural Compliance

At least three participants reported increased use of discipline for procedural compliance:

- Utility 9 reported that discipline was used frequently as a part of its effort to ensure compliance with operating procedures.
- As a part of a movement toward greater accountability, Utility 12 reported that it was “refocusing” on using discipline to enforce work practices.

- Utility 16 reported that within the past year there had been a shift from coaching to increased use of discipline, in part to correct inconsistencies in the administration of discipline.

Discipline for Switching Errors

All participating utilities had discipline policies that *allowed* discipline for switching errors. However, they varied significantly in the frequency with which discipline was actually administered.

Utilities such as 3 (and until recently 17) stated that they do not use discipline for switching errors.

The majority reported that discipline was rarely used unless the error resulted from deliberate circumvention of a rule. "Honest mistakes" are seldom punished unless they are repeat offences. Note, however, that some actions that are not technically disciplinary are probably nonetheless quite aversive: revocation of certification for switching until retrained (in the case of Utility 3); appearing before a committee to explain what happened; or making a presentation to one's peers about an error that they have committed.

Respondents from Utilities 2, 7, and 24 said that they believed the threat of punishment was counter productive to efforts to ensure all relevant information is brought out in incident investigations. These utilities use discipline infrequently, only for deliberate circumvention of rules or multiple offenses.

A few reported they used discipline routinely, though not necessarily frequently. For example, Utility 1 reported that of the 20 investigations performed this year, 5-7 resulted in discipline.

3.2.3 Supervision

As noted in Section 2, effective supervision may ensure procedural compliance and thus help to mitigate the likelihood of errors. The respondent from Utility 17 stated that he believed the supervisor's presence/involvement in the work helps keep switchpersons more focused on the task at hand. However, several respondents noted that supervisors' "creeping administrative load" may interfere with their primary duties of actually supervising their employees, thereby reducing their effectiveness in averting errors. For example:

- The respondent from Utility 13 stated that SO supervisors have too much administrative work to spend much time supervising.
- The respondent from Utility 4 noted that it was hard to find time for field visits by supervisors.

Some have recognized this as a problem and have acted recently to reduce the administrative burden, with the intent of increasing the amount of time their supervisors are in direct contact with their workers. For example:

- In the past two years, the number of committees and meetings required of Utility 9's System Operations supervisors were reduced with the expressed purpose of allowing them to spend more time on the control center floor supervising their operators.
- In a similar vein, 1½ - 2 years ago, Utility 12 reduced the time field supervisors spent in meetings so they could get out with their crews, especially when high-risk work was being done.
- About two years ago, Utility 16 adopted a goal of having each supervisor spend 40% of his time with crews in the field. The explicit quantitative goal is an enhancement of a long standing policy of encouraging supervisory presence.
- Utility 15 has also increased supervisor presence for field people in past two years.

Table 3-3 summarizes the number of respondents whose supervisors spend time in the field overseeing field switching. The question addressed field switchmen (substation or other roving operators) who usually work alone: crews performing maintenance or other work usually have a supervisor or foreman with the crew while they work.

Table 3-3
Supervisory Oversight of Field Switching

Approach Supervisors required to spend some time in the field with their workers	**Utilities Reporting**
Yes	14
No	5

3.3 Task-Related Approaches

Task-centered approaches discussed in Section 2 have to do with the processes used to plan and perform switching and the provision of appropriate tools, documents and other sources of information to support its accurate performance.

In this section we first consider the processes and techniques that are used to minimize errors within four of the major tasks[9] used in performing switching, namely:

- Writing switching instructions for removal and return of lines and equipment
- Reviewing (switching) on the day of scheduled work
- Implementing switching for removal of lines/equipment
- Placing tags and issuing/receiving a clearance

[9] The reference here is to the tasks that were identified in the Job and Task Analysis Performed by the Switching Safety and Reliability Project (EPRI Report #1001789)

We then consider other task-related techniques and approaches including:

- Usability of switching procedures
- Equipment labeling
- Use of locks and interlocks

Note that in this report the term “switching procedure” is used differently from the term “switching instruction.”

- “Switching instruction” is used to refer to the specific steps needed to remove equipment from (or restore it to) service.
- “Switching procedure” is used to refer to the general processes used to perform switching which may include writing and reviewing switching instructions, issuing instructions, communication protocols, and so on.

The use of selected task-centered techniques for error prevention by participant utilities is summarized in Table 3-4.

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Table 3-4
Use of Task-Centered Techniques that May Aid in Error Avoidance

Task	Utilities Reporting
Preparation of Switching Instructions	
Switching instructions checked by second party before issued to field	23
Changes to format or contents of switching instructions	5
Face-to-face meetings between SOs and field personnel are routinely held to discuss planned switching[1]	4
Field Preparation for Switching	
Line-by-line review of switching instructions by field operator with SO before beginning job	11
Instructions reviewed in pre switching meeting	2
Instructions dictated & reviewed during dictation	5
Detailed review only if field operator has questions	6
Field operators review switching against one lines or other diagrams before starting work[2]	
Required	17
Recommended or encouraged but not required	3
Not required	3
Walk through switching before beginning it:	
Required	13
Recommended or encouraged but not required	4
Performing Switching and Follow up	
Use self verification when performing switching	
Required	13
Taught and encouraged but not required	7
Being considered for implementation	2
Walk through of completed switching[3]	
Required/expected	4
Recommended	1

Notes:

1. Several utilities mentioned that pre-switching meetings were sometimes conducted for special jobs, such as bring a new substation on line.
2. Review of diagrams is assumed for those field operators who write their own switching (they are not included in the number given).
3. Many noted that the clearance holder was required to walk through clearance points (often with the switchman) before the clearance was accepted. These cases are not included in the numbers reported.

3.3.1 Writing Switching Instructions

Participants reported both commonly used practices in the planning and preparation of switching and recently introduced enhancements intended to mitigate the occurrence of errors. The practices that they report include:

- Use of written switching instructions
- Changes to content and format of the instructions
- Supporting documentation
- Responsibilities of CC and field personnel for writing the instructions
- Review of written switching instructions

Use of Written Switching Instructions

All respondents reported using written instructions for all but the simplest switching operations, although a few will allow one- or two- step operations to be performed without a written plan.

In response to an error, one utility (#24) has instituted a policy that *any* activity that can potentially lead to a chargeable event must be performed from a reviewed written work plan: even non-switching operations (e.g., testing, calibrating) involving only a single switch.

Enhancements to Content and Format of Switching Instructions[10]

A number of respondents reported recent modifications to the content or format of their written switching instructions. These modifications are listed below:

- At Utility 7 switching orders are written in the field on an "order card" by the field operator; all orders are dictated by phone and then read back. The order card has been revised to include space for writing the intent of the switching to be performed. This is a change that resulted from an incident review.
- Utility 13 employs color coding on Control Center copies of switching instructions. Grounding steps are highlighted with a yellow background (which appears gray when faxed) to make it easier for reviewers to be certain each application of grounds has a corresponding step for their removal.
- Utility 15 is revising the format for presenting switching instructions in the field. In particular they are changing the switching forms used by field operators to provide space for sign-off of each instruction. Such spaces were provided on the forms used when the switching was dictated, but several years ago the utility switched to a computer-based system and field operators got computer generated instructions (written in all caps) with no space for check-off. This change was made as a result of a presentation at the 2003 Switching Safety and Reliability conference.
- As a recommendation of an incident investigation, several years ago Utility 19 redesigned their switching order format so that there is a blank line between groups of steps performed at different locations. In addition, each line of instructions generally includes the location (a

[10] A more detailed analysis of switching instruction forms is now in progress and will be published in late 2005 or early 2006.

three-letter station code) as part of the switch identification. This company uses 3-digit coded switch numbers. Each switch in a station has a unique number, but similar numbers exist at different locations, and incidents had occurred in which the operator opened a switch of the correct number at the wrong station. Utility 19's instructions also indicate if a switch is on the front or rear of a panel.

- Utility 20 has recently made a number of changes to their written instructions as a result of presentations at the 2003 Switching Safety and Reliability conference.
    - The format of printed instructions has been changed to use mixed-case rather than all upper-case lettering. They report that users like the change.
    - The traditional instruction "open and check open" has been divided into two steps. This is in recognition of the fact that, though logically connected, "open" is done from a control panel, and "check open" is done in the yard, so the actions are separated by time and space.
    - A notes section has been added to switching instructions to provide more information, mostly for the dispatcher. The form now includes a purpose section, and notes of any required coordination with other utilities, conditions for cutting-in/cutting-out of reactors, etc.

Use of Supporting Documentation and Analyses

Some of the participants have introduced requirements for supporting documentation and/or analyses when writing switching instructions, partly as a means of error avoidance:

- Utility 7 requires the SOs to print out one lines and trace out all clearance points in colored markers. They are supposed to do this before writing orders on their new electronic system, though sometimes it is done after the fact. Operators are now required to attach the marked-up diagrams to a paper copy of the switching order to facilitate reviews.
- As the result of an incident 2 - 3 years ago, Utility 24 has made it a procedural requirement that drawings, manuals, and other documents used in creating switching instructions be recorded on the outage request. Persons reviewing the switching are expected to make use of all listed documents (plus any additional documents they see fit, which are also recorded on the outage request). The utility has also used these reviews to identify discrepancies between documents, which are then written up and corrected.
- Utilities 8 and 12 perform Failure Modes and Effects Analysis on switching procedures for "sensitive" customers.

Responsibility for Writing and Reviewing Switching Instructions

The majority of respondents follow the practice of having switching instructions prepared by a System Operator and checked by one or more other SOs before being approved for execution. These practices are accepted aids to error avoidance.

However, three of the participating utilities are exceptions to this general practice:

- At Utilities 12 and 21 the majority of routine switching (e.g., to isolate a component within a single substation for maintenance) is written by field operators (switchpersons, journeypersons, control technicians, etc.), often aided by station operating instructions that contain instructions for isolating individual pieces of equipment. At these utilities the SOs write the instructions only if multiple locations are involved, or if the switching at the single location has significant potential for impacting the electrical system.
- Switching at Utility 17 is generally written by substation operators. Because of the great complexity of protective schemes used on their system it is felt that the station operator responsible for a single station has a better understanding of these than would an SO responsible for dozens of substations within an operating region. The switching plan is discussed with the SO before being executed, but such reviews are largely *pro-forma*, limited to a determination of whether the system conditions are such that the switching should be allowed to proceed. This is also the protocol in some geographic areas of Utility 18, while in other areas the instruction is written by a control center operator and reviewed by the field operator prior to execution.

In recognition of one particular error-likely situation, Utility 16 has a rule that SOs are not to write or review switching after 1 AM.

Where the SOs plan the switching and write the instructions, it is a near-universal practice to have switching instructions (other than emergency or operational switching) checked by someone other than the author before dispatching. The one exception in the survey sample is Utility 14, where the switching is written the day it will be performed and is usually not checked by a second party prior to dispatching. Another (Utility 7) began second-party checking of instructions prior to dispatching them only in October of 2003.

Many utilities also require additional reviews for special situations such as new equipment cut-ins (e.g., Utility 8 requires 4-5 reviewers for cut-ins).

Two utilities that allow field operators to write their own switching (#s 12 and 21) require review by a second person (a system operator or someone in the writer's line of business) prior to execution. However, the switching written by Utility 17's substation operators is discussed with but not formally checked by the system operator.

Some interesting variants on the practice of second party review of switching were reported:

- Utility 6 encourages checking by a second party for emergency switching, though it is not a procedural requirement.
- In addition to the check by a second SO, Utility 15 tries to have an SO from a different geographic region do a review as a sanity check (but no sign-off). This utility has a long-standing requirement on the books for 72 hours advanced notice for switching requests. In practice this interval had gradually dropped to 48 or even 24 hours. They have gone back to enforcing the 72-hour rule, largely because it allows more people to look at the proposed switching.

- Utility 24 has instituted additional reviews of switching instructions. Instructions for planned switching are faxed out 1-2 days in advance. In addition to the reviews by SOs, the switchperson (or his or her work group leader) also verifies the instructions against prints and other documents. To date there have been at least two "good catches" from this process.

3.3.2 Pre-Switching Reviews of Planned Switching

Following the preparation of switching instructions (planning) and immediately prior to executing the plan, most utilities review/tailgate/walk through the switching to be performed. These processes include both CC and field personnel.

Pre-switching Meetings

Utilities 4, 13, and 20 have face-to-face pre-switching meetings between SOs and field operators or clearance holders to review switching instructions:

- Utility 4's switching is prepared a week in advance; crews see it and review it with the dispatcher before going to the field. This utility is a relatively small operation where all switching persons are stationed in the same building as the Control Center, so they can have face to face tailgates of all switching before doing it. The Outage Coordinator or Senior SO attends all such meetings. The face to face meetings are a long-standing tradition rather than a procedural requirement.
- All planned switching for #13 is reviewed in an office switching meeting by representatives of all concerned parties, e.g., person requesting switching, switching authority (chief dispatcher, usually the writer), district engineer, and the coach, clearance holder, or group leader of the group that will perform the work in the field. There may be several meetings on the same job. A frequent outcome of the meetings is revision of proposed tag and ground placements. Switching is also reviewed on the day of the job by the SO who will dispatch it and by a crew coach at a tailboard meeting between the coach and the switchman or crew.
- Utility 20's dispatchers generally have face to face discussion of switching with field persons in the Control Room before sending them out to do it.

The above utilities all have relatively small service areas. However, such routine meetings are simply not practical for a utility that has a large service area over which field crew bases are dispersed.

- Utility 15 has recently instituted a System Operator caucus to go over switching to be performed that day: it is an analog of the field people's tailboards.

Several utilities (#s 2, 6, 16, 23, 24) that do not routinely have pre job meetings between dispatchers and field operators sometimes hold them for important or complex jobs such as new equipment or station cut-ins. The foreman may come to the CC to personally review it with the outage scheduler (Utility 2); the dispatchers may participate in a pre-job briefing of crew (Utilities 6, 16); or the dispatcher may go to the field and walk through everything for his/her own satisfaction to be sure documents are correct, and talk to the crews who will be doing the work (Utility 24).

Dispatcher/Field Switchperson Review of Switching Instructions

Eighteen respondents reported that their field people were required to review the switching instructions line by line with the dispatcher before beginning work. Of those that did not require this, most expected the field operators to have reviewed the instructions to their own satisfaction before contacting the dispatcher, and to ask questions about anything they did not understand or agree with.

Five of the respondents reported dictating switching instructions to field operators rather than electronically transmitting or faxing them to the crews. Some of those who dictated instructions rather than transmitting written documents to the field felt that this provides an opportunity for line-by-line review when the instructions are read back. However, we believe that this is a different kind of review than the one that occurs after the switchperson has taken time to compare the instructions to appropriate diagrams. The focus may be more on correct transcription rather than making sense of what is to be done.

Review of Switching Instructions against One Lines or Other Drawings/Diagrams

Eighteen of the 24 utilities surveyed required their field operators to review the switching against one lines or other drawings before beginning to perform the switching. The others said that it was required for more complex jobs or “encouraged” and usually done for all jobs, even if not “required.” As one of several changes recently introduced to combat errors, Utility 7 now encourages field operators to trace the switching order out on one lines before executing it, but does not yet require them to do so.

Walk Through of Switching

Sixteen of the survey respondents reported that a walk through of the switching before beginning the job was required (or “recommended” or “encouraged”). Utility 24 has a “check station normal” step in their procedures that requires such a walk through at a minimum.

3.3.3 Performance of Switching

Use of Self-verification Routines

Twenty of the respondents required or encouraged their operators to use a self-verification routine such as “the six steps of switching,” STAR or related procedure (Utilities 9 and 12 have different, though conceptually similar self-verification procedures that are provided in training). Utility 19 notes that when an error occurs in switching in the field, the operator is almost always found to be deficient in performance of the self-verification routine.

Utility 4 reported that they used to have a sort of "over the shoulder" switching where an SO would announce the action he or she intended to perform and other operators would repeat the intention back (or voice any reservations they had). The utility is considering going back to that procedure after hearing the presentation describing a similar procedure at the 2003 Switching Safety and Reliability Project annual conference.

Use of Two-person Switching

In Section 2 the use of two-person teams to perform switching or other critical operations was proposed as a way to increase reliability. Thirteen of the 24 utilities surveyed reported using two-person switching in at least some situations, usually those involving high voltage equipment. However, their responses indicated that two-person switching is done primarily for safety reasons: the second party is essentially there to help or call for assistance if something happens to the person switching. For example:

- Utility 10 reported that 2 people were required for operations that involve "exposed copper" specifically, the attachment of personal protective grounds, and
- Utility 14 requires it for 24 kV "indoor switching" and 4800 V switching that involves handling live jumpers.

Utilities 2, 11 and 19 use two-person switching for most jobs. However, the respondent from Utility 19 reported that manpower shortages make it impractical to tie up two people for that long if they need switching performed at a location 2-3 hours away. He also noted that some people prefer to do switching alone.

The utilities that occasionally employ two-person switching report that no particular technique is mandated: some variant on reader/doer, or doer/observer is usually used.

Utility 9 does not use two-person switching because they believe that the presence of the second person is a distraction that may actually increase the probability of an error or accident.

Communications during Switching

Faulty communications during switching are sometimes the cause of errors; conversely switching communications may be used to assist in error prevention and – after the fact – to diagnose what went wrong:

- Utility 1 emphasized that radio communications are preferable to communication via cell phones. The utility believes that the use of radios contributes to safety by allowing greater situational awareness because crews can hear the communications of others working in the area.
- Utility 3 has focused on improving communications by observing a more formal protocol. When the SO tells the field operator to do certain steps, the field operator is required to repeat them back in detail rather than just saying "OK." The utility made a point of mentioning this even though this is a technique that many others use routinely.

- Utility 20 has also recently re-emphasized importance of two-way communication with repeat-backs. This protocol has existed for several years, but compliance had grown sloppy.
- Where switching involving operators at multiple locations is being performed, Utility 24 has instituted a procedure they call "conference-call switching." This requires all parties to be on a conference call so that they can hear the instructions given to each other. The procedure requires all parties to stay on the line until all the switching is completed, not just their portion of it. This procedure was instituted about two years ago following an incident that resulted in a 30-minute outage. Utility 18 has a similar procedure for coordinated operational switching which involves regional control center operators in a conference call with the bulk system operators.

Walk Through of Completed Switching

Only five of the respondents reported that walk through of switching prior to reporting it complete was required or encouraged. Utility 4 reported that such a walk through was required on return to service switching, but not switching to remove from service. Many noted that such walk throughs were performed by the clearance holder (who may be accompanied by the switchperson) prior to accepting or releasing a clearance.

Independent Review of Completed Switching by a Second Party

Respondents from participating utilities reported that an independent review of completed switching was performed only in special circumstances, such as tying a new substation to the grid.

3.3.4 Tagging and Clearances

Following switching for a scheduled outage, tags are placed and a clearance is issued. Several utilities have instituted special steps to avoid the errors that may occur when these tasks are performed.

Equipment Tagging

Various methods of tagging cleared equipment to avoid errors are reported by participants.

- As the result of an incident involving partially overlapping clearances involving the center breaker on a breaker & a half scheme, Utility 7 now double-tags equipment common to overlapping clearances, both in the station and on SCADA displays.
- Thirteen utilities reported that their EMS allowed the placement of information tags as well as the "*do not operate*" tags that typically block operation of the equipment until they are removed. Utility 23, which does not have this feature on its EMS, places information tags on its mapboard and annotates maps.

- Utility 4 has special yellow hold tags that signal “if line breakers trip, do not close without contacting System Operations.” These are a safety feature in case breakers trip while doing hot line work. Switchmen hang new tags on all field-house breaker switches every year. The utility also tags SCADA points with a similar tag that will not allow closure of the breaker if it trips unless the tag is removed. The utility also has white “special condition” information tags in addition to their red *do not operate* tags.
- Utility 19 does not use paper tags. Instead, each station has a set of sequentially numbered durable tags hung in marked hooks on the wall. The station tags do not have the clearance number written on them, just the station and a number, from 1 to about 30 depending on the station. If a tag is not on its hook in the station it is on equipment somewhere. Tag numbers are included in written orders to hang and remove/operate. The one- or two-digit numbers are thought to make it more difficult to inadvertently remove the wrong tag.

Checks Prior to Issuing/Accepting Clearance

Most respondents require their clearance holders to personally walk through the protection/ clearance points provided before signing onto the clearance.

For example, Utility 7 has recently instituted a policy for the clearance holder to walk through and personally verify all clearance points: this should be done before the clearance is accepted, and required to be done before applying grounds. Similar policies, some of very long standing, are in effect at many of the utilities surveyed.

This practice in effect provides an independent review of the switching, except in those cases where the clearance holder performs his/her own switching. Clearance holders doing their own switching is very common, and becoming more so; at least one utility surveyed had recently changed their procedures to allow craft people (as opposed to operations personnel) to perform the switching required for their work.

Utility 14 revised their standard tagging and clearance policies and procedures in 2003 to establish greater consistency and reliability. The biggest change is a new form on which the clearance holder and all crew members all sign off that there has been a tailboard and a review of the protection provided. The protection – a list of clearance points – is printed on a form. The clearance holder is now required to walk through protection before signing it. An additional change is that all members of the crew must sign off before a clearance is released or a protection point closed (even temporarily, as for testing purposes).

3.3.5 Switching and Clearance Procedures

In Section 2, we noted that the “externalization” of information in the form of procedures and job aids was a way of mitigating errors by reducing the burden on working memory. Only one of the respondents (Utility 22) specifically mentioned the use of procedure writing/review methods designed to prevent errors including:

- The utility rewrote its Safety Manual in 2000. The revised manual was streamlined to tell what steps were expected when performing switching (e.g., test for dead), but to remove the specific procedures for doing the steps since these were already in the various department manuals. The duplication of instructions created the possibility of conflicting instructions from equally authoritative sources (and likely was something of a problem for document control when the department procedures were updated).
- To ensure the readability of the revised manual, the utility hired a consultant to make sure the language in the manual was appropriate for intended users. In particular they sought to avoid "legalisms" and other language that often appears in manuals that are based in part on regulations such as OSHA. The utility also validates revisions to operating procedures for understandability with a sample of users before they are made official.
- At the same utility (#22), any incident prompts a review of procedures that were in use to determine if they are accurate and understandable.

More information on the scope and content of switching procedures will be available as a result of an additional study that will be initiated by the Switching Safety and Reliability project in 2005.

3.3.6 Use of Information Labels and Signs

Labeling of equipment, when used effectively, was identified in Section 2 as a task-related tool for mitigating errors. Examples of techniques used by respondents include:

- Utility 5 has warning labels on OCBs and information labels describing equipment peculiarities, and labels warning of cathodic protection for underground cables.
- Utility 22 has added information labels about special conditions to representations of airbreak switches: these are shown by a tag on SCADA and the Control Center mapboard. Anyone planning to use the switch looks up the tag number to see what the applicable restrictions are. Utility 18 has a similar practice of adding SCADA tags on devices which have unusual operating limitations. Each tag is cross-referenced to another database where expanded details are available including the progress of follow-up actions to resolve deficiencies.
- Utility 22 makes use of special signage. For example, each airbreak switch has a sign that identifies the next switch location on the line (what it is feeding). The utility also has warning signs (e.g., "Caution opposed circuits") for situations such as elbows in underground distribution vaults.
- Utility 23 employs switch numbering where the switch number is related to voltage class. For example, for 138 kV equipment, all breakers have 3-digit numbers, disconnects have 3 digits plus L for line (e.g., 123L), or A, B, or C (e.g., 123C) for bus disconnects. Such coding may provide an additional means of sanity checking whether the instructions make sense.

Changes to equipment labeling that were made as a result of switching errors include:

- Utility 4 changed labeling of field cabinets for MCCs, and also now adds the cabinet number to switching orders.

- Utility 5 got rid of duplicate line numbers, names, and substation abbreviations throughout their system.
- Utility 19 places cabinet labels on the rear side of cabinets to aid technicians who work on relays only accessible from the back of the cabinet. This was implemented as a way to combat work performed on the wrong equipment.

3.3.7 Use of Locks and Interlocks

Individually Keyed Locks on Equipment in the Field

Individually keyed locks provide a safeguard against going to and operating the wrong switch because the user has to possess the matching key to be able to operate a given device. Two respondents (#s 4 and 17) reported they use individually keyed locks for at least some types of switches in substations, and Utility 21 uses them for all power equipment locks, using common locks for cabinets and other less critical components. In addition, Utility 10 uses combination locks for disconnects and ground switches. The dispatcher issues the combination with the switching instructions.

Use of Interlocks

Interlocks may be used to prevent the non-sequential operation of critical controls. When asked, all but three (Utilities 7, 16, and 22) reported that a minority of their components have interlocks to prevent inappropriate operation, the most common example being interlocks that prevent ground switches from being closed unless the line disconnects are open.

3.4 Workplace and Organizational Support for Error Avoidance

In Section 2.3 we discussed several ways the organization as a whole seeks to understand and learn from errors (incident investigation, distribution of lessons learned from investigations, the attention paid to routine incidents by senior management) and proactive steps that can be taken to reduce some of the factors that contribute to incidents, such as provision of adequate staffing and auditing to ensure that appropriate practices are faithfully followed. This section reports the workplace and organizational methods that participant utilities use to mitigate the occurrence of errors.

3.4.1 Investigation of Errors and Incidents

All survey participants reported that they investigated errors and incidents in an effort to reduce the number of errors. Table 3-5 summarizes the number of utilities using specific techniques.

Table 3-5
Incident Investigation and Follow-Up Activities

Investigation/Follow-Up	Utilities Reporting
Conduct root cause analysis for at least some incidents/errors	24
Program for reporting near misses • Informal or “sporadic” reporting of near misses	19 4
Circulate incident reports to those who would benefit	21
Review of at least some incident reports by standing committees	17
Review of at least more serious incidents by VPs	14

All survey participants reported that they employed some form of Root Cause Analysis in at least some of their incident investigations, and 19 reported that they investigated near misses if they were aware of them. Again, 21 utilities circulate the incident reports to those likely to benefit.

Incident investigation and reporting have been the focus of two reports published by the Switching Safety and Reliability project:

- *Collecting and Using Near-Miss Information*, EPRI Technology Review 1001956, September 2001
- *Incident Investigation and Reporting*, EPRI TR 1002077, May, 2003

Because the above treatments of the topic are available, only the more unusual of the practices of the participating utilities will be presented here. These include:

- At Utility 2, the persons performing the investigation present their findings to monthly safety meetings for SOs and field operators. This is possible because the utility, though large, conducts regional safety meetings rather than holding them where a work group is stationed.
- Utility 5 docks operators 5 % of their short-term bonus incentive pay for their first incident if they do not report it themselves. However, they earn this back by meaningful participation in the postmortem analysis.
- Utility 7 discourages recommendations that involve (just) more training.
- The system used by Utility 13 has a “quick fix” option for incident investigations. If any obvious problems led to error, they can alter procedures to avoid a recurrence before the investigation is completed.
- Utility 22 makes a point of using multi-disciplinary groups to conduct incident investigations.

Circulation of Reports of Incidents and Investigations

Twenty-one of the 24 respondents reported that incident reports were circulated to those who could benefit from them. Incident reports or sanitized summaries are distributed in two ways:

1. **Distribution by intranet or posting on a website** available to virtually anyone in the organization.

2. **Distribution only to managers or supervisors** of "those likely to encounter similar situations or to profit from any lessons learned." These are supposed to then be reviewed in crew or safety meetings by supervisors. At least one utility has found that many people who should have received reports this way are ignorant of them.

Several utilities have unique methods for presenting information on incidents.

- At Utility 1, lessons learned are talked about in safety meetings approximately 30 days after an incident. The delay is intended to allow any emotion attached to the incident cool off.
- At Utility 3, if a dispatcher had been involved in an incident, he/she is assigned to research it and give a presentation to other Control Center personnel. Many – though not all – dispatchers feel the presentations are valuable for them as well as for the person doing the research.
- In Utility 7's Control Center they maintain a "Critique Book" in which operators write up their own errors and lessons learned from them. All SOs are encouraged to review it. At this utility system operators also make presentations on their own errors at quarterly meetings.
- If a really serious error occurs at Utility 16, they have special presentations and discussions are taken to safety meetings throughout the utility ("almost a stand-down").
- Since 1997, Utility 22 has been publishing a "weekly focus" sheet which presents reminders about procedural and technical issues. Readers can phone in concerns to be addressed. Problems (non-incidents) experienced in the field are included so everyone is aware of potential issues they may face.
- At Utility 23, the Operations Superintendent personally reviews all incident reports with all dispatchers.

Committee Review of Incident Reports

Seventeen utilities reported that at least some incident reports are reviewed by standing committees.

- At Utility 4, if there are recurrent problems, an ad hoc group of regional superintendents gets together to discuss them. This practice was instituted about a year ago.
- Utility 5, which is a transmission operator, has constituted a group of representatives from each connected distribution company that meets to review switching errors occurring at any of the companies. The transmission company is trying to initiate discussions of best practices in switching. The transmission company manager is hoping meetings will encourage sharing of

information. Information on all switching errors on connected systems is shared among the transmission Control Center's SOs. However, it is not known whether members share information from the committee meetings within their own respective utilities; it probably varies among the membership.

- Utility 6 presents all errors in the Control Center to a committee of their fellow System Operators. This committee is primarily concerned with the implications of the incident for processes and procedures, i.e., whether the incident points for a need to alter processes and procedures.
- At Utility 9, error reports are reviewed quarterly by each department. This may involve a committee but is often done by a single individual.
- Utility 13 was in the process of developing a review committee when contacted for the survey.
- At Utility 14, reports of tagging violations or incidents related to work of which tagging was an element are reviewed by the Protective Tagging System Review Committee ("Red Tag Committee"). The focus of this committee is on possible improvements to process, though none have been found so far. It also makes recommendations for discipline for violations. This committee is a recent development; it was formed as part of an extensive overhaul of tagging and clearance procedures undertaken in response to an incident.

One respondent (#22) reported that at one time they had a "best practices" committee of peers and SOs that reviewed incident reports, and the utility is strongly looking at resurrecting this committee as an error prevention management tool.

Review of Incident Reports by Senior Management

Twelve respondents reported that Vice Presidents reviewed at least the most serious incidents; another 6 said other senior managers (below the VP level) routinely reviewed incident reports. At Utility 24, two or three vice presidents routinely attend committee meetings in which incidents are reviewed.

3.4.2 Compliance Audits of Work In Progress

At least ten of the utilities surveyed perform internal audits of various kinds[11]. Several utilities include auditing of paperwork for jobs as one of the supervisors' duties. Utility 9's error reduction program is built around audits, and audits are one of the elements in the five other programs described in Section 3.5 below.

Many of these audit programs are relatively new or recently expanded. Features of interest include:

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[11] These internal audits are not to be confused with NERC audits.

- In Utility 2, an engineer on the control center staff audits all switching paperwork and also listens to tapes of conversations between the SOs and operators in the field to review outages and any jobs that had a problem.
- Utility 3 is instituting (in 2004) field audits by trainers; this is in addition to a long-standing program of safety audits. Features of these audits include:
  - Audits are to be unannounced.
  - The auditors pick a crew at random and monitor their performance on the job.
  - Three to six audits are performed every month, with a goal of one audit per crew per year.
- The same utility (#3) is planning to apply a similar process in the Control Center for dispatchers. This utility is also planning to introduce what they call "coordinated two-ended audits." These will involve an auditor in the Control Center and one with the field crew for the same job (rather than random sampling of each), and is expected to allow a better critique of communications. The utility contact said the idea was an outgrowth of discussions at the Switching Safety and Reliability Project conferences.
- Utility 6 has been doing compliance audits in the Control Center for 3 or 4 years. These audits are performed by the Training department. This utility also recently began audits of written switching, which they found frequently contained several corrections – some of them barely legible. As a result, they now require a complete re-write and rechecking by a second party if any corrections are made. The rewrite and review requirement is fairly new; it was "encouraged" (or "preached" in the words of the utility respondent) before but has now been made a requirement. The requirement was adopted in response to an error.
- In 2003, Utility 8 began auditing SOs, performing about two audits a month.
- Utility 10 changed from two to four audits a year about two years ago. The enhanced auditing is a part of their overall error reduction program.
- Utility 13 has been using a system of "Peer Audits" for about a year: each dispatcher is required to review the paperwork for 20 completed switching orders. They often find documentation errors, e.g., tags and temporary notations are not removed from system maps when work has been completed. This utility also has its dispatchers review circuit maps associated with the switching they audit, and the maps for tied-in circuits, looking for inconsistencies such as a switch being shown as normally open on one map and normally closed on another, or inconsistent labels. Maps are reviewed against master documents and one another. When discrepancies are discovered, the utility sends someone to check the true situation in the field.
- At Utility 14, compliance with their new switching and tagging manual is monitored via audits of work in progress, with a goal of auditing a crew for each certified clearance holder at least once a year. Violations may result in disciplinary action against clearance holders. Also, each department and subgroup is supposed to audit one set of completed paperwork per month. Each department or subgroup has a local champion who helps in audits, fields questions, etc., and generally helps to get buy-in from all affected rank and file workers.

- Utility 16 is working to establish self-auditing for dispatchers. The utility always had critique sessions when there were problems with jobs, but review of routine jobs is something new. The change is the result of what the utility learned at the 2002 Switching Safety and Reliability conference.

Utility 4 used to audit paperwork & tags for one in 25-50 clearances. The practice has been discontinued, but some in the organization want to resume these audits.

3.4.3 Staffing

Several respondents mentioned staffing issues as pertinent to their error-reduction efforts:

- At least two utilities (#s 1 and 8) have reported problems in attracting the qualified applicants needed to maintain "comfortable" levels of staffing in their Control Centers.
- Utility 2 has resisted pressure to decrease staffing. They now have six crew staffing for all Control Center positions (the utility contact said most have five; he believes the sixth adds to reliability). With the six-crew rotation, every sixth week is devoted to "training" which seems to be mostly self-directed, and often consists of visits to crews in the field, new construction projects, etc. SOs are encouraged to get out with the field operators, and to have first-hand knowledge of all equipment they switch.
- Utility 5 also has six-shift rotation which includes one week off and one week of training every six weeks.
- The respondent from Utility 15 believes it is very important to maintain 6-crew shift rotation to ensure adequate time for training. So far he has been able to convince his management that the six-crew rotation is important for the reliability and safety of operations.

3.5 Cultural Factors Believed to Contribute to Error-Free Operation

The importance of culture as a contributor to error reduction was mentioned by several utilities.

At Utility 2, the survey respondent said they had no program for managing errors, but that he believed their success was a matter of culture. Their very low error rate is attributed to the high experience level in the company (an average of 20+ years for dispatchers). Cultural factors mentioned in the interview include:

- A tradition of good procedural compliance: no shortcuts and everyone knows strict compliance is expected, even in the face of time pressure.
- All employees are empowered to STOP if something does not feel right or is not understood.
- SOs are taught that the field person is the lead and must be satisfied: the field has final go/no-go say for any instruction.
- A premium is placed on communications. SOs must answer all questions and be willing to ensure that all information is understood by both parties.

- System Operations management is trying to encourage a questioning attitude among its field operators rather than simply accepting what the dispatcher says on the basis of his authority.
- Efforts are made to foster good relations and understanding between SOs and field people; SOs attend field bi-monthly safety meetings on routine basis.
- The utility abolished time off for errors a long time ago because they felt it tended to lead people to hide facts. Investigators just want to find out what happened.

Other specific components of culture that were mentioned by several utilities include face-to-face communications; empowering employees to resist time pressures; and professionalism.

3.5.1 Face-to-Face Communications

Discussions of Safety Culture, High Reliability Organizations, and Thomen's book on the very successful DuPont approach to safety management all emphasize the value of face-to-face communications. These sources, and many of the survey participants, emphasize the importance of such meetings in building trust between participants. Moreover, questions of trust aside, it is virtually certain that when it is a matter of reviewing planned switching instructions, more information is exchanged at such meetings than in a brief review of the switching conducted over the radio.

However, as a practical matter, the ability to hold frequent face-to-face meetings is largely a function of (and hostage to) geography. However beneficial they may be, it is likely that trends toward mergers and consolidation of utilities (which tend to increase their geographical span) and centralization of control functions (which often increases the separation of dispatch offices from the locations of field crews) militate against the adoption of face-to-face meetings to review routine switching.

To encourage face-to-face contact, at least five utilities (2, 7, 11, 16, and 22) encourage their SOs to spend some of their training days visiting stations in the field or other control centers, attend or present training, and attend safety meetings with field people. One utility encourages face-to-face contact by sending SOs to field work sites. Utility 11 also invites new-hire field people to spend a day in the system control center so they can meet the SOs and see what they do. These practices were first noted in EPRI's 1996 report *Field Operation Power Switching Safety*.

Utility 4 encourages meetings of their SOs with SOs from adjoining utilities, though the respondent noted that the frequency of such meetings has declined. The person responding to the survey feels that face-to-face meetings are helpful in promoting safety and minimizing errors, as is the fact the SOs and field switchpersons know each other.

3.5.2 Empowering Employees to Resist the Perception of Time Pressure

Several respondents spontaneously mentioned that they were trying to address one particularly error-likely situation, that is, the stress created by the perception of time pressure.

- Utilities 2, 10, 11, 12 mentioned that all employees are encouraged to stop if something doesn't feel right or is not understood. We believe that this is a near-universal practice.
- Utility 6 has experienced three errors in the past year, two of which involved seemingly inexplicable omissions on the part of very experienced people. These appeared to be mental lapses due possibly to excessive workload. The managers in Utility 6's Control Center are now encouraging SOs to "slow down, take all the time you need." The respondent felt that this approach is somewhat contrary to the high-achieving personalities of the operators, who feel they should be able to handle everything.
- At Utility 8, the control center manager has empowered his System Operators to say "no" to extra work and defer it rather than rush to do everything (this echoes the comments from Utility 6). He has also attempted to reduce stress on SOs by various other means: maintaining adequate staffing, minimizing overtime, and instituting a full-time Outage Coordinator position.
- Utility 11's SOs and field people are encouraged to proceed at their own pace and to request help if they feel overloaded or pressured.
- Utility 12's performance improvement training includes instruction to be aware of the perception of time pressure, which the instructor stated was usually "bogus" and in any event seldom justified the increased risk of error or accident associated with rushing to complete something.

3.5.3 Professionalism

The endorsement of the professionalism of switching personnel was noted by several respondents. At one utility (# 19) the trainer posts each region's error rate, with the expectation that it will lead to a competition to achieve the lowest numbers. The utility trainer also mentioned that these postings are intended to engage the professional pride of the switchmen, which he feels will make them more attentive to their own performance. The idea of professional pride as a motivation for more attentive performance was also mentioned by respondents from Utilities 12 and 17. Utility 12's emphasis on "disciplined professionalism" is discussed in more detail in connection with the utility's error prevention program in Section 3.6.

3.6 Utility Error Reduction Programs

Sections 3.1 – 3.4 have identified individual strategies that the participant utilities in this study have used in an effort to reduce switching errors. But it may be argued that an individual initiative or set of initiatives will be more effective if it is implemented in the context of an overall program in which the different elements work together and are appropriately prioritized. In this section we examine, at a more holistic level, the formal error reduction or "performance improvement" programs that the participant utilities have implemented.

Four of the utilities contacted have error reduction programs that are of fairly long standing (Utilities 12 and 24) or in the process of revitalization (Utilities 10 and 18). An additional utility (#9) has a program of workplace audits that is, in effect, such a program. A sixth (#21) has a number of initiatives under way that are not organized under the umbrella of a “program” but represent the major components of one, and may soon be officially called a program. These six utilities comprise one quarter of the survey sample.

Each of these programs is described here, with emphasis on the programmatic aspect and its details. Note that several of the practices have already been described or alluded to in the earlier sections. A table at the end of the section summarizes the individual practices that form part of each of these six programs.

3.6.1 Error Prevention Program at Utility 9: Rigorous Auditing

Utility 9 has a series of audit programs for compliance with company procedures that is at the heart of its error reduction program. The information collected for this report concerned the program as applied to Control Center operations, but each operational department – maintenance, construction, etc. – has a similar program administered within the department.

Major features of the system are:

- All control centers (and operators) are audited for compliance with company procedures four times a year, roughly on a quarterly basis.
- Audits are unannounced.
- Audits examine everything switching center operators are supposed to do, but switching and documentation are weighted more heavily than other components.
- Each center gets an average score, which is published so all can see how their center compares to others. This generates a degree of unofficial but healthy competition that may provide an extra incentive to do well.
- The audit teams also rate individuals. This information is given to their supervisors and may affect performance evaluations.
- Auditing and realization that individuals will be graded sparks lots of questions about the expected way to do things. This seems to be an antidote to complacency.

Similar audits had been done by this utility for years, but the program of grading was imposed recently from VP level. The program met with initial resistance from working levels, but the response has now passed through the stages of denial, resistance, and acceptance, leading finally to change based on results.

The utility also has in place several other elements that together make up a program to address errors. These include:

- An aggressive program of incident investigation with company-wide dissemination of reports. Links to computerized reports of all incidents are sent out weekly via e-mail to a list of recipients; anybody can be on the list. Incidents are also mentioned in newsletters.
- The department gives presentations on major incidents (to local area only, and only if major).

- Audit results are examined for trends, and audit findings are also examined to see if non-compliance is a result of ambiguity in procedures. The utility is willing to consider that procedures are not perfect and may themselves be part of the non-compliance problem if it is widespread. The department often issues clarifications of procedures if several audits show that misunderstanding is common.
- In addition, all operating procedures are reviewed and updated every two years.
- The utility uses incident scenarios in simulator training of System Operators.
- Testing is also used in training, but more for feedback than for evaluation.
- Training in the INPO Human Performance Enhancement System used at the company's nuclear power plants is offered to managers & supervisors, but it is not required.

This program appears to have achieved some success. For Control Centers, compliance scores have risen from an average of 70% in 2000 to 94% in 2003. Utility error rates have declined from pre-audit levels and appear to be holding more or less steady (with random fluctuations).

3.6.2 Error Prevention Program at Utility 10: A Combination of Elements

Utility 10 has recently intensified a program intended to enhance error avoidance by System Operators. This is on the books as a single program, but the utility contact stated that its development was a result of integrating several pieces over time rather than being instituted as a complete program at one time.

Significant elements include:

- Simulator training scenarios for emergency situations
- A significant increase in the frequency and scope of audits (the company has been using audits for a long time)
- Increased supervisory oversight
- Continued communication audits and a recently-added objective rating component
- Identification of problem areas via audits and incident analysis
- Additional training to include:
    - Awareness and skills to prevent errors (self monitoring)
    - Heeding early warning signs
    - Effective communication
    - Coaching on supportive management skills for supervisory personnel
- Re-instituting use of the STAR system. It had been tried before, and the utility is now providing training and distributing literature to reinforce its use.

A similar program is also being implemented for substation operators under the direction of a Substations Department Task Force on Error Prevention. Substations is focusing on pre-job briefings, error-likely situations (which they call “traps”) and self verification using STAR. STAR and the information on error-likely situations are adapted from INPO materials used at the utility’s nuclear power plant. The Substations trainer has devised a suitcase-sized control panel with an array of switches with very similar sounding labels that is used to demonstrate the importance of using a technique such as STAR, and also the importance of using the phonetic alphabet when talking about control numbers.

The training courses on error-likely situations, STAR, and pre-job briefings have been incorporated into the mandatory yearly refresher training for substation personnel.

Additional programmatic elements that were in place for many years before the current program include:

- The company supports a wide variety of training, especially for managers. At the time of the interview, they were being given training on INPO root-cause analysis techniques; more INPO-derived training on other aspects of human performance is also to be provided.
- Like Utility 9, this company has a long tradition of incident reporting and investigation, and wide distribution of incident reports via its intranet.
- The company also has a system for near-miss reporting. This is mostly for field people; the definition of error used in the Control Center is based on procedural compliance rather than outcomes, and there is little middle ground between “correct” and “error.” The company believes that the strict standard leads to increased awareness of operating personnel while performing, reviewing and evaluating switching operations.

3.6.3 Error-Prevention Programs at Utility 12: Disciplined Professionalism

Utility 12 has a long-standing program to avoid errors and incidents. This program is coordinated under a single manager and includes strong (and again long-standing) investigation and reporting components, and correction of identified problems.

Disciplined Professionalism

The proactive element of the program is training that aims to instill a “disciplined professionalism” in the workforce. Important components of this state include:

- Practice of strict procedural use and adherence. (“100% safety requires 100% compliance. Every time you don’t follow the rules and get away with it you reinforce bad habits – which will eventually catch up with you.”)
- Attention to *all* details. Dotting the *i*’s and crossing the *t*’s – every time.
- Emotional acceptance that **you** are responsible, including the responsibility to find out what you don’t know. This requires maturity and acceptance of accountability.
- A habit of anticipating what could be a problem and planning how to avoid it.
- Avoidance of over-confidence.

The Training Component

Training is an important component of this program. The training is performed by presentations that the program manager gives to work groups. The premise of the training is that event-likely situations are predictable, manageable, and preventable. Events can be avoided by an understanding of the reasons errors occur and applying lessons learned from previous events.

The central element of the program is training to recognize error-likely situations (see the list of error-likely situations given in Section 2.1) and steps to ensure accurate performance in almost any situation.

The training differs from a simple presentation of information in that it is intended to provide the trainees with a set of specific actions they can take to improve their performance, all of which relate to how each operation or task is approached. These include:

- Use the "3 Vs", a self-verification technique; this is a technique similar to STAR that is applicable to switching and other jobs such as testing and maintenance.
- Avoid autopilot.
- Maintain a questioning attitude (identified earlier as an element of safety culture).
- Always ask four questions of any task (related to the "rigorous and prudent approach" described in the IAEA document on safety culture):

  1. What critical steps need to be done 100% correctly?
  2. How could I make a mistake at these critical tasks? *(This helps to "notch-up" attention to the task)*
  3. If I do make a mistake at a critical step what would the impact be on the system and my customers?
  4. What defenses do I need to put in place to prevent failure at a critical step?

- Practice strict procedural use and adherence.
- Use clear concise communication techniques.
- Perform a risk analysis: identify the steps which are either most susceptible to error or, should an error occur, would have the greatest adverse impact on the system or its customers.
- STOP if in doubt about the consequences of your next action (this is considered the most difficult thing for members of a skilled workforce to learn to do, but also the most powerful of the tools).

To reinforce the message of the training, each trainee is given a set of three two-sided pocket cards with colorful graphics that contain the tools described in the presentation. These are attached to a retracting string clip that may be clipped to a belt or pocket.

It should be noted that the intellectual content is only a small portion of the training presentation. For its goals to be achieved, the instructor needs to motivate the audience, create belief that the techniques given will work, and get them to actually try them. The credibility of the presenter was key in the training session that was observed by the investigator: he had done all the things the crew members do, had many personal stories, and was familiar with their recent events, which he reviewed at the end of the session.

The program manager feels that it takes a supportive organizational environment for a program such as this to work. He feels there has been measurable progress in error reduction on the transmission side and that the emphasis on transmission is very likely appropriate, because the potential impact of errors is larger for transmission than for distribution.

3.6.4 Error Prevention Program at Utility 18: Focus on CC Operator Awareness and Incident Investigations

Awareness Training and Control Room Audits

Utility 18 is a transmission company that is responsible for system operation. The company has several regional control centers and controls the majority of switching and other operations in the field. The program that the company is now developing is confined to Control Center operations.

The program is a revival of an awareness training program that was in place for several years at the parent vertically integrated utility. Because the workload during a reorganization interrupted follow-up training, the program needed revitalization. A commitment has now been made to augment the original training with refresher training by individual managers and an increased number of control room audits. The program focuses effort on the identification of inconsequential errors categorized as “at risk behavior” and “operating in an undesired state.” These are considered the precursors for consequential errors that result in outages, equipment damage, or injury. The intent is to develop a proactive error avoidance culture among all operating staff where non-consequential errors are identified and addressed before they develop into consequential events.

Incident Investigation and Reporting

This part of the program focuses on the investigation and root cause analysis of consequential errors. It is the reactive component of the error avoidance measures. The program is a system of incident investigation, reporting, and remedial measures, supported by a central committee that collects the incident reports, meets on a periodic basis to review all current reports, and analyses reports for trends in the incident data.

The current committee has revised the procedure for reporting operating incidents, and submitted the revisions for review by the regional managers who are responsible for the investigation and reporting.

The initial reports are now entered into a company-wide database that is accessible to virtually everyone in the company, and provides on-line entry into a report template to make reporting easier. If the incident also results in a safety-related incident there will be a separate in-depth analysis of root cause and corrective actions within the company's safety management system.

Other Elements

Several additional elements of a complete program have been implemented at various regional Control Centers.

- One of the regional Control Center managers produced a set of training materials on human reliability and awareness of error-likely situations using materials from the Switching Safety and Reliability Project's conferences and other sources. This was put on a CD, and implemented as an interactive web-based multimedia Computer-Based Training program for all Control Center operators. The CD was distributed to the other control center managers who had their dispatchers watch it. This was part of the initial training effort to raise awareness.
- The utility has recently acquired a new full-scope simulator and has an ambitious program for using it in training and procedure development.
- The utility also has an electronic disturbance reporting system that is accessible company-wide. Entries include human performance events which trigger an analysis by the committee described above.
- One of the regional Control Centers has addressed the problem of fear of reprisal for reporting events. A senior union representative listens to reports of errors and near errors. He or she develops anonymous reports distilling the essence of the problem and discusses them at local staff meetings. This is intended to encourage reporting of small incidents and near misses (e.g., an isolation point left off a switching order, but caught by the field crew) that otherwise would probably be hidden. This program is only at one regional Control Center now, but there is some discussion of expanding it to others.

3.6.5 Utility 21: An Emerging Program

Utility 21 does not have a coordinated "error prevention program," but they have several of the pieces, and may soon integrate them into a unified program. The existing pieces of a program include:

Organization

- Formation of a high voltage (HV) switching task force. In a recent corporate reorganization, maintenance crews were authorized to do their own switching for protection; this was followed by an increase in the number of reported incidents, most of which were errors. HV switching is considered a high-risk job.
- A team has also been formed to devise methods for "mitigation of human operational errors." The team has a subgroup focused on the inadvertent operations caused by Protection and

Control (P&C) technicians and journey person troubleshooters, as well as traditional switching errors. The membership of this team is similar to that of the HV switching task force, that is a representative from each of the utility's departments, including Work Methods and Training.

- The utility has instituted two-man P&C teams to perform work in which an error could affect large power plant switchyards or other critical customers. Such cross-checking is designed to mimic the two-person process for developing switching orders.

Training

- The company revised switching safety training materials and trained about 90% of their workforce on the new materials. This training is continually enhanced. Although the training is officially voluntary (on an as-identified basis), senior management want all people to have it.
- The utility has traditionally discussed errors in training, but this is at instructor discretion rather than being a formal part of training programs.

Incident Investigation and Reporting

- The company has a long standing system of investigating and reporting errors, though reports are scattered and vary greatly in quality from the very brief to complete investigations performed by a team (generally only for safety-significant incidents) using a proprietary program.
- The company is attempting to get all human error incidents into a central management information system, which will have the capability to track and trend them.
- The utility is also planning to set up a committee to review all errors semiannually.

Audits

- Substation and line work is subject to formal audits called "Work Process Inspections" conducted by the field crew supervisors. Supervisors are to monitor and evaluate every crew once a month, from start to finish of a job. This requirement has been in place for about four years. In addition, all paperwork from every job is to be audited by the supervisor on completion of the job.
- The utility also has a separate audit program for both control centers and field crews, performed yearly. For field crews this is more an audit of the supervisor's performance rather than that of the crew.

3.6.6 Error Prevention Program at Utility 24: Centered on the Operations Review Committee

Utility 24 has a program that began in 1997 with the formation of an Operations Review Committee (ORC). This is the most truly integrated and programmatic of the programs reviewed here, and we believe it is also the most successful. The System Operations, Transmission Operations and Maintenance, and Construction departments participate in the program. Membership on the review committee is composed of fairly senior managers from the participating departments. However, the utility encourages all employees at any level to attend and participate in the ORC.

Hierarchy of Events

This utility recognizes a four-level hierarchy of events:

- "Chargeable events" are incidents that occur within 24 months or less of the initiating cause and result in a customer outage, loss of generation, or a significant power quality impact to the customers.
- "Latent events" are incidents that occur 24 months after the initiating cause and result in a customer outage, loss of generation, or a significant power quality impact to customers, or other system impact. While these incidents involve an actual error, they do not cause an event immediately, investigations are less certain, and typically no one was at the location of the incident when the problem manifested itself. These incidents are part of the "lessons learned" reports.
- "Reliability events" are incidents that cause an opening of connectivity on the grid, but do not result in any loss of load, generation, or cause any power quality impact to the customer. These incidents are part of the "lessons learned" reports.
- "Avoided events" is an error that is discovered before it translates into an incident, e.g., an error that was discovered and corrected in design, construction, switching instructions, or testing instructions before the pending incident occurred. Other utilities might call these near misses. This is a relatively new category. The committee is encouraging the reporting of avoided events because these may contain clues to process deficiencies that could be corrected before contributing to a more serious event. These incidents are part of the "lessons learned" reports.

Incident Investigation

The program consists of investigation of incidents (service interruptions and errors that did not result in interruptions), presentation of the results of the investigation to the review committee, followed by publication of a report. A larger percentage of events receive a more rigorous apparent cause analysis now than in the past. This is possible in part because there are fewer "chargeable events" now than in the past, and in part because the local managers who perform the investigations have more collective experience in doing them.

Its growing confidence in its ability to determine an actionable cause has led the committee to review outage records to identify those that may have been due to a human performance event, (though not so identified at the time of occurrence) and then to look into them.

When applicable, the committee publishes recommended corrections, which are generally modifications to administrative barriers. These are assigned to a responsible individual and tracked through completion. Greater experience on the part of the individual reviewers and the committee as a whole is thought to have also increased the likelihood of devising better quality (i.e., practical and effective) solutions. A number of changes instituted as a result of the program have been described in the preceding sections of this chapter.

The utility has recently improved its capabilities for tracking follow-up actions. Where a similar event has occurred in the past, the tracking system also facilitates the identification and investigation of the failure of previous “corrections” to prevent re-occurrence.

The committee has found that events typically can be traced to one of the following:

- lack of procedures
- insufficient details in procedures
- management follow-through/communications/enforcement to employees for procedure implementation

Event Reporting and Distribution

The committee coordinator feels that reporting has improved over the 7 years of the program’s existence. Most serious events (even those without system impact) are generally reported, but “avoided events” are still under-reported (e.g., none had been reported from the Control Center at the time the information for this report was collected). The utility acknowledges and tries to reward employees who prevent errors e.g., “good catches” from the pre-switching review of switching instructions or a work plan. Nonetheless, the coordinator feels that people often don’t want to take the time to make a report and appear before the ORC, even if to be rewarded for a good catch.

The ORC coordinator feels improved reporting is largely due to a cultural change: over time employees have come to better understand the importance of human performance events. He emphasized that the program required several years to reach its present level of acceptance and cooperation. He feels that better reporting is a matter of awareness and clear management expectations. Employees are generally trying to help each other when reporting events so others will not get into the same situation.

Event reports and recommendations are published on a website on the company intranet which the ORC has maintained for several years. The site has been recently upgraded to have the capability to search and compile lists of incident reports by various categories. Reports on the ORC website are accessible by all company employees. On occasion, management has tried schemes such as contests to encourage employees to review events posted on the site.

Training

This utility has made INPO courses related to human performance improvement available to at least their managers, and many of the ORC members (who are all managers) have taken them.

Senior Management Support

The utility contact noted that the program has enjoyed greater support since their Executive VP called for a reduction in the number of "chargeable" events. Two or three VPs regularly attend committee meetings. Among other benefits, this makes it easier to get approved corrections implemented. Once the committee approves corrections, they are mandatory (rather than simply "recommended"), with a person assigned responsibility for their implementation, and tracked to completion.

The program appears to be successful in reducing interruptions to service, though the contact noted that there seemed to be more P&C-related events now.

3.6.7 Elements Common to Most Error Reduction Programs

Table 3-6 summarizes major components of the six programs described above, organizing them in the categories used elsewhere in this report: Person-related, Task-related, and Workplace or Organization-related. Elements that these utilities have in common include certain aspects of training, use of a self-verification technique and the approach to incident analysis and reporting.

When we examine the utilities that have or aspire to have an error-prevention program, a few commonalities emerge.

One thing that the six utilities having or moving toward formal error reduction programs have in common is that they are large enough to experience several errors a year. Given that budgets are tight and staff already stretched thin almost everywhere, many utilities may not experience enough errors to justify the investment in an ongoing program. However, those surveyed remain keenly interested in error avoidance, and most, even those that have few errors, follow many practices that are parts of others' "programs."

A second common feature is management support for the commitment of resources required (a manager and his staff for Utility 12, dedicated auditors for Utility 9, senior managers' time for Utility 24) or additional burdens on existing staff (Utilities 10, 18, and 21). The investment may be justified by exposure, and the return on investment visible in a measurable reduction in incidents. In some cases a dedicated champion has been responsible for sustaining the focus on error reduction efforts.

Table 3-6
Summary of Components of Error Prevention Programs

Practice	Utility 9	10	12	18	21	24
Person-Related Factors						
Refresher on S&T Procedures for Field	✕	●	✕	—	●	●
Refresher on S&T Procedures for SOs	●	●	●	☐	●	✕
Use errors in training: Field	✕	●	●	—	●	●
Use errors in training: SOs	●	●	●	●	●	●
Supervisors required to observe field	?	●	●	—	●	☐
Discipline used?	●	●	●	●	●	●
Train in error-likely situations: field	●	●	●	—	✕	✕
Train in error-likely situations: SOs	●	●	●	●	✕	●
Train SOs to adjust to shift work	●	●	●	●	●	✕
Task-Related Factors						
Require review of one lines by field	●	●	●	—	●	●
Walk through switching before performing	✕	●	●	—	●	✕
Use a self-verification technique	●	●	●	●	●	●
Workplace/Organizational Factors						
Near-miss reporting	●	●	●	●	●	●
Investigation of incidents	●	●	●	●	●	●
Root Cause Analysis of incidents	●	●	●	●	●	●
Reports of incidents widely circulated	●	●	●	●	✕	●
Committee review of incident reports	●	●	●	●	●	●
Reports reviewed by senior management	?	●	●	●	●	●
Audits of field work at the jobsite **	●	●	●	—	●	●
Audits of SOs at their consoles	●	●	●	●	●	●

* Utility 18 is a transmission company, most field work is done by another company.

** Jobsite audits in addition to required Safety audits

Legend:

- ● Yes / Required
- ☐ "Encouraged"
- ✕ No / Not required
- ? Utility contact unsure of answer
- — Not applicable. Utility 18 does not employ the field people (though these things might be done by the company that does control the field people)

Respondents from Utilities 9 and 24 acknowledged that their programs met with some skepticism and resistance at first, and the effectiveness of their programs was enhanced by a firm direction from the vice-presidential level. Both also noted that acceptance from middle managers and rank-and-file employees took several years to develop.

3.7 Summary of Common or Emergent Themes

From the review of participant utilities' error-prevention efforts, the overall picture is that there are a variety of practices thought to aid in error avoidance and many changes to existing practices that have been motivated at least partially with improving reliability in mind.

3.7.1 Key/Emerging Components

Many of the utilities that do not claim to have error avoidance "*programs*" nonetheless have several of the key elements of the programs reviewed above. The utilities surveyed all reported investigation of errors or incidents and wide distribution of the findings of their investigations, which are the key reactive components of such programs. Many also engage in several proactive practices, such as the use of self-verification routines when performing switching and regular auditing of switching records to ensure conscientious compliance with switching practices (or at least their documentation aspects).

We were rather surprised by the spontaneous emphasis on "culture" in many of the responses. Important aspects of this include a belief in the value of face-to-face communications and the notion that the pride of the workers (or pride in their own professionalism) was a barrier to errors, which was mentioned spontaneously in several interviews.

Several respondents are moving toward more explicit standards for which compliance is required rather than encouraged.

3.7.2 Motivation for Change

Some of the changes that utilities reported were made in response to changes in the organization itself, such as efforts to eliminate duplicate switch numbers in merged utilities, but many were the result of an error or an incident.

A majority of the utilities surveyed do not believe that the frequency of switching errors they experience represents a particularly serious problem. Although this may be viewed by some as complacency, many of these organizations have instituted changes in response to the errors that they themselves have experienced, which suggests not complacency but rather the practical approach of waiting for a clearly demonstrated need before taking action.

Established error avoidance programs are not rigid, but evolve to adapt to changing realities. Many of these incorporate enhancements of long-standing practices (e.g., increasing the frequency of audits) or revivals of earlier practices that, for whatever reason, had fallen into disuse.

A striking aspect of the utility reports is the frequency with which recently instituted changes are not innovations, but a renewed emphasis on existing but inconsistently followed, or previously abandoned, practices. Several utilities acknowledged a drift from recognized good practices such as strict observance of communication protocols or long lead times for scheduled work. It may well be that it is difficult to maintain practices that require extra effort in the face of production pressures and infrequent demonstrations of the need for them, a situation described in Section 4.7 as the difficulty of “persisting in the face of success.”

Finally, we are pleased to note that a few of the changes described by survey respondents have been motivated in part by information presented at the Switching Safety and Reliability project conferences.

4
TOWARD BEST PRACTICES

In this final section of the report we summarize recommended error-prevention practices within the context of the Defense in Depth model.

4.1 Defense in Depth

There is no single "magic bullet" against errors. Thus the practice of multiple defenses or "defense in depth" is universal for systems of which high reliability is required. The "Swiss cheese" graphic introduced in Section 2.5 and reproduced as Figure 4-1 below shows how multiple barriers reduce the likelihood of an undesired outcome; while at the same time acknowledging that no defensive barrier is 100% reliable.

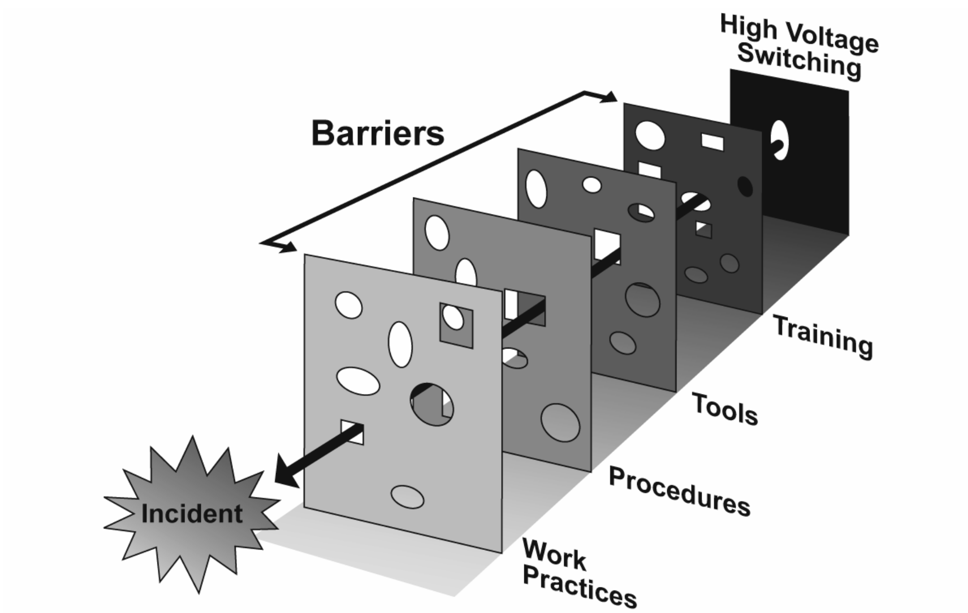

Figure 4-1
Defense in Depth Model

The defense in depth graphic shows that the likelihood of a potential error becoming an actual incident or accident is a function of the number and the effectiveness of the barriers erected to prevent that happening. The model suggests that reliability may be increased by increasing the number of barriers or by increasing the effectiveness of those already in place (i.e., closing the "holes"), or some combination of both approaches.

4.1.1 Three Types of Barriers

Tools for error avoidance – or barriers – fall into three fairly distinct categories:

1. Techniques or practices that provide either a narrowly focused defense against a specific type of undesirable occurrence (typically engineering controls such as interlocks) or a general defensive strategy that is applicable in a variety of situations (typically work practices). We will call these *primary barriers*.

2. Conditions or practices that are not themselves barriers but that directly support or reinforce barriers – or are necessary for them to work at all (e.g., training, maintenance, an effective system for updating and distributing documents). We will call these *secondary barriers*.

3. Practices that provide information on the effectiveness of defenses already in place so that deficiencies can be corrected (e.g., incident investigation). We will call these *meta-barriers*.

Practices that address all three of these levels are required for effective control of errors.

Every utility has one or more primary barriers in place for each of the four levels shown in the figure. We believe that the existing primary barriers (work practices in particular) *should be*, and in most circumstances actually are, effective. This is attested to by the relatively low error rates experienced by project participants.

Although it is, in theory, possible to add more primary barriers directed at specific occurrences, at some point the law of diminishing returns sets in and the expense is difficult to justify by the small increments in safety and reliability so purchased. In a mature industry such as ours, the low hanging fruit has for the most part already been picked. For this reason, the majority of the recommendations (other than those related to task-related barriers) involve secondary and meta-barriers rather than primary barriers. We believe that this focus is consistent with the trend in the literature reviewed in this report.

4.1.2 Recommended Practices

This section of the report provides a number of discrete recommendations for strengthening barriers to errors in high voltage switching. The section title "*Toward Best Practices*" is used advisedly. As with other studies in this series there is little in the way of hard, quantitative data to support our assertions that the practices recommended here are the "best" or most effective in mitigating switching errors. However, our study of the literature (including the experience of other safety-critical organizations) and our study of individual utility's practices provided in earlier sections, provide a strong basis for these recommendations.

The discussion of recommended error avoidance practices follows the organization based on person-, task-, workplace- and culture-related factors employed in Sections 2 and 3 of the report. Each recommended practice is followed by a brief discussion of the basis for the recommendation, generally a combination of utility practices given in Sections 3 and recommendations from the literature discussed in Sections 1 and 2. The recommendations are summarized in a job aid (provided in the Executive Summary of this report) that utilities may use to assess their own error prevention strategies.

4.2 Person-Related Strategies and Techniques

Person-related strategies cover the areas of training, supervision, and discipline, falling for the most part into the category of secondary barriers to switching errors.

4.2.1 Training

Recommendation: System operators and field switchpersons receive regular refresher training in switching and clearance procedures.

Basis: Refresher training helps to ensure that operators remain aware of the letter of the procedures and practices, the rationale for them, and the consequences of not following them. It may be especially valuable for field switchpersons who frequently switch alone, because it helps to combat the "drift" from the official model that may occur when individuals perform an activity frequently with minimal feedback in the form of an undesired outcome.

In terms of the Defense in Depth model, switching and tagging procedures may be viewed as barriers to undesired outcomes, while drift, that is incomplete or "relaxed" compliance, opens or enlarges the holes in the barrier through which an error may pass. Thus refresher training is a secondary barrier or barrier maintenance activity.

Other industries (nuclear power operations, commercial aviation) perform refresher training to maintain skills critical to safe operation, even those that are exercised fairly regularly. A strong emphasis on training is a characteristic of High Reliability Organizations (HROs) and a key component of the safety culture model as applied in many domains. Refresher training is a common practice among utilities, though by no means universal (slightly over half the utilities contacted for this study give such training to their field operators – see Table 3-1).

Recommendation: System operators and switchpersons receive specific training in error prevention strategies, including recognition of error-likely situations and specific techniques for dealing with them.

Basis: This is a common practice in the nuclear industry as a part of INPO's human performance improvement program, and is diffusing into the T & D side of the industry as utilities draw on the experience of their nuclear plants for aids in reducing errors. As a part of this training, operators should be taught to recognize when they themselves (or their co-workers or subordinates) are becoming more liable to err. Such training is given by Utility 10 to its System Operators as part of their error reduction program.

Recommendation: Utility-specific or industry incidents are used in training system operators and field switchpersons.

Basis: This is a common practice among study participants and a longstanding one among other safety-critical industries, such as nuclear power generation and commercial aviation. For example, if a US airliner experiences a malfunction for which the crew's response is critical to flight safety, within six months every crew rated to fly that aircraft in the country will have been trained on appropriate responses and practiced them in a simulator. A similar system of incident sharing among nuclear power plants is run by the US Nuclear Regulatory Commission. Although the power delivery side of US utilities does not currently have the infrastructure in place to support such sharing of incidents, participants in this project have expressed an interest in the sharing of incident data.

Recommendation: Training or information about techniques to mitigate the effects of shift work is provided to System Operators and field switchpersons who work rotating shifts.

Basis: Several participants in the present study mentioned that they had done this. Sleep deprivation and feelings of fatigue are error precursors (or error likely situations), and fatigue is a common problem among workers who are on the job when they would normally be asleep. The practice of providing training to mitigate the effects of shift work is supported by experts in the field.

Recommendation: System operators participate in the training of field personnel.

Basis: Several utilities in the present study mentioned that this was desirable because it helped to establish trust and maintain the flow of communications between field operators and the SOs with whom they work. An emphasis on face-to-face communications is one of the characteristics of the High Reliability Organizations (HROs) described in Section 2.4. This recommendation also supports the building of mutual respect and trust that Reason identified as an important aspect of a safety culture.

4.2.2 Supervision

Supervision is a secondary rather than a primary barrier against error. It is a way of maintaining existing barriers, i.e., compliance with applicable procedures and work practices.

Recommendation: Supervisors spend sufficient time with their crews to actively monitor real-time performance.

Basis: Several utilities in our study reported that they were taking steps to increase the amount of time that supervisors spent with the people who they supervise. The direct supervisor is the primary channel for communications from management, the coach and role model, and enforcer of policy. All of these things are best done through face to face contact, and to be done well all of them require more than occasional contact.

This recommendation is supported by OSHA 29 CFR1910.269(a)(2)(iii) which states: '*The employer shall determine through regular supervision and through inspections conducted on at least an annual basis, that each employee is complying with the safety-related work practices required by this section.'*

4.2.3 Discipline

Discipline is not itself a primary barrier to incorrect performance; rather, like supervision, it is a way of maintaining the effectiveness of existing barriers.

Recommendation: Personnel may be disciplined for deliberately failing to follow procedures even if the failure does not result in an incident.

Basis: Procedures are barriers to error, and strict procedural compliance is almost always adequate to prevent errors. Non-compliance is an error-precursor, if you will. Although the majority of utilities supplying information for this report stated that discipline is rarely used for errors per se, all reserved the right to use it for infractions of rules that are frequently revealed by the occurrence of an error. This is consistent with the disciplinary policies described by Thomen and advocated by Reason as a component of effective safety cultures (see next recommendation).

Recommendation: Disciplinary action following an incident is administered only for willful procedural non-compliance and in a manner that is perceived as just.

Basis: The majority of utilities supplying information for this study use discipline in this way, and many reported that their policies were adopted with the explicit goal of avoiding a climate that discouraged reporting of incidents and encouraged full cooperation with incident investigations. Reason, Woods, and others writing on safety culture emphasize that a disciplinary policy that is perceived by workers to be "fair and just" is a necessary step in the development the open communications necessary for an effective safety culture, and such communications are necessary if all errors and (especially) near misses are to be reported and investigated.

4.3 Task-Related Strategies and Techniques

Under task-related strategies, we start with a general item and then proceed to switching-specific items relating to each of the main phases in the switching process.

Many of the recommendations in this section come from the utility study and discussions of reliability-enhancing efforts undertaken by project participants. Some of the recommendations in this section are of the "everyone knows that" or "everyone does that" variety. The justification for their inclusion is two-fold. In the first place, it has come to our attention that "everyone" doesn't know or doesn't do; some commonly-accepted practices are not in fact universally applied. And, secondly, institutions as well as individuals can become lax in their observance of their own official practices.

4.3.1 General

Recommendation: The entire switching process, from the initial request for switching through filing of paperwork upon completion of the job, is performed in strict accordance with a set of complete, clear, and well understood written procedures.

Basis: Written procedures are used for critical operations in virtually all industries. Working in accordance with a set of written procedures ensures consistency in the process and its results. In addition, such procedures provide an objective set of criteria against which the performance of the task can be evaluated: they define "correct" performance. Without such a standard it is difficult to evaluate how well the process is running, and there is no objective basis (or at least none that will be universally recognized as fair or just) for discipline in the event of an undesired outcome.

Recommendation: Procedures and practices are reviewed and updated on a periodic basis by those who perform them.

Basis: We believe that this is common policy in most utilities and many other industries. Having the procedures revised by representatives of the groups that will execute them is thought to be an efficient, if informal, way of ensuring that they are written in an understandable manner and to the right level of detail for the intended users.

Recommendation: Revised documents are tested with a sample of intended users prior to being issued for use.

Basis: Although only one utility in this study reported that they made a point of doing this, it is standard – indeed required – practice for revisions to safety-critical procedures in industries such as nuclear power generation and commercial aviation.

4.3.2 Planning Switching

Recommendation: Written instructions are prepared for all switching operations for removal and restoration of equipment under both normal and abnormal conditions.

Basis: This is a nearly universal practice in electric utilities, and virtually every other industry where errors can be costly. We mention it only because it is not entirely universal, and because one of the more progressive and effective error reduction programs (Utility 24) is expanding the number of situations in which written instructions or plans are required.

The majority of errors we see in our industry seem to be simple slips (in execution of switching) or oversights (in the planning of it). Although Reason himself claims that these are probably the least amenable to correction, working from an appropriately designed written instruction (a checklist) is an effective counter to lapses in memory.

Recommendation: One-lines and other pertinent documents are used in preparing switching and are attached to or referenced in the instructions.

Basis: The specific recommendation is based on a practice recently adopted by Utility 24. This makes it much easier for the persons receiving the instructions to check them for accuracy, and somewhat less likely that an unsupervised operator in the field will skip such a review. Several utilities submitting procedures for a study of switching procedure content and format (in preparation) reference the appropriate drawings or even include them in the packet of information sent to field operators who will perform switching.

Recommendation: At least one independent person reviews and signs off on each switching instruction.

Basis: This is also a nearly universal practice among participating utilities, and was recently adopted by one of the study participants for the explicit purpose of aiding in error reduction. We were surprised that one utility reported that their instructions were not checked by a second party before being dispatched.

4.3.3 Performing Switching

Recommendation: Field switchpersons conduct a walk through of the intended switching and verify equipment status before starting to switch.

Basis: This is a long-standing practice among some utilities, though they were not in the majority in the sample. Some utilities check station normal in addition to walking through the switching procedure. In the *Failure Points* study (EPRI 1008692, 2004), a common form of incident was caused by station conditions being other than anticipated when the instructions were written (e.g., personal grounds still in place). Walk throughs prior to switching help to detect conditions so that they can be corrected or the switching can be modified to accommodate them.

This recommendation is supported by OSHA regulation 29CFR1910.269(a)(3) which states:

> *'Existing conditions related to the safety of the work to be performed shall be determined before work on or near electric lines or equipment is started. Such conditions include, but are not limited to, the nominal voltages of lines and equipment, the maximum switching transient voltages, the presence of hazardous induced voltages, the presence and condition of protective grounds and equipment grounding conductors, the condition of poles, environmental conditions relative to safety, and the locations of circuits and equipment, including power and communication lines and fire protective signaling circuits.'*

Recommendation: Use of a self-verification technique, such as the Six Steps of Switching or STAR, is required.

Basis: Use of self-verification techniques such as STAR or the Six Steps of Switching is a practice of long standing with many of the utilities in the present study. Incident reports from those utilities that use them suggest that they are effective in preventing errors in the execution of switching from written instructions if conscientiously performed. The STAR technique is trained and used at virtually all nuclear power plants in the US. Six Steps is specifically designed to prevent operation of the wrong control, the single most frequent kind of switching error. Application of the Six Steps safeguards against lapses in memory (Step 1: Carry and refer to the written instruction when switching) and slips (Step 2: Touch the control and then check it against the instructions to verify that it is the one intended).

Recommendation: Use of a formal three-part communication protocol is required.

Basis: The three-part protocol provides an opportunity to detect and correct misstatements or "mis-hearings" of information conveyed verbally. Its use is a long standing practice in many utilities, and common in aviation and the military wherever important information is conveyed verbally rather than in writing.

4.3.4 Issuing Clearances and Tagging

Recommendation: Clearance holders inspect the clearance points (with the switchperson if possible) before accepting the clearance.

Basis: This is a common (majority) practice among participating utilities. The clearance holder provides a redundant check on the accuracy of the switching, at least the most vital part of it.

Recommendation: Separate tags are hung for each clearance (for SCADA as well as in the field), resulting in multiple tagging of equipment that is common to all clearances.

Basis: The presence of multiple tags provides an additional barrier that should prevent a very specific (and very dangerous) kind of error, namely removing the tag and operating equipment without completely reading the tag. Multiple tagging is believed to be a fairly common practice, and was recently adopted by one of the utilities participating in this study in response to an incident.

This recommendation is supported by the following extract from OSHA 29CFR1910: *'If two or more independent crews will be working on the same lines or equipment, each crew shall independently comply with the requirements in paragraph (m)(3) of this section'*. [29 CFR 1910.269(m)(3)(viii)]

Recommendation: Information tags or permanent information labels warning of special conditions or equipment peculiarities are provided on field equipment and SCADA displays.

Basis: This is a common practice among study participants and in many industries where systems are complex and many components are infrequently used. In such cases, the tags provide information that the operator of the equipment may have been exposed to, but should not be expected to remember because it is used so infrequently.

Recommendation: Tags in the field for a long period of time are inspected periodically and missing or deteriorating tags are replaced.

Basis: We believe this to be a common practice among utilities. At least two of the study participants reported doing it, but it was not a question that was asked in the survey protocol. In addition, the authors are aware of incidents in which missing or badly deteriorated tags were a significant contributing factor. In our terms, this is a secondary barrier.

Recommendation: The number and locations of personal protective and other temporary grounds are recorded.

Basis: This is an aid in preventing failure to remove grounds before energizing equipment, the most common source of grounding incidents. It is an administrative barrier aimed at a single, and invariably consequential, kind of error. There have been many incidents of this type and attempts to address them have been reported in several of the conferences held by the Switching Safety and Reliability Project. Although it appears to be far from universal, this kind of documentation is consistent with standard practices that require documentation of all changes to system configuration.

4.4 Workplace Strategies

Workplace factors provide significant barriers to switching errors. The first group of workplace strategies discussed below focuses on eliminating error-likely situations in the workplace. That is, they are secondary barriers. The other two groups of recommendations focus on collecting information on the state of current barriers against errors so that deficiencies can be corrected. They are meta-barriers in the terminology of the introduction.

4.4.1 Working Conditions

Recommendation: Staffing levels are adequate to minimize predictable stress on employees.

Basis: Adequate staffing was believed to be important to error avoidance by several participants in the current study. Inadequate staffing leads to overtime, overwork, and in extreme cases, to the taking of shortcuts just to get the work done. In the utility industry, time devoted to training is one of the first casualties of understaffing. Although reduced training may not be immediately detrimental in the short term, in the long term it almost certainly undermines the effectiveness of existing barriers against error.

Recommendation: Where rotating shifts are used, the rotation schedule is optimized based on knowledge of circadian rhythms.

Basis: There is a good deal of information in the literature indicating that some shift schedules are easier to adapt to, and thus potentially less disruptive to performance, than others.

Recommendation: Distractions in the work environment are minimized by engineering or procedural controls.

Basis: Being distracted is recognized as an error-likely situation. In the nuclear industry, control rooms have been redesigned to keep traffic out of the primary operating areas.

Recommendation: Accessibility, usability, and other human factors engineering issues are considered in the design of facilities and the purchasing of new equipment.

Basis: Human Factors Engineering (HFE) analysis is a legal requirement for safety-critical systems in aviation, and most military systems as well. This is in part a reflection of the complexity of such systems, and the fact that lives depend on their correct operation. Human engineering assessment and redesign became a major initiative in the nuclear industry after it was discovered that human engineering deficiencies contributed to the accident at Three Mile Island.

Although human engineering deficiencies do not appear to play a role in the vast majority of switching errors, at least one utility in the present study indicated that human factors were being considered in the design of new substations. It is likely that HFE considerations will become more critical as the sophistication and complexity of the devices used to control the power system increases, a trend that is well underway.

Recommendation: Maps, drawings, and other job aids are updated in a timely fashion: current revisions are available to all who need them.

Basis: Drawings and other job aids are primary barriers against error. Incorrect drawings constitute traps that are almost guaranteed to result in error sooner or later. Ensuring their accuracy and availability is a form of barrier maintenance. At least two of the participants in this study are performing audits of maps and drawings because errors or near misses have been occasioned by inaccurate documentation. Document maintenance is a significant effort in all complex systems.

4.4.2 Audits

Most of the barriers to error are procedural, and most of the "holes" in the barriers result from imperfect compliance or deficiencies in the procedures themselves. Audits are a way of assessing procedural compliance. The role of audits is to allow an organization to identify the number and nature of the deficiencies in its existing barriers, i.e., whether they are adequate and working effectively, and to guide appropriate corrective action.

Widespread non-compliance with *specific parts* of a procedure is probably a sign of a defect in either the procedure itself (i.e., its contents), its written presentation (e.g., passages that are open to multiple interpretations), or the training provided in its use.

Recommendation: Regular audits are performed to ensure procedural compliance.

Basis: Several of the utilities participating in this study reported audits of SOs, far fewer reported auditing field switchmen. All six of the error reduction programs examined employed auditing as one component, and one (Utility 9) used it as the primary component of their program. Auditing appears to be more common, which is a sign that its benefits are recognized. As discussed in Section 2, Tripod Delta in the petroleum industry and the EPRI *leading indicators* work at nuclear power plants are essentially audits of very broad scope.

This recommendation is similar to the recommendation on Supervision (see above) and is addressed by the same clause of OSHA 29CFR1910.

Recommendation: Audit findings indicating procedural deficiencies, ambiguities, or misunderstanding are acted upon in a timely fashion.

Basis: Any information discovered by auditing should be used to improve operations: that is the reason they are performed. Most utilities in this study who employ auditing reported that they had instituted one or more corrections to practices or documents as a result of the audits, and all were willing to do so. Also, as Reason and others have noted, seeing that audits can directly benefit them makes the process of being audited more palatable.

Recommendation: Audit findings are posted and tracked.

Basis: With few exceptions (i.e., deficiencies in training or the procedures themselves) audit findings reveal patterns of behavior in the performance of tasks that are done very frequently. Posting results is a way of giving feedback which allows all concerned to assess their current level of performance and provides a reminder that it can be improved. In addition, the findings show the specific kinds of performance that need to be improved, thus helping to keep attention focused on these aspects of the job. Posting of findings also allows comparison on the same measures with other groups, which is thought by several respondents in the current study to inspire a spirit of competition that is also a motivation for improvement.

Tracking results is essential for assessing progress in correcting the undesirable behaviors. It is also required as a part of the next recommendation.

Recommendation: Audits have “teeth” in that they influence individual and unit performance evaluations.

Basis: Audits provide the information necessary to improve performance, and a spirit of competition among individuals or work groups can help provide the motivation to do so. However, Utility 9’s experience suggests that tangible consequences are a more effective motivation for improvement than appeals to pride alone.

4.4.3 Incident Reporting and Investigation

The practices recommended in this section are essential for learning from and responding appropriately to errors and near misses that actually occur in each utility’s system. They are *reactive* in that they do not come in to play until something has happened. Wreathall, in *Final Report on Leading Indicators of Human Performance* (2001), makes the point that success in reducing events in the nuclear industry has to date been largely the fruit of the reactive approach as set out in the following recommendations: an event occurs, is investigated and analyzed in some depth, and corrective actions are undertaken. This approach has historically been very successful – since the mid-1980s events at nuclear power plants have decreased by an order of magnitude. For this reason, the thrust of much of our work on the Switching Safety and Reliability project has been to foster adoption of this “reactive approach” to investigating and learning from switching incidents and near misses. The recommendations below are similar to those found in our earlier reports, *Collecting and Using Near Miss Information* and *Incident Investigation and Reporting*.

Recommendation: A system of incident and near-miss reporting and investigation is in place.

Basis: Incident reporting and investigation are nearly universal among utilities contributing to this study and other industries concerned with safe and reliable operation, e.g., nuclear power plants and commercial aviation. Such a system is essential if anything is to be learned from incidents. Having a ‘system’ for reporting and conducting investigations means that procedures for performing these activities are in place and personnel have been trained in their use. As is the case with any other activity where consistent and reliable performance is expected, both procedures and training are necessary for the desired results to be obtained.

Near-misses are thought to follow from the same causes as actual incidents, and to be more common. Data from this project’s 2000 *Switching Practices Survey* suggest that either the latter may not be true of switching incidents, or alternatively, that they are seriously under-reported (we suspect that the latter is the case). In any event, near-misses present an opportunity to learn about deficiencies in operating procedures or practices before they contribute to an incident that has an impact on the system.

Recommendation: Some form of root cause analysis is performed for incidents and near-misses.

Basis: In depth investigation is required to detect deficiencies in procedures and practices, and to determine appropriate fixes that will lessen the probability of a similar incident occurring in the future. Some form of “root cause” analysis is universal practice among sampled utilities and other industries concerned with safety and reliability. There is however, great variation in the formality and rigor of the processes among utilities, and between different incidents within a single utility. Analyses are applied selectively, with consequential events receiving more rigorous analysis than those with little visible effect.

The literature supports the approach to root cause analysis used by at least one survey participant: that investigations should start with the presumption that the processes used to direct the work rather than the actions of individuals are somehow at fault (see the discussion of root causes in *Incident Investigation and Reporting* (EPRI 1002077, 2003).

Recommendation: Reports of incidents and the findings of investigations are widely disseminated, including to senior management and training staffs.

Basis: This again is a nearly universal practice among sampled utilities and other industries concerned with safety and reliability. In *Collecting and Using Near Miss Information* we argued that dissemination of such reports served to both remind employees of the error potential in their own day-to-day activities and to motivate them to maintain their own vigilance and procedural compliance.

Recommendation: Actions to correct deficiencies identified through incident investigation are undertaken in a timely fashion.

Basis: Correction of deficiencies is the primary reason that investigations are conducted. “Institutional learning” has no meaning unless the behavior of the members of the institution are changed in some way. Reason (1997) and other literature cited in our earlier report, *Incident Reporting and Investigation*, makes it clear that *being seen to result in changes* is critical to maintaining the motivation of workers to participate in a reporting system. Where the utility is large enough to experience several incidents a year, we recommended in *Incident Reporting and Investigation* that incident reports be reviewed by a committee that looks for trends and has sufficient authority to implement corrections at whatever level required.

4.5 Cultural Factors

“Culture” is manifest in the behavior of individuals as well as in the behavior of the organization as a whole. The appropriate culture greatly facilitates the discovery of weaknesses in the system by which operations are conducted, and the workforce’s acceptance of safety-or reliability-enhancing changes (e.g., additional barriers). Although it cannot eliminate them entirely, a culture that engrains and actively reinforces punctilious observation of desired practices can help individuals to avoid slips and lapses. A culture that encourages a questioning attitude and the free flow of information is in a better position to detect error-producing conditions before they can affect the system.

Cultural level methods include practices associated with creating and maintaining the elements of a safety culture described in Section 2.4. Both Safety Culture and the culture of HROs emphasize the critical importance of attitudes and ways of approaching work, rather than organizational structure as such. These are in a sense “free” because they require no investment in hardware or programs, but may require changes in mindset, which is neither easy nor quickly accomplished, and they require leadership by example.

Because so much of utility work is explicitly focused on providing reliable service, it would seem likely that many of the elements of a safety or HRO culture are already in place. We are certain that many of the appropriate attitudes exist among many individuals in T & D operations. Although the existence of a cadre of “enlightened” individuals does not constitute a culture, it is certainly a valuable resource in creating one, and a definite “leg up” on the process.

Reason (1997) thinks culture evolves from practices and that a safety culture can thus be “engineered” by instituting appropriate practices. Some of these practices such as disciplinary policies that are perceived as fair and “just”, and incident analyses and audits to detect and correct weaknesses in barriers to incorrect performance, have been presented earlier in this section. Others are discussed below.

Recommendation: System operators and switchpersons are empowered to stop work if they are not confident the switching they are performing is correct.

Basis: Uncertainty or more accurately, proceeding despite uncertainty, is a common precursor to error. “When in doubt don’t” has been a watchword within HROs for several years. In addition, this is a common (though not, to our knowledge, universal) and long standing practice within the utility industry.

Recommendation: System Operators and switchpersons are encouraged to take the time needed to perform a job correctly “by the book” and not to rush. They are empowered to stop or slow the pace of work to compensate for fatigue, overload, or other error-producing conditions.

Basis: This is a way of dealing with common error-producing conditions, and was mentioned as an aid to error avoidance by six of the utilities surveyed for this study. It is a counter to perceived time pressure, which is a factor cited in a significant proportion of switching errors, particularly those committed by system operators, who are frequently involved in overseeing two or more jobs being performed more or less simultaneously.

Recommendation: Individual responsibility and accountability are encouraged.

Basis: This is a key element of safety cultures and HROs. Among other benefits, it helps to ensure that conditions that may contribute to error are brought to attention so that they can be corrected.

Recommendation: A “questioning attitude” is encouraged.

Basis: This is mentioned as an important characteristic in the literature on safety culture and HROs. A questioning attitude helps to detect potential problems before they result in an actual error or incident.

Recommendation: Opportunities are provided for face-to-face contact between system operators and field personnel.

Basis: Several utilities in the present study mentioned that this was desirable because it helped to establish trust and maintain the flow of communications between field operators and the SOs with whom they work. It is also mentioned as a consistent and culturally-valued characteristic of HROs.

Recommendation: Senior management is *personally* involved with the error reduction efforts, including participation in incident review meetings (and membership and regular participation in the incident review committee if one is established).

Basis: Senior management participation increases the “clout” (effectiveness) of the committees on which they serve, and is also among the most convincing ways that management can communicate the importance with which it views error avoidance. This is also a key recommendation from Thomen (1991) on the safety practices and safety culture at DuPont.

Recommendation: Management communication is frequent, clear, and consistent as to the priorities it accords safety and reliability, and how these priorities relate to other potentially competing priorities such as timeliness, efficiency, utilization of available resources, etc.

Basis: No one doubts that safety and reliability are important to management. However, the knowledge of this importance among the workforce tends to be taken for granted, and the vast majority of communications in most organizations is directed at operational goals that may, under some circumstances, appear to conflict with the "baseline" or "bedrock" goal of safety. Thomen (1991) emphasizes that frequent communication, by personal involvement in safety-related activities as well as by words, is a very important element of the very successful safety culture at DuPont.

4.6 Choosing Among Recommendations

Because some of the approaches recommended above are expensive in light of the already small probability of error in switching tasks, and the fact that none can guarantee its complete elimination, it is recognized that it is likely that they will be applied selectively, where the potential payoff is judged to be largest.

Selection of recommendations for implementation may be based on criteria such as:

- Those that are effective across a wide range of switching tasks (for example, self-checking has proved to be a particularly effective technique).
- An evaluation of the risk attached to *not* implementing the measure. This may lead to selective application of certain barriers. For example, additional precautions may be appropriate where switching involves critical customers or the high voltage grid.
- The need to address a particular localized vulnerability exposed by an incident of some sort (a number of practices intended as barriers to a specific kinds of errors are given in Section 3).
- Corrections or enhancements that are do-able within a given context (e.g., it may be easier to place tags warning of design peculiarities on control panels, instructions, drawings, and SCADA displays than to re-design a substation).

The weight given to current utility practices reported in Section 3 should reflect the limitations inherent in this study, particularly the paucity of quantitative data as to the effectiveness of individual techniques. Nonetheless, concurrence by different participants in use of a given practice is, at the very least, an indication that the practice is worthy of consideration, particularly if it is a practice that is endorsed by the literature in the field.

4.7 A Final Note

Both Reason and Woods note that a major challenge in implementing safety or error reduction programs is "*persisting in the face of success*." In his testimony to US Senate hearings on the loss of the space shuttle *Columbia*, David Woods (2003) notes that in organizations where there is competition for limited resources and a rapid pace of change the temptation is to divert resources from an apparently successful effort to other pressing priorities. He makes the point that it is at just those times where resources are most urgently needed elsewhere that they are also needed for safety because the system is under added strain from the challenges it is facing (including scarcity of resources).

Too often, success in error reduction or safety leads to complacency: that there are no incidents is taken as evidence that "the problem" is "solved." What success really means (aside from random fluctuation in the occurrence of infrequent events) is that the problem is being controlled. Safety/error avoidance is a process to be performed rather than a state that can be achieved once and for all. If the process is neglected, the errors and incidents will return.

5
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A
PARTICIPATING UTILITIES AND UTILITY CONTACT PERSONS

Alabama Power, Dile Brooks

American Transmission Company, Don Morrow

BC Transmission Company, Bob Stone

Bonneville Power Administration, Wade Walter

Consolidated Edison Company of New York, Rudy Francin and Gerry Rumold

Consumers Energy, Linda Perez

Dairyland Power Cooperative, Larry Ryberg

DTE Energy, Arlene Agy

Duke Energy, Eric Linker

Electric Energy Inc., Jerry Boggess

Great River Energy, Richard Hendrickson

Hawaiian Electric Company, Dean Mizamura

Hydro One Networks, Chris Cooper

Lower Colorado River Authority, Jerry Willms

Mid American Energy, Nick Gill

Northeast Utilities, Jim Jiottis

New York Power Authority, Mike Murtagh

New York State Electric and Gas, Mike Craven

Pacific Gas & Electric, Bob Cooper

Public Service of New Mexico, Richard Krajewski

Tennessee Valley Authority, Calvin Underwood, James Regg, and Richard Dearman

TriState G&T, Robert Eubank

United Illuminating Company, Joe Flach

Western Area Power Authority, David Waag

B
QUESTIONS USED IN TELEPHONE SURVEY OF PARTICIPATING UTILITIES

1. Do you have a problem with switching errors? If so, what are you doing about them: if not, to what do you attribute this? (Big picture questions)

   (If yes, the organizational side of it is very important: is it part of a larger corporate initiative or a local patchwork?)

2. Does your utility have any *programs or practices* intended to reduce human errors or increase human reliability?

3. Has your utility developed or employ *training* materials or presentations related to error prevention or awareness (see big sheet):

4. Are there any characteristics /conventions of any of the following (from supplemental list) that are intended to promote error reduction/enhance ease of use: or that you *think* promote reliability? Has your utility made any changes in any of these to promote reliability?

5. Do you draw on other company resources, e.g., safety, consultants, HPES folks from your nuclear plants?

6. Does your utility have any practices (recent or of long standing) that were adopted explicitly to minimize errors, or that seem to be effective in reducing errors?

Supplemental questions following outline of Chapter 2

Person-Centered Approaches

1. Is routine scheduled switching written by the **SOs** or **field** people?

2. Is routine scheduled switching checked by someone other than its writer before being Ok'd for Dispatching? Y N

   If yes, how long have you been doing this?

3. Is refresher training on Switching and Tagging procedures required for

   Field operators: Y N How many hours _______ how frequently ______
   System operators: Y N How many hours _______ how frequently ______
   Any changes lately?

4. Are operating errors and lessons learned routinely incorporated into training sessions?

   Field operators: Y N How frequently ______
   System operators: Y N How frequently ______
   Any changes lately?

5. Are supervisors required to spend time on the job site observing their crews?

   Field operators: Y N How many hours _______ how frequently ______
   System operators: Y N How many hours _______ how frequently ______
   Any changes lately?

6. Is discipline used to enforce observance of procedures and work practices?

   Field operators: Y N How frequently ______
   System operators: Y N How frequently ______
   Any changes lately?

7. Is training to recognize and avoid error-likely situations a part of the training in initial, refresher, or special one time classes?

   Field operators: Y N Init Ref 1-time
   System operators: Y N Init Ref 1-time
   Any changes lately?

8. Are operators trained in techniques to help minimize the adverse effects of shift work?

   Field operators: Y N Init Ref 1-time
   System operators: Y N Init Ref 1-time
   Any changes lately?

Task-Centered Approaches

1. Are face-to face meetings between dispatchers & field switchmen routinely held before beginning a job? Y N

2. Are field operators required to

   – review the switching line by line with the dispatcher before beginning? Y N
   – review switching instructions against one lines before beginning a job? Y N
   – walk down the switching before beginning to perform it? Y N
   – walk down completed switching before reporting it complete? Y N
   – use a self-verification such as six steps of switching when performing switching?

Y N

3. Is two-man switching used on any jobs? Y N

   Which? ________________________

4. Is independent review by a second party used on any jobs? Y N

   Which? ____________________

5. Are "information labels" or tags used on SCADA or field equipment? Y N

6. Are locks used in the field individually keyed? Y N

   Which? ______________________

7. Are interlocks provided to prevent the non-sequential operation of critical controls? Y N

Workplace & Organizational factors

1. Is there a program of near-miss reporting? Y N
2. Are errors and incidents investigated? Y N
3. Is some attempt at root cause analysis used for at least some incidents? Y N
4. Are reports of incidents and investigations widely circulated? Y N

   To whom? __________________

5. Are reports reviewed by a committee that analyses and trends them? Y N
6. Are reports routinely reviewed by senior management? Y N

   Who? _______________________

7. Are compliance audits of work in progress (non safety audits) performed routinely?
   Field operators: Y N How frequently ______
   System operators: Y N How frequently ______
   Any changes lately?

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