EPRI

Switching Practices Survey

Toward Improved Safety and Reliability

Technical Report

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Toward Improved Safety and Reliability

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Topical Report, June 2000

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REPORT SUMMARY

Switching safety and reliability are ongoing concerns in the utility industry. This report summarizes the results of a survey of utility practices in switching operations and relates these practices to the rate at which switching errors or incidents are experienced.

Background

Improperly performed switching operations can create unsafe conditions that may result in injury or death of utility personnel, lower system reliability or ability to respond to contingencies, and cause customer outages with a consequent decrease in customer satisfaction and potential loss of revenue. In 1996, EPRI published a report entitled Field Operation Power Switching Safety (TR-106465), which presented initial data on the incidence, effects, and causes of errors in switching operations. Publication of the report was followed in June 1997 by a conference to share information about programs and tools to enhance safety and reliability in their own utilities. As an outgrowth of that conference, EPRI is sponsoring an ongoing project to identify practices that can help utilities reduce switching errors and thereby improve personnel safety and reliable performance. A major part of this project has been an industry-wide survey to collect data on switching-related practices in the areas of personnel and training, planning switching, implementing switching, and incident investigation and reporting. This report provides a summary of the survey results and analyses relating switching practices to error rates.

Objectives

- To provide a descriptive “snapshot” of current utility practices related to power switching safety and system reliability.
- To identify commonalties and differences in those practices.
- To provide data on which to base the first steps toward development of a set of industry "best practices" and eventual standardization.

Approach

Following the 1997 conference, a small Steering Committee was formed to guide the collection and dissemination of additional information on practices related to safety and reliability. During the conference it was apparent that there is considerable variation in how utilities conduct their operations. The present survey was proposed as a way of collecting information on the commonalties and differences among work practices in the industry. The Steering Committee suggested the topics for exploration in the survey and helped to formulate the particular items related to each area. The survey contained five sections requesting information on error rates, the selection and training of switching personnel, practices related to planning switching, practices followed when executing switching, and the investigation and follow-up of switching incidents.

Many of the items were designed to elaborate or shed light on information collected during the earlier EPRI study. Surveys were mailed to all participants in earlier project conferences and to members of mailing lists obtained from EPRI and other industry sources.

Results

This document provides a summary of responses to the *Survey of Switching Practices* conducted in 1998 and 1999. Data from 159 surveys returned by operating units of 133 utilities are included in this analysis. The data from each survey item are presented in tabular form, supplemented by appropriate graphics to help portray the range of variation that exists for many common practices. The analysis also identified a few work practices for which there were substantial and statistically reliable differences between a group of "low–error" and a group of "high–error" respondents. These results are reported as "findings" of the study. Careful examination of these findings, together with the areas of industry consensus as reported on the survey and the experience of other safety-critical interest, has enabled the investigators to develop a preliminary set of industry best practices. The report concludes by suggesting additional avenues of investigation to develop and confirm the list of best practices and provide better understanding of their transferability industry-wide.

EPRI Perspective

Safety and reliability are paramount concerns in all aspects of utility operations. Day-to-day switching operations are subject to variations that can lead to errors and accidents that can endanger personnel, cut off customers, and compromise system reliability. This report summarizes the results of a survey of utility practices employed in the planning and execution of power switching operations and provides data relating these practices to the incidence of errors. Several lines of evidence are presented that some current switching practices are candidates for consideration as "best practices."

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Keywords

Safety practices
Switching
Power system operation
Power system control

ABSTRACT

EPRI is sponsoring an ongoing project to identify 'best practices' that can help utilities to reduce switching errors and thereby improve reliable performance. Part of this project was an industry-wide survey to collect data on switching-related practices in the areas of personnel and training, planning switching, implementing switching, and incident investigation and reporting. This report provides a summary of the survey results and findings relating switching practices to error rates, as well as a preliminary list of best practices based on the data.

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1
INTRODUCTION

This document provides a summary of responses to the *Survey of Switching Practices* conducted in 1998 and 1999 to collect data on switching-related practices in the areas of personnel and training; planning switching; implementing switching; and incident investigation and reporting. The Introduction provides background information to the study and provides an overview of survey goals and approach. Section 2 provides more detail on the respondent sample and the methods used to collect and analyze the data. In Section 3, the method used to establish error rates and the statistical methods used to correlate error rates with switching practices are described. Section 4 presents the survey results and Section 5 draws implications for switching Best Practices.

Background: An Industry in Transition

The 1990s have been a period of unprecedented change in the electric power industry:

- Deregulation and increased competition have resulted in a drive to accomplish the same or more work with fewer people.
- Corporate downsizing, mergers, and re-organizations have often resulted in crews from different corporate cultures used to different procedures and different terminology working together.
- Downsizing has also led to the loss of many experienced personnel; and mergers or consolidation of geographic operating areas have frequently resulted in even the most experienced personnel being less familiar with some of the equipment and people with which they must work.
- Contracts with major customers and agreements with local public service commissions now routinely include penalty clauses if a predetermined high level of reliability is not met. So, the burden of increased reliability is increased just as the means for providing it are being more thinly stretched.
- New operating agreements, under the rules of the deregulated industry, combined with changing technologies and philosophies of maintenance have led in many places to an increase in the requests for clearances and associated switching.
- Rapid changes in technology promise increased efficiency and support for the human operator, but (at least temporarily) the innovations burden the people who operate the system with additional and often complex tools to master while performing their primary duties.

While innovation is not in itself detrimental to safety, and all personnel in a utility are generally deeply committed to maintaining safety, there is often the assumption on the part of management

and engineering that safety and reliability are problems that "have been solved." Whereas the operations people are more acutely aware that safety is the product of their constant vigilance [1]. With so many changes competing for their attention, many operations people fear that safety may not get the attention that they know it requires.

In 1996, EPRI published *Field Operation Power Switching Safety*, EPRI TR-106465 [2], describing the results of a project initiated in June of 1993 as a tailored collaboration with Consolidated Edison Company of New York. The project used questionnaire data and an analysis of over 400 incident reports, contributed by the study's participants, to catalog the causes of switching errors and strategies used by utilities to enhance system reliability and personnel safety. As a part of that project, a meeting was held in June of 1995 to describe the findings to the study participants and other interested utilities. Several attendees at that meeting felt that their own error rates were increasing, and were then in the process of developing programs to reduce errors in their own operations. In addition, there was a general recognition that incidents that reduced reliability were becoming increasingly unacceptable in the more competitive market into which the industry was moving. But, many of the changes described in the preceding paragraph, and perhaps the rapid pace of change itself, were creating situations in which safety could be reduced.

Following publication of the report, several attendees at the June meeting expressed an interest in a follow-up meeting for people to share information about programs and tools to enhance safety and reliability in their own utilities. A conference for that purpose was held under EPRI sponsorship in June 1997. Following the 1977 conference, a small steering committee was formed to guide the collection and dissemination of additional information on the topic. Members of the committee believed that safety and reliability were functions of the day-to-day work practices rather than special programs. During the conference it was apparent that there is considerable variation in the procedures and work practices used in the conduct of routine operations. The present survey was proposed as a way of collecting information on the commonalties and differences among work practices in the industry.

Survey Goals

The survey had three goals:

- To provide a descriptive "snapshot" of current utility practices related to power switching safety and system reliability.
- To identify commonalties and differences in those practices.
- To provide data on which to base the first steps toward development of a set of industry "best practices" and eventual standardization.

The information may also be used to help EPRI's Energy Delivery and Utilization Division to prioritize research needs in the next few years.

Survey Development

The Steering Committee formed after the 1997 conference suggested the broad topics for exploration in the survey and helped to formulate the particular items related to each area. Committee members are listed in Appendix A. Committee members also reviewed several drafts of the survey for completeness and clarity.

After several drafts, sample surveys were sent to eight individuals who had participated in the 1997 conference or the 1994 survey reported in EPRI TR 106465. The pilot survey was conducted to verify that a knowledgeable individual could complete the survey form in less than half an hour. Participants in the pilot survey were requested to report any ambiguities in wording or anything they felt had been left out. Several minor changes in wording were made before the final survey was mailed out.

Surveys were mailed to all participants in the 1995 and 1997 conferences and to members of mailing lists obtained from EPRI and the NERC website. Additional surveys were sent out in 1999 to enlarge the database in terms of both numbers and representativeness.

Survey Content

The survey contained five sections requesting information on error rates, the selection and training of switching personnel, practices related to planning switching, practices followed when executing switching, and the investigation and follow-up of switching incidents. Many of the items were designed to elaborate or shed light on information collected during the earlier EPRI study. The content of many items reflected practices that utilities participating in the earlier study had adopted to help reduce operating errors.

Because of the differences in terminology across the industry, an addendum describing how selected terms, such as clearance, switching instructions, and others that may be subject to different interpretations, were used in the survey. This addendum was included with all 1999 mailings. The survey form and addendum are presented in Appendix B.

2
DATA TABULATION AND ANALYSIS

The Sample

Number of Respondents

Responses from 159 respondents representing operating units of the 133 utilities listed in Appendix B are included in this analysis. Although 159 is a relatively small sample from a statistical point of view, it is more than three times as many responses as were obtained in the survey that formed the basis of the 1996 report on switching practices [2] for which this study is a follow-up.

Respondents were asked to submit separate surveys for Distribution and Transmission operations. Some indicated that the information applied to both groups. The respondents are categorized as follows:

- Transmission 83
- Distribution 54
- Both transmission and distribution 22

Size of Utilities

A second means of categorizing utilities or their operating units is by their size, which may be described in a number of ways: peak load, size of the service area, number of customers, etc. These measures are highly correlated, but produce different orderings. Because the survey focused on switching practices, we have categorized survey respondents in terms of the amount of switching they perform, quantified as the number of requests for switching. This number represents the volume of routine scheduled switching and is used as a surrogate for the total amount of switching performed. Although it does not include all switching, this value was chosen because most utilities track the number of switching requests, but few track the amount switching performed remotely from the control center for other purposes, such as voltage regulation. The distribution of the number of switching requests processed by responding utility operating units is shown in Figure 2-1 (note that the intervals are logarithmic).

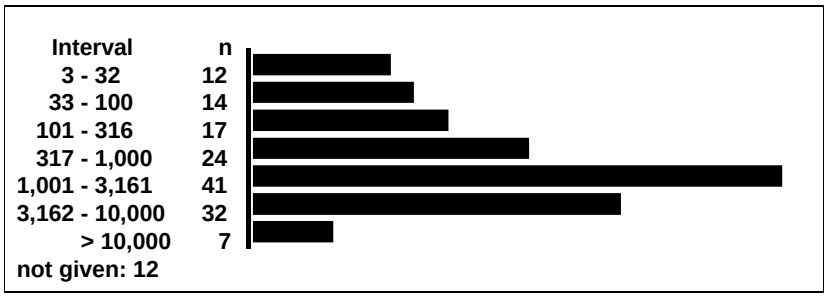

Figure 2-1
Switching Requests Processed Annually by Survey Respondents

Selection of Responses

The surveys analyzed were selected from 196 that were returned. All 196 were not used for the following reasons:

- Several utilities submitted multiple responses, e.g., from different operating centers as well as their Transmission and Distribution departments. Although it is recognized that regional operating centers in many utilities operate quasi-independently (almost as though they were separate), it was desired to keep these "over-represented" utilities from having an undue influence on the data. Thus a maximum of two surveys from each utility were retained, one for transmission and one for distribution. Twenty-two (22) surveys were excluded as redundant under this rule. Where it was necessary to exclude surveys, the choice was made among the duplicates on the basis of apparent completeness of the data given.
- Twelve non-redundant but very incomplete surveys were excluded from the compilation.
- In addition, three surveys from utilities outside North America were excluded to make it easier to characterize the sample.

In interpreting the data it should be kept in mind that the survey respondents were self selected and thus do not represent a truly random sample. In addition, the sample was not stratified so that major groups were represented in proportion to their occurrence in the population of utilities. For example, the ratio of surveys from Distribution operating units to those from Transmission units was approximately 3:5. This is likely the reverse of the ratio in the population of North American utilities. It is possible that these factors bias the results in unknown ways. For example, the proportion of utilities reporting using simulators in training might be different if there were more cooperatives and fewer large investor-owned utilities in the sample.

Data Compilation and Reporting

Data Compilation

Most survey items required the respondent to check a box if the statement applied to his utility. These "yes/no" responses are presented as proportions or percentages of the total number of

surveys in the group, less any blanks for non-response to that item. The survey was designed to be completed with a minimum of research; many respondents left blank those items of information that were not readily available or of which they were uncertain. Blanks were most common for those questions relating to the training of different kinds of personnel and those items requiring that a number be entered for the response.

Some items required the respondent to enter a number. These items are reported as the average of the values supplied, along with the highest and lowest values. The distribution of values provided in response to selected questions are also provided in the report. In those cases where the respondent supplied a range rather than a single value, the mid-point of the range was entered. For responses that explicitly or implicitly asked for a minimum and the respondent supplied a range, the lower end of the indicated range was entered.

Presentation of Data

Section 4 of this report presents the data in response to each of the questions in one of three forms, depending on the nature of the data:

- Simple tabulation of responses from the 159 surveys analyzed.
- Figures showing distributions of values for those items requesting that a number be entered.
- Write-in answers. A few items required respondents to write in an answer, and many had a space for additions or amplifying comments. In general, there were very few additions or amplifications. Brief summaries of the responses are reported where germane.

Tabulations

Data are reported as percentages, averages, minimum values, or ranges depending on the question asked.

Each table generally contains three sets of data. The “Overall” percentage or averages reported are based on response from the entire set of 159 surveys. Because practices often differ between the Distribution and Transmission departments within a given utility, responses from Distribution and Transmission units are tabulated separately, as the second and third columns in the table. These tabulations are subsets of the Overall data. Where a single survey was completed for both Distribution and Transmission, the data are included in the Overall column but NOT in the Distribution and Transmission columns. This is done to highlight differences between Distribution and Transmission practices where they may exist, and to avoid “double-counting” the data.

Where the responses are reported as the percentage of responses (the vast majority of cases), two values are given within each cell of the table. The first is the percentage of those responding who checked the “yes” box for each item. The second number (in parentheses) is the number responding to the item. The number responding was frequently less than 100%. In some cases this was due to the nature of the item itself. For example, only those who had a program of periodic refresher training could answer the questions about the interval at which training was administered. In some cases the item was simply left blank, presumably because accurate

information was not readily available. There are also a few blanks where the utility chose not to release the information (e.g., number of errors).

The survey contained several items where the respondent was asked to check all that applied. In these, the statements listed were usually not mutually exclusive; so, the proportions given in a table frequently do not add up to 100%.

3
THE INCIDENCE OF SWITCHING ERRORS

This section discusses the definition of error and error rate used in the study and the statistical methods used to relate error rates to switching practices.

Definition of Error

The definition of error is critical to any scientific understanding of the causes and prevention of errors. A consistent definition is necessary for error statistics to have any meaning. To determine the types of incidents commonly recorded as switching errors, survey item V.1 provided a list of five common kinds of incidents and asked respondents to check all that would be classed as "switching errors" in their utility. The responses are shown in Table 3-1. They indicated a fairly strong consensus on all the actions/consequences included in definitions of error or incident, with the exception of mis-operation of equipment. There were few additions to the list, although several respondents differentiated between "errors" and "incidents," reporting that the term "error" was used only if there was a violation of a procedure. However, respondents indicated that all of the mishaps listed—regardless of the definition used—are considered cause for an investigation and appropriate follow-up action.

Table 3-1
Components of the Definition of Operating Incident or Error

Item V.1. Actions/consequences included in utility definitions of an "operating error" or "incident" (proportion of those responding)			
	Overall % (n)	Distribution % (n)	Transmission % (n)
Personal injury	85 (158)	89 (54)	88 (82)
Damage to equipment	84 (158)	85 (54)	87 (82)
Loss of service to customers	92 (158)	100 (54)	87 (82)
Violation of procedures	86 (158)	89 (54)	87 (82)
Mis-operation of equipment	75 (157)	72 (54)	80 (81)

Error Rates

Error rates were calculated as the ratio between the number of errors reported per year, as tabulated by each utility using **its own definition** of error or incident, and the number of switching requests processed annually (survey item I 3a). Use of the utilities' error data was considered unlikely to significantly distort the data because of the high level of agreement on situations constituting an error as shown in Table 3-1 and the paucity of write-ins that differed substantially from the items in the list.

One hundred and twenty (120) of the 159 surveys supplied the two values necessary to calculate error rates. That roughly 20% of the sample did not supply the necessary information is, unfortunately, not surprising. Some do not track or would not release the number of switching requests; many (especially among the smaller utilities) do not have a sufficient number of errors to have a tracking system in place to track the numbers; and some utilities that do track errors consider error numbers sensitive information.

The calculated error rates from the present survey and the data reported for 28 utilities in EPRI TR 106465 [2] are shown in Figure 3-1 below. Note that the intervals in the figure are logarithmic, and values falling within a given interval can differ by a factor of 3. The lowest interval includes those reporting error rates of zero (12 in the current survey and 2 in the EPRI TR data).

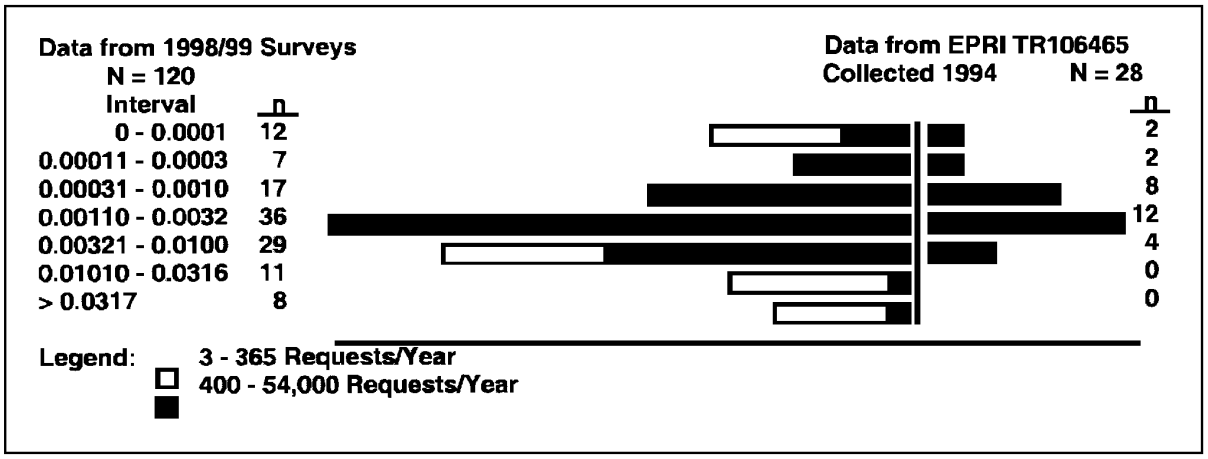

Figure 3-1
Comparison of Error Rates calculated from Survey responses to those reported in EPRI TR-106465

Examination of the figure shows that the modal error rates are very similar in the survey sample and the sample from the earlier EPRI study; but, the number of rates falling into the tails of the distribution is much larger in the more recently collected survey. The differences at the extreme ends of the distribution are largely attributable to the data from the smaller utilities, and we believe that it is more reasonable to consider them to be due to the denominator effect than to any inferred superiority or inferiority of operating practice.

When tabulating the data, we noticed that smaller utilities tended to have more extreme calculated rates. Examination of the data showed that almost all of the "high" error rates for utilities that report relatively few switching requests are due to one or two errors. We believe this is largely the result of what may be called the "denominator effect." For example, a utility processing 250 requests a year will have error rates that are multiples of 0.004 (itself a fairly "high" rate by the standards of the earlier EPRI data) unless that rate is zero. Thus, if they experience any errors at all, the "high" error rates for those who do relatively little switching may be determined more by the small denominators rather than a high number of errors. For the same reason, zero error rates for the utilities that do little switching are ambiguous. They may reflect superior practices or simply that flaws in the system have had insufficient opportunities to reveal themselves.

To examine the influence of the denominator effect on our results, utilities were divided into two groups. The first group consisted of those who have fewer than 365 switching requests a year (the number was arbitrarily chosen to represent one a day on average). The error rates for these utilities are shown by the open bars in Figure 3-1.

Relating Operating Practices to Error Rates

A major premise of attempts to enhance safety and reliability is that the occurrence of error may be reduced by proper work practices. A secondary goal of the survey was to help to identify such practices. Accordingly, an attempt has been made to identify practices that are associated with lower error rates. The strategy used is to form a group of utility operating units having low error rates and a group having higher error rates, and to compare the proportions of each group reporting specific work practices via the survey form.

Approach

The following analysis is based on a comparison of the survey responses from a "low–error" group of the 28 utilities that had the lowest calculated error rates to those of a "high–error" group of the 28 who had the highest rates. Because of the denominator effect described above, these groups were drawn from those utilities in the sample reporting processing more than 365 switching requests a year. The error rates in the "low–error" group ranged from 0 to 0.001. The rates in the "high–error" group ranged from 0.0024 to 0.048.

Error rates form a continuum with no natural break points. What is a "high" rate and what is a "low" one is largely a mater of perception (and **any** non-zero rate is likely to be considered "too high"). The groupings of "high–error" and "low–error" operating units are arbitrary, and represent a compromise among a number of factors:

- The groups should be as large as possible to be representative of their respective groups, and to increase the power of the statistical tests applied to them.
- It is desirable to exclude some portion of the middle range to increase the average difference in error rates between the two groups.
- Utilities reporting less than 365 switching requests a year were excluded from the analysis. "High" error rates for those who do relatively little switching are often determined more by

the small number of switching requests used as the denominator in the rate calculation than by a high number of errors. "Zero" error rates for them may reflect "good luck" as much as superior practices. This consideration excludes the 50 utilities that do relatively little switching, or 31% of our sample.

Cases chosen for analysis were chosen without respect to whether they represented responses for Distribution, Transmission, or both. The 56 surveys used for this analysis are categorized as shown in Table 3-2.

Table 3-2
Comparison of Low–vs High–Error Samples to Overall Sample of 159 Utility Operating Units

Comparison of Low–vs High–error sample to overall sample of 159 utility operating units (n = the number in each group)			
	Low–Error % (n)	High–Error % (n)	Whole Sample % (n)
Distribution	36 (10)	36 (10)	34 (54)
Transmission	43 (12)	57 (16)	52 (83)
Both transmission and distribution	21 (6)	7 (2)	13 (22)

Statistical Analysis

As detailed below, there are differences between the proportions of the two groups reporting many of the practices addressed in this survey. Many of these differences may be more apparent than real, due simply to minor variations in the sample. To avoid being misled by such normal variations, we have used inferential statistics to test the differences. The two tests used were:

- The Chi-square ($\boldsymbol{X}^2$) test for the significance of the difference between two proportions using categorical or yes-no data. These tests were calculated using the "crosstabs" function of the Statistical Package for the Social Sciences (SPSS) software [3].
- The independent sample ***t***-test of the differences between the means of continuous variables. For this study we used a more conservative version of the ***t*** test that does not assume that the variance in the two samples is equal, as this was very frequently the case. These tests were also performed using SPSS.

For these analyses we have used a statistical rejection criteria of $p < 0.10$, two-tailed. This means that there is less than a 10% probability that the differences between the two groups being compared reflect simple random variation in samples drawn from the same underlying distribution. When differences meet this statistical criterion, the exact probabilities reported by SPSS are shown in the tables in Section 4. The $p < 0.10$ is rather liberal (10% of the findings could be due to chance variation alone), but is largely offset by our use of two-tailed tests, which assume that the direction of the difference between the two groups is not predicted in advance. However, for most items it would be expected, *a-priori*, that the low–error group would exhibit "more" of the item being tested (a higher value or a greater proportion of "yes" responses).

Reporting of Error Analysis Results

The results of the error analysis are presented in Section 4 alongside the tabulations and descriptive results from the respective survey question. Results for the high–error and low–error groups are reported together with the results of the appropriate statistical test. For the most part, the results are only presented where a finding of statistical significance was obtained. However, some results where there was an interesting difference between the two groups that did not achieve statistical significance are also included. Statistically significant results of the error analysis are reported as findings.

4
SURVEY RESPONSES

The material presented in this chapter is organized by survey section and item. The survey item number is shown at the top of each data table. The data includes both tabulations and distributions, as described in Section 2 and error data.

The comparison of high– and low–error groups described in Section 3 identified several practices where there was a substantial and statistically reliable difference between the proportions of the two groups reporting following a particular practice. These results are reported as "findings" in this section where applicable. These differences **may** contribute to the observed differences in error rates.

Data reflecting differences between the low– and high–error groups supporting the findings are presented in tabular format. Items for which there were no meaningful differences are not shown. However, in some cases there appear to be trends across several parts of a multi-part item for which the differences between low– and high–error groups on the individual parts did not achieve statistical significance. In such cases the data are presented and discussed.

Background Information

Range of Voltages

Voltage ranges covered by respondents' answers are shown in the table below. Not unexpectedly, the high voltage range for distribution overlaps the low voltage range for transmission. Average low and high values are numerical and do not imply that these were actual voltage values cited by respondents.

Table 4-1
Voltage Levels Included in Distribution and Transmission Groupings

Background Information Item: Voltage Levels Covered by Survey Submitted				
	Low Voltage	Low Voltage (mode)	High Voltage (mode)	High Voltage
Distribution (51)	120 V	4160 V	34.5 kV	138 kV
Transmission (77)	480 V	69 kV	345 kV	765 kV
Combined Distribution and Transmission (21)	2.4 kV	4 kV	230 kV 345 kV *	500 kV

* Evenly distributed between 230 kV and 345 kV.

Section I: Respondent and Organizational Data

Respondent's Responsibilities

The majority of the respondents were based in the control center. As the numbers indicate, some respondents reported that they were also responsible for switching in substations or on the lines.

Table 4-2
Respondents Responsibilities in Relation to Switching

Item I.1. Respondent's responsibilities in relation to switching, as the percentage of respondents in each group (proportion of those responding)						
	Overall		Distribution		Transmission	
	%	(n)	%	(n)	%	(n)
Control Center Operations	85	(159)	81	(54)	87	(83)
Switching in Substations	58	(159)	59	(54)	53	(83)
Line Switching	57	(159)	63	(54)	52	(83)

Switching Authority

In the majority of companies, the Control Center has switching authority. In a very few cases authority is **shared** between the Control Center and Substation or Line operations.

Table 4-3
Organizations with Switching Authority

Item I.2. Organization with switching authority (as percentage of respondents in each group)						
	Overall		Distribution		Transmission	
	%	(n)	%	(n)	%	(n)
Control Center	96	(159)	94	(54)	99	(83)
Substation Operations	8	(158)	8	(53)	5	(83)
Line Operations	9	(157)	13	(53)	2	(83)

Number of Switching Requests

In this report, the number of requests for routine switching processed annually is used as a measure of the size of the utility. In the final sample, this value varied over a very wide range. Judging from the predominance of round numbers in the data, most of these were estimates rather than exact counts.

Table 4-4
Annual number of Switching Requests

Item I.3a. Average number of switching requests (R) processed annually by responding organizations						
	Overall		Distribution		Transmission	
	R	(n)	R	(n)	R	(n)
Average	3,488	(147)	2,225	(50)	4,120	(76)
High Value	**54,000**		**10,000**		**54,000**	
Low Value	**3**		**3**		**4**	

The distribution of the number of switching requests processed by responding utility operating units is shown in Figure 4-1 (note that the intervals are logarithmic).

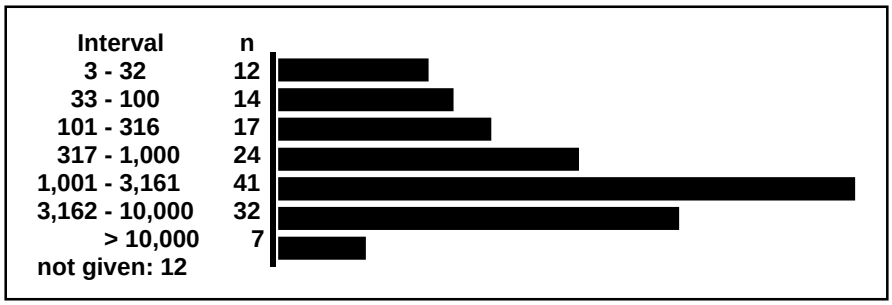

Figure 4-1
Number of Switching Requests Processed Annually

Switching by Extra-Utility Personnel

A related question asked respondents to estimate the percentage of switching requests that involved switching by other-utility or non-utility personnel. The distribution of the proportion of switching requests involving other-utility or non-utility personnel is shown in Figure 4-2.

Table 4-5
Proportion of Switching Requests Involving Extra-Utility Personnel

Item I.3b. Percentage of switching requests involving other-utility or non-utility personnel (proportion of those responding)						
	Overall		Distribution		Transmission	
	%	(n)	%	(n)	%	(n)
Average	11	(144)	9	(48)	13	(75)
High value	67		60		67	
Low value	0		0		0	

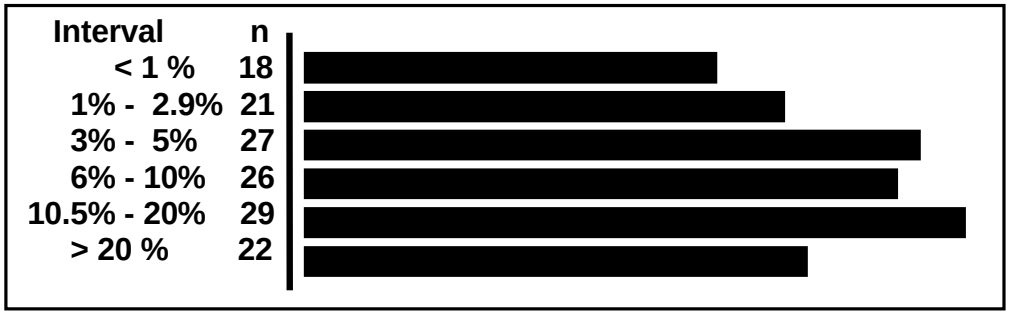

Figure 4-2
Proportion of Switching Requests Involving Other–Utility or Non–Utility Personnel

Those with a high percentage of switching requests that involved other–utility or non–utility personnel tended to be either large regional utilities or smaller utilities who have relatively few requests. Of the 22 respondents reporting that more than 20% of their requests involved extra-utility personnel, 14 (64%) were from utilities processing fewer than 300 switching requests per year.

Personnel Authorized to Perform Switching

For the majority of companies, linemen, substation operators, or maintenance personnel are authorized to perform switching at both distribution and transmission levels. Generating plant personnel are more likely to be authorized to perform switching on the transmission than the distribution system. Customer personnel or contractors are only authorized to perform switching in about one fifth of the responding operating units.

Table 4-6
Categories of Personnel Allowed to Perform Switching

Item I.4. Categories of personnel allowed to switch on survey respondents' systems (proportion of those responding)			
	Overall % (n)	Distribution % (n)	Transmission % (n)
Substation Operators	77 (159)	78 (54)	73 (83)
Maintenance Personnel	71 (159)	69 (54)	75 (83)
Linemen/Troublemen	89 (159)	93 (54)	86 (83)
Generating Plant Personnel	61 (159)	31 (54)	82 (83)
Customer Personnel	20 (159)	15 (54)	25 (83)
Contractors	19 (159)	28 (54)	13 (83)

Authorized Switchman List

About 65% of respondents maintain lists of those qualified to perform switching, with slightly higher percentage for transmission switching than for distribution switching.

Table 4-7
Qualified Switchman List

Item I.5. Proportion of respondents who keep lists (by name) of persons qualified to perform switching			
	Overall % (n)	Distribution % (n)	Transmission % (n)
In the Field (line or SS)	65 (149)	60 (52)	68 (75)
In the Control Center	66 (151)	64 (50)	67 (81)

Section II: Personnel Selection, Training, and Qualification

Selection and Training Requirements

For field personnel (substation, maintenance, or line personnel), there was no mention of qualification for entry into training programs (survey Item II.1a). Once accepted, the modal training requirement is completion of the utility's training program, which involves some classroom work and, most commonly, a 4-year apprenticeship leading to formal journeyman status.

For Control Center personnel, selection is almost always based on prior qualification as a journeyman and several years of field switching experience (Item II.1b). Only 10 of the 159 respondents (2 for Distribution and 8 for Transmission) mentioned college education as a consideration for selection. For most of these, an Associates' degree in electrical engineering or electrical technology can be substituted for a portion (though not all) of the experience requirement. One utility admits BSEE electrical engineers without field experience into their training program for Control Center operators; but they are the only utility in the sample willing to accept people without field experience, and they provide a rigorous four-year training program for their system operators. Anecdotal evidence suggests that many utilities are encouraging Control Center personnel to acquire college degrees. A majority of respondents (76%) provide a formal program of training for Control Center operators, combining classroom instruction with a period of OJT.

Years of Experience

As indicated in Table 4-8, the average of the number of years of experience in their current job were remarkably consistent across categories of personnel, and higher than expected given the widely-held opinion that there is a rapid turn-over of experienced personnel. However, the average values in the table mask the very wide range of average experience reported (from 1 to 25 years), and a more accurate picture of the responses can be gleaned from the distributions shown in Figure 4-3. A substantial minority of respondents reported that the ***average*** experience level of their workforce was in excess of 19 years, suggesting that they may expect significant turnover of personnel in the near future.

Table 4-8
Average Years of Experience in Current Job

Item II.2a. Average or typical years of experience of personnel in their current jobs. (Y = average of number of years entered on survey)						
	Overall		Distribution		Transmission	
	Y	(n)	Y	(n)	Y	(n)
Line personnel	12.9	(115)	13.4	(46)	12.3	(51)
Substation personnel	13.7	(119)	14.7	(45)	12.7	(55)
Control Center personnel	11.7	(145)	10.9	(48)	11.9	(76)

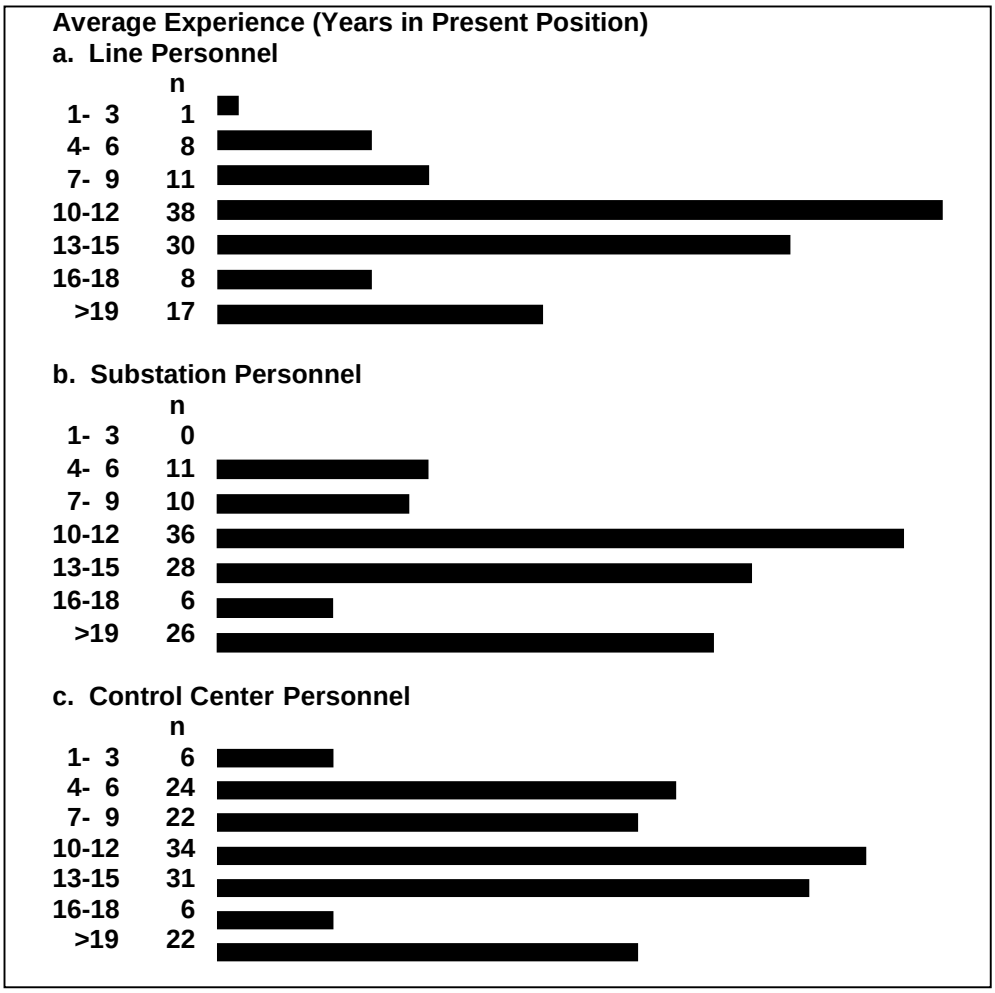

Figure 4-3
Average Years of Experience in Current Job

As shown in Table 4-9, personnel in the group of low–error operating units tended to be more experienced than those in the high–error group, and those in the remainder of the overall sample as well. The difference for Substation personnel is statistically reliable.

Table 4-9
Differences in Average Experience of Personnel in Low– and High–Error Groups

Item II.2a. Average or typical years of experience of personnel in their current jobs (M = average of number of years entered on survey)				
	Low–Error % (n)	High–Error % (n)	Statistics Test df p	Excluded % (n)
Line personnel	14.0 (19)	12.0 (24)	*NS*	12.9 (72)
Substation personnel	15.8 (22)	12.2 (21)	***t*** = 2.27 37.3 .029	13.5 (76)
Control Center personnel	12.5 (25)	11.6 (28)	*NS*	11.5 (92)

Expected Turnover of Personnel

The average turnover expected in the next two years is shown in Table 4-10. The average expected turnover is reasonably consistent across categories of personnel at a little over 10% in two years, but the values submitted by individual respondents ranged from 0 to 75%. The distributions of expected turnover rates shown in the three panels of Figure 4-4 show that the majority of respondents reported low turnover rates for each position. However, the data also show that many utilities are experiencing high turnover rates for Control Center personnel. Considering the very high value placed on experience for system operators, these data support the wide-spread notion that a substantial number of utilities (though not a majority) may be experiencing turnover of crisis proportions in positions that are critical to both the reliability and safety of operations.

Table 4-10
Expected Turnover in Next Two Years

Item II.2b. Expected percentage of turnover of switching personnel in the next **two** years (% = average of percentage turn-over)						
	Overall		Distribution		Transmission	
	%	(n)	%	(n)	%	(n)
Line personnel	8.9	(109)	9.6	(44)	8.9	(48)
Substation personnel	10.4	(113)	11.4	(43)	10.6	(52)
Control Center personnel	11.5	(141)	10.5	(47)	10.7	(73)

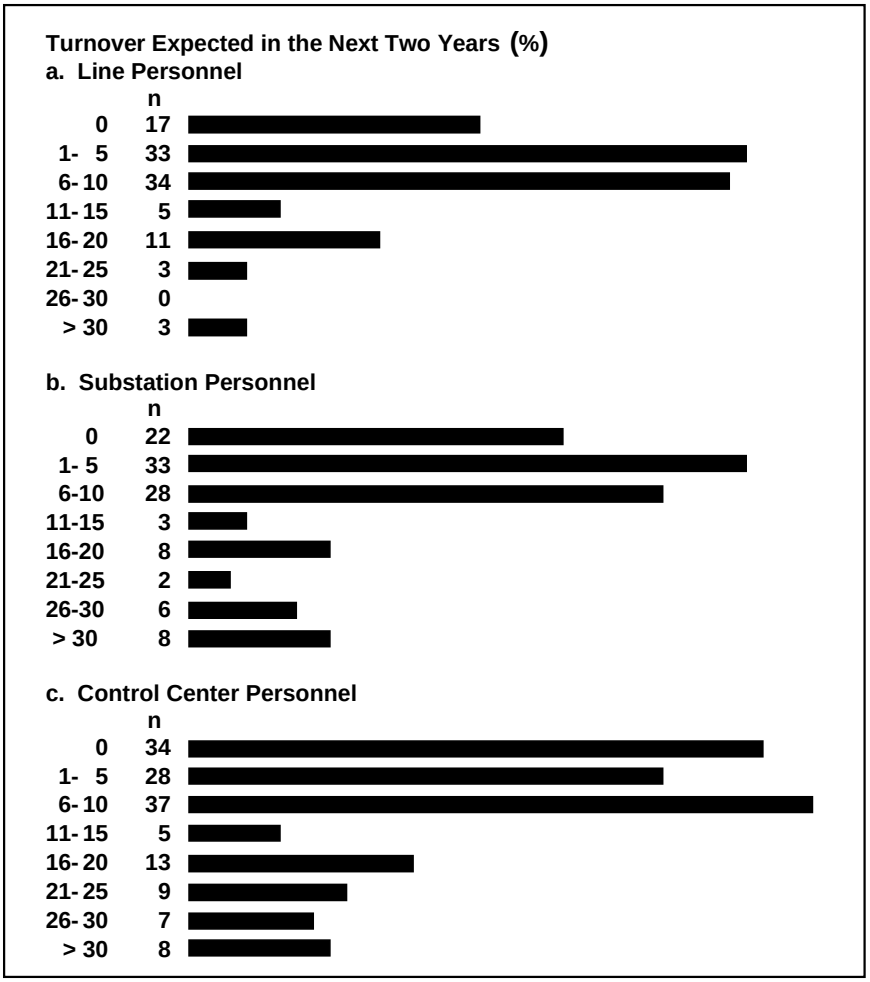

Figure 4-4
Expected Turnover in the Next Two Years

Formal Training Programs

The percentage of respondents with a formal training program for switching personnel is encouragingly high (about 78% overall) with, perhaps surprisingly, a slightly higher percentage of formal programs for line and substation personnel than for control center personnel. Reported initial classroom training periods are longer for Transmission than for Distribution personnel. The average duration of the classroom portion of such training programs is consistent for substation and line personnel and longer for control center personnel. However, as shown in Figure 4-5, these averages again mask very wide variations among respondents.

Table 4-11
Proportion of Respondents Reporting Formal Training Programs

Item II.3a. Percentage of respondents having formal training programs for persons with switching responsibilities			
	Overall % (n)	Distribution % (n)	Transmission % (n)
Line personnel	77 (132)	76 (49)	83 (65)
Substation personnel	79 (141)	78 (50)	82 (71)
Control Center personnel	76 (147)	73 (51)	78 (77)

Table 4-12
Average Length of Initial Classroom Training for Those Who Report Training Programs

Item II.3b. Average length of initial classroom training in weeks (W) for respondents with formal training programs			
	Overall W (n)	Distribution W (n)	Transmission W (n)
Line personnel	7.6 (76)	4.1 (27)	10.8 (41)
Substation personnel	7.9 (87)	5.5 (30)	10.9 (46)
Control Center personnel	11.6 (94)	7.9 (33)	13.5 (50)

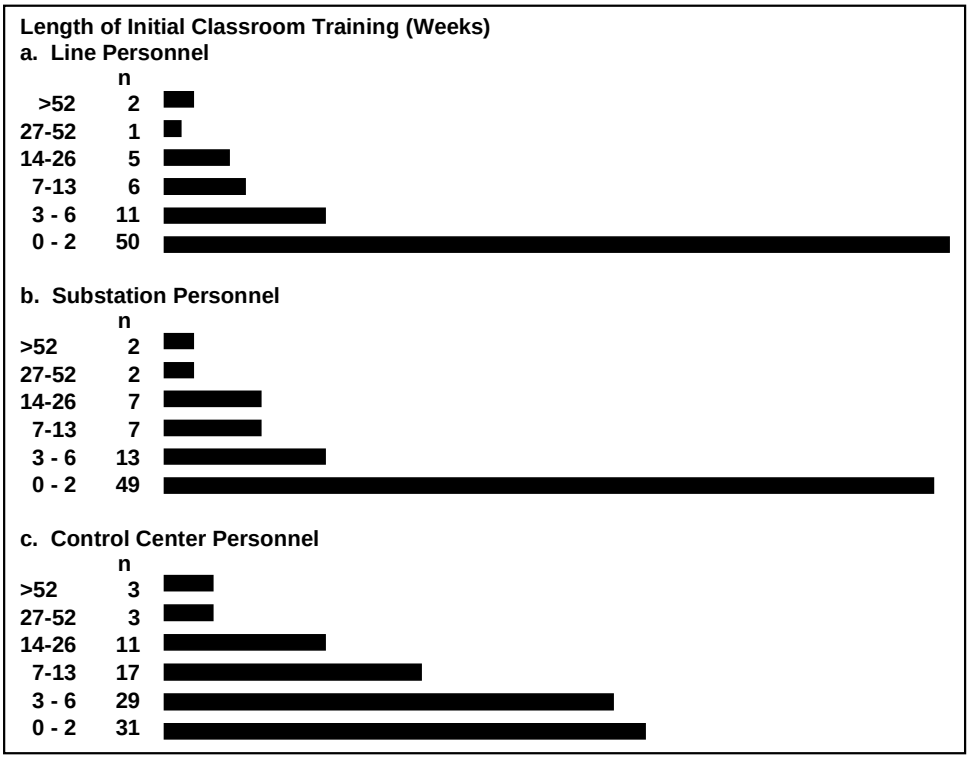

Figure 4-5
Reported Length of Initial Classroom Training

Time on the Job

Line and substation personnel must spend an average of two or more years on the job before they perform switching on their own. The shorter "in the job" requirement for control center personnel is most likely a consequence of the near-universal requirement for several years of prior field experience.

Table 4-13
Time On–The–Job Before Entrusted with Performing Switching Unassisted

Item II.4. Average time in weeks (W) on the job before personnel are entrusted with switching on their own			
	Overall W (n)	Distribution W (n)	Transmission W (n)
Line personnel	133 (91)	143 (36)	113 (42)
Low Value	0	0	0
High Value	408	408	408
Substation personnel	109 (100)	116 (38)	90 (46)
Low Value	0	0	0
High Value	408	408	408
Control Center personnel	65 (122)	62 (41)	54 (62)
Low Value	0	1	1
High Value	364	260	260

Internal Qualification or Certification Process

Approximately 71% of respondents overall have an internal qualification/certification process. The percentage is slightly higher for all groups (line, substation, and control centers) for Transmission personnel than for distribution personnel.

Table 4-14
Proportion Reporting an Internal Qualification/Certification Process

Item II.5a. Percentage of respondents requiring personnel performing switching to complete an internal qualification / certification process			
	Overall % (n)	Distribution % (n)	Transmission % (n)
Line personnel	70 (127)	69 (48)	75 (63)
Substation personnel	74 (136)	73 (49)	76 (68)
Control Center personnel	68 (149)	69 (51)	71 (78)

Finding: *The proportion of those reporting an internal certification process was higher in the low error rate group than in the high error group for all 3 categories of personnel.* These data are shown in Table 4-15.

Table 4-15
Differences Between Low– and High–Error Groups Regarding Internal Qualification/Certification

Item II.5a. Percentage of respondents requiring personnel performing switching to complete an internal qualification/certification process				
	Low–Error % (n)	High–Error % (n)	Statistics Test df p	Excluded % (n)
Line personnel	94 (18)	69 (26)	X^2 = 4.16 1 .060	65 (83)
Substation personnel	95 (22)	71 (24)	X^2 = 4.84 1 .049	70 (90)
Control Center personnel	85 (26)	59 (27)	X^2 = 4.20 1 .066	67 (96)

Kinds of Tests Employed in Qualification Programs

A follow-up Item (II.5b) presented a list of kinds of testing that could be employed in the qualification or certification process, and requested respondents to check all that were used for the qualification of each major group of personnel. Written tests are the most commonly used form of evaluation overall, although informal on-the-job observation is equally common in control centers. Formal job performance tests are used by about half the operating units that have a formal qualification program. The percentage of respondents using simulators for testing is, as expected, low. However, given the problems that companies are having in maintaining an active simulator training program, it is surprising that 23% of respondents who reported having a qualification program (103 or 68% of 149 who responded to the item) are using simulators for testing control center personnel.

Table 4-16
Types of Testing Used in Qualification/Certification

Item II.5b. Proportion of those with qualification/certification program who use different types of tests as a part of their qualification/certification process			
	Lineman % (n)	Substation % (n)	Control Center % (n)
Written test	69 (88)	69 (100)	71 (103)
Oral board	24 (88)	27 (100)	33 (103)
Formal job performance test	47 (88)	48 (100)	50 (103)
Informal on-the-job observation	58 (90)	62 (101)	80 (104)
Simulator test	4 (92)	8 (101)	23 (103)

Finding: *The proportion of respondent organizations requiring each of the above forms of testing in their certification program was* ***higher*** *in the high error rate group than in the low error group for all three categories of personnel.* Data showing these unexpected differences are presented in Table 4-17. This result is contrary to what we would expect to find, although a greater emphasis on testing would be consistent with an aggressive program to improve operating performance and reduce errors. However, the survey data do not supply any information with which to confirm or deny such a hypothesis.

Table 4-17
Differences Between Low– and High–Error Groups in Tests used in Qualification/Certification

Item II.5b. Proportion of those with qualification/certification program who use different types of tests as a part of their qualification/certification process									
		Low–Error %	(n)	High–Error %	(n)	Statistics Test	df	p	Excluded % (n)
Written test	Line	47	(17)	76	(17)	*NS*			74 (54)
	SS	52	(21)	81	(16)	X^2 = 3.32	1	.091	71 (63)
	CC	68	(22)	75	(16)	*NS*			71 (65)
Oral board	Line	6	(17)	41	(17)	X^2 = 5.89	1	.039	24 (54)
	SS	5	(21)	50	(17)	X^2 = 10.10	1	.002	29 (63)
	CC	23	(22)	44	(16)	*NS*			34 (65)
Formal job performance test	Line	29	(17)	65	(17)	X^2 = 4.25	1	.084	46 (54)
	SS	29	(21)	69	(16)	X^2 = 5.90	1	.022	49 (63)
	CC	55	(22)	63	(16)	*NS*			46 (65)
Informal on-the-job observation	Line	47	(17)	78	(18)	X^2 = 3.53	1	.086	55 (55)
	SS	71	(21)	88	(16)	X^2 = 4.01	1	.071	58 (64)
	CC	77	(22)	88	(16)	*NS*			79 (66)
Simulator test	Line	0	(17)	6	(18)	*NS*			5 (57)
	SS	5	(21)	9	(16)	*NS*			6 (65)
	CC	23	(22)	25	(16)	*NS*			23 (65)

Refresher Training Requirement

About half of the respondents overall require periodic refresher training of personnel performing switching (Item II.6a). Respondents from Transmission operating units were somewhat more likely to report that refresher training was provided than were those from Distribution organizations.

Table 4-18
Periodic Refresher Training Requirements

Item II.6a. Proportion of those responding requiring formal periodic refresher training for switching personnel						
	Overall %	(n)	Distribution %	(n)	Transmission %	(n)
Line personnel	52	(124)	44	(48)	58	(60)
Substation personnel	53	(132)	48	(48)	59	(66)
Control Center personnel	47	(147)	41	(49)	49	(78)

For those requiring refresher training, the modal interval is once a year, and the modal duration is 8 hours. However, there are a very wide variety of schedules, as shown in Tables 4-19, 4-20, and 4-21. Inspection of these three tables shows that refresher sessions for control center personnel are, on average, longer than for the other groups, and that refresher sessions for control center personnel are more likely to be scheduled more frequently than once a year.

Table 4-19
Duration and Frequency of Refresher Training for Line Personnel

II.6b and 6c. Refresher Hours and Interval For Line Personnel							
Hours/ Session	Refresher Interval (Months)						
	1	2	3-4	6	12	24	36
40					1		
24					1		
16						2	3
12					2		
8					18	1	4
5-6	2				2		
3-4				1	7	3	1
2		1			6		2
1					4		
	1	2	3-4	6	12	24	36

Table 4-20
Duration and Frequency of Refresher Training for Substation Personnel

II.6b and 6c. Refresher Hours and Interval For Substation Operators							
Hours/ Session	Refresher Interval (Months)						
	1	2	3-4	6	12	24	36
40					1		
24							2
16		1				2	2
12					2		
8					23	1	4
5-6	2				2		
3-4				1	6	4	1
2		1			5		2
1					3		
	1	2	3-4	6	12	24	36

Table 4-21
Duration and Frequency of Refresher Training for Control Center Personnel

II.6b and 6c. Refresher Hours and Interval For Control Center Operators							
Hours/ Session	Refresher Interval (Months)						
	1	2	3-4	6	12	24	36
80							1
40			1	1	1		
24	1				1		1
16			1		2	2	2
12	1				3		
8			2	1	19	1	4
5-6	1				2		
3-4				1	4	4	1
2		1			3		2
1	1				3		
	1	2	3-4	6	12	24	36

Finding: *The average interval at which refresher training sessions for Control Center personnel are presented is shorter for those utilities in the low–error group (11.1 months) than for those in the high–error group (21.4 months).* Inspection of Table 4-22 below suggests that this finding is due to the fact that the average interval at which training is given for the utilities in the high–error group is longer than the average for other utilities.

Table 4-22
Differences Between Low– and High–Error Groups in the Interval at which Refresher Training is Provided

II.6c. Average frequency in months (M) of refresher training required for those utilities that require it				
	Low–Error M (n)	High–Error M (n)	Statistics Test df p	Excluded M (n)
Line personnel	16.1 (9)	16.9 (11)	*NS*	15.9 (42)
Substation personnel	18.1 (10)	17.4 (10)	*NS*	15.9 (45)
Control Center personnel	11.1 (13)	21.4 (9)	***t*** = 2.24 13.9 .042	12.6 (42)

Inspection of Tables 4-19, 4-20, and 4-21 above shows that the number of hours of refresher training and the interval at which it is given both vary greatly among utilities, and comparisons can be confusing. To simplify the refresher training data, a third variable, the number of refresher training hours per year, was created. This value was obtained by multiplying the number of hours of refresher from Item II.6.b by the frequency of training (Item II.6.c, expressed as frequency per year rather than interval in months, as recorded on the survey forms). These data are shown in Table 4-23, and Figures 4-6 and 4-7.

Table 4-23
Annual Number of Hours of Refresher Training

Composed Item. Average number of hours of refresher training per year (H/yr) provided by those organizations that reported refresher training programs			
	Overall H/yr (n)	Distribution H/yr (n)	Transmission H/yr (n)
Line personnel	8.4 (61)	8.8 (20)	5.2 (23)
Substation personnel	9.1 (64)	11.3 (22)	5.0 (35)
Control Center personnel	20.3 (63)	9.7 (18)	18.0 (35)

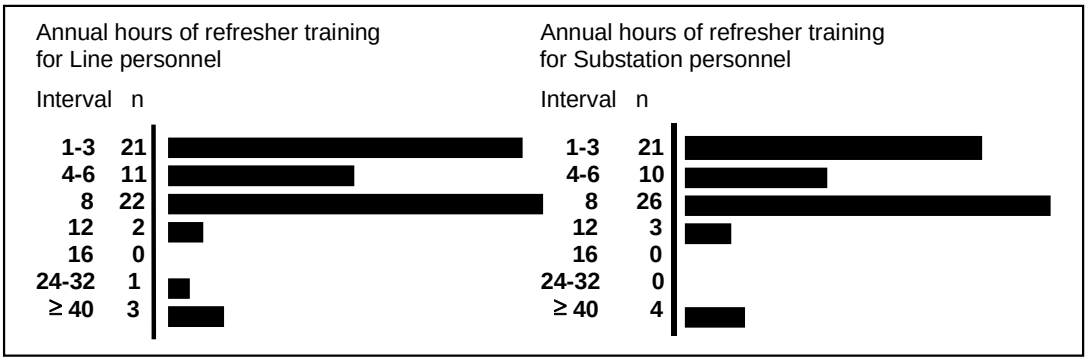

Figure 4-6
Annual Hours of Refresher Training for Line and Substation Personnel

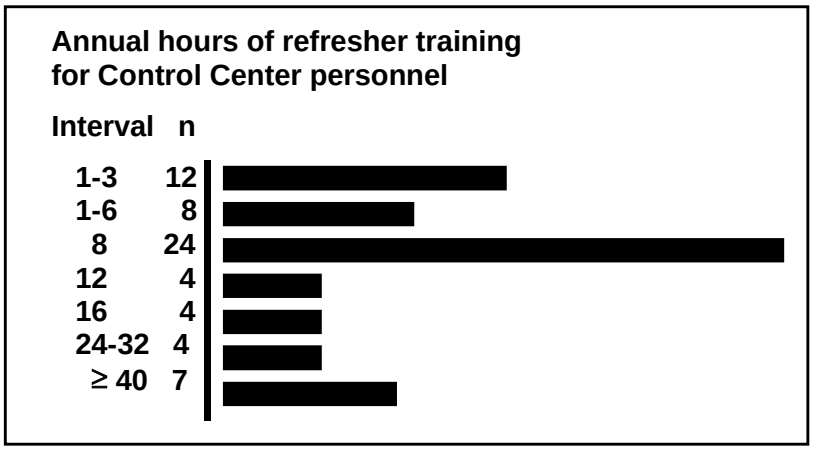

Figure 4-7
Annual Hours of Refresher Training for Control Center Personnel

Data from the Low– and High–Error groups for the composed variable, hours of training per year, are shown in Table 4-24. These data suggest that those utilities in the low–error group that give periodic refresher training provide substantially more training than do those in the high–error group. However, the seemingly large differences in favor of the low–error group are not statistically significant because of high variance within each group, which is due to the very large range of values making up each average.

Table 4-24
Differences Between Low– and High–Error Groups in the Yearly Hours of Refresher Training Provided

Composed Item II.6d. Average yearly hours (H/yr) of refresher training required for those utilities that require it				
	Low–error H/yr (n)	High Errors H/yr (n)	Statistics Test df p	Excluded H/yr (n)
Line personnel	12.1 (9)	5.9 (11)	*NS*	8.2 (41)
Substation personnel	11.9 (10)	6.3 (10)	*NS*	9.1 (44)
Control Center personnel	40.3 (12)	9.3 (9)	***t*** = 1.26 11.3 .232 *NS*	16.9 (42)

Re-testing Requirements

A relatively low percentage of respondents require personnel to be periodically re-tested to maintain their qualification. The percentage is slightly but consistently higher for Transmission than for Distribution, and slightly less for control center positions than for field operators.

Table 4-25
Proportion of Respondents Requiring Periodic Retesting of Personnel

Item II.7. Proportion of those responding requiring formal periodic **retesting**			
	Overall % (n)	Distribution % (n)	Transmission % (n)
Line personnel	21 (117)	13 (45)	26 (58)
Substation personnel	20 (120)	16 (44)	25 (60)
Control Center personnel	17 (136)	11 (47)	19 (72)

Switching by Non-Utility Personnel

As shown in Table 4-26, approximately 1/3 of respondents allow non-utility personnel (customers or contractors) to perform switching on equipment within their jurisdiction.

Table 4-26
Switching by Non–Utility Personnel

II.8a. Proportion of those responding who allow non–utility personnel to perform switching on equipment under their jurisdiction		
Overall % (n)	Distribution % (n)	Transmission % (n)
31 (159)	30 (54)	34 (83)

In answer to a further question concerning qualifications for non–utility personnel allowed to switch on the system (Item II.8.b) —responses were about evenly divided between those requiring training provided by the utility on equipment and procedures, and those requiring certification that the customer or contractor personnel performing switching were journeyman electricians.

Section III: Planning Switching

Advance Notification Required for Scheduled Switching

The average number of hours advance planning required for switching is 37 hours for distribution and about 54 hours for transmission, with individual values varying widely, as is shown by the distribution given in Figure 4-8. Several respondents noted that within Transmission departments the required advanced notice varies with the voltage being switched, with longer lead times required for the higher voltages.

Table 4-27
Advanced Notice Required for Routine Switching Requests

Item III.1. Number of hours in advance of the scheduled time of the switching (H) that requests for routine switching are required to be submitted			
	Overall H (n)	Distribution H (n)	Transmission H (n)
Average hours in advance	44.9 (156)	36.8 (52)	54.3 (82)
High value	336	240	336
Low value	0	1	0

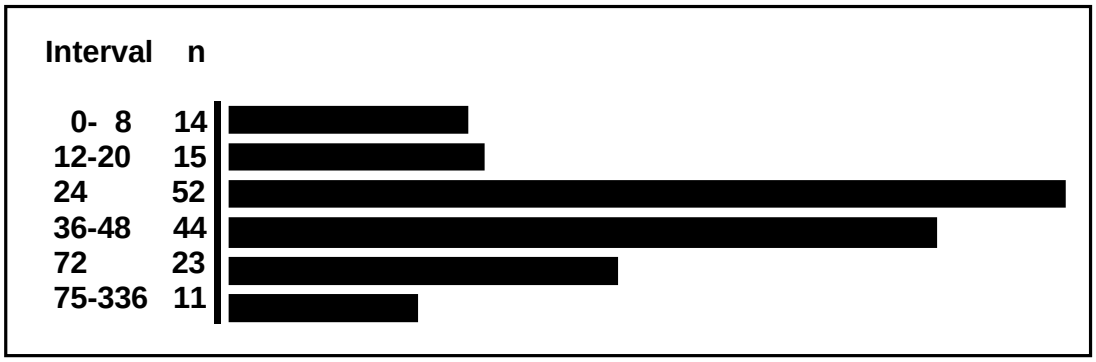

Figure 4-8
Required Advanced Notice for Routine Switching Requests

Person Preparing Switching Instructions

In the majority of cases the control center operator prepares the written orders used for switching. In some cases the control center supervisor may designate an engineer or system operator to write the orders; in others the supervisor writes the orders for critical customers, with the operators handling the more routine requests.

Table 4-28
Positions Responsible for Preparation of Switching Orders

Item III.2. Percentage of respondents for whom the stated position is responsible for preparing the step-by-step written instructions (proportion of those responding)			
Position	Overall % (n)	Distribution % (n)	Transmission % (n)
Control center supervisor	27 (158)	28 (53)	25 (83)
Control center operator	81 (158)	83 (53)	80 (83)
Substation/line supervisor	12 (158)	15 (53)	6 (83)
Substation/line operator who will perform the switching	11 (158)	15 (53)	8 (83)

Use of 'Canned' Switching Orders

The responses shown in Table 4-29 show lack of consistency across respondents in regard to the use of canned switching orders. The split between those who say they used canned orders wherever possible and those who say they never use them is essentially equal. The dry language of the survey form conceals some very strongly held opinions on each side of that split. It is also interesting to note that the 1/3 "use canned switching wherever possible" and 1/3 "never use canned switching" split is identical within both the high–error and low–error groups created for the error analysis. Whatever their merits as labor-saving devices, use or non-use of canned switching orders seems to be completely unrelated to error rates.

In discussions of canned switching at the 1998 conference two types of "canned" procedures were identified: those that are explicitly written in advance of the need, such as instructions for isolating a bus at a substation, and those that form a reference database of previous orders that have been saved for later re-use. The former are created in anticipation of use sometime in the future. Such a database can require considerable effort if a system-wide database is created. The second accumulates as orders are written for various jobs and saved for future reference. Although the survey data do not show changes over time, write-in responses and discussions at the three conferences suggest a trend toward more use of canned switching, at least in the second sense of a reference database of previous orders. The construction of such databases is enabled by the widespread use of word processing technology that allows saving and indexing of orders, as well as software for producing and archiving orders that is available from many EMS vendors.

In addition, at the 1998 conference it was pointed out that many orders nominally written from scratch contain "sort of canned" components, because operators often save personal copies of orders and can look back and see how complex switching was handled previously. To determine exactly how the previous or pre-prepared orders are used by operators who prepare the order from scratch is an area that merits further investigation.

As expected, many respondents emphasized the need for checking previously prepared orders whenever they were to be used.

Table 4-29
Use of "Canned" Switching Instructions

Item III.3. Proportion of those responding who use a database of previously prepared switching orders						
	Overall		Distribution		Transmission	
	%	(n)	%	(n)	%	(n)
Where possible	32	(158)	34	(53)	36	(83)
Only for routine switching	26	(158)	21	(53)	25	(83)
Never	34	(158)	34	(53)	30	(83)
Only under special circumstances	12	(158)	13	(52)	12	(82)

Uniformity of Procedures used in Switching

Respondents indicated that there was a high level of standardization of switching procedures within each utility. Note that when asked about changes to procedures and practices, (Item 16b. below) 15 of the respondents said that they were making changes to increase standardization. However, it is also worth noting that amongst the responses to this survey were several from different control centers of the same utility indicating different practices in different regions or areas of the company.

Table 4-30
Uniformity of Switching Procedures and Forms

Item III.4. Uniformity of switching order forms and associated procedures within responding utilities			
	Overall % (n)	Distribution % (n)	Transmission % (n)
Standard throughout utility	77 (158)	81 (53)	75 (83)
Different between control center and field operations	7 (158)	8 (53)	7 (83)
Vary between departments and districts	7 (157)	4 (53)	9 (82)
Vary between generating stations and field	14 (149)	12 (49)	13 (78)

Contents of Written Instructions

Respondents were asked to indicate whether each of a list of items was included in their company switching instructions. The responses shown in Table 4-31 showed a high degree of consistency among respondents for most of the items included in the survey question. Items for which utility practices are inconsistent include applying and removing portable grounds and applying and removing locks. We believe that some actions to be performed (such as applying portable grounds) are considered skill-of-the-craft or always-check items and not included in the written instructions in the interest of keeping orders that are to be transmitted verbally as short as possible.

Table 4-31
Content of Written Switching Instructions

Item III.5. Instructions included in written orders for switching (proportion of those responding)			
	Overall % (n)	Distribution % (n)	Transmission % (n)
Opening/closing breakers	99 (157)	100 (53)	98 (83)
Opening/closing disconnects	99 (157)	100 (53)	98 (83)
Closing/opening ground switches	80 (155)	77 (52)	80 (83)
Applying/removing portable grounds	51 (157)	53 (53)	45 (83)
Bypassing/restoring protective schemes	83 (157)	87 (53)	78 (83)
Applying/removing tags	95 (157)	94 (53)	95 (83)
Applying/removing locks	63 (157)	62 (53)	60 (83)
Checking open breakers	91 (157)	94 (53)	90 (83)
Disabling/restoring reclosing	92 (149)	96 (49)	90 (79)
Enabling/disabling local control	73 (150)	70 (50)	73 (79)

Number of Operations per Step

Respondents were evenly divided between those who included only one operation per step and those who included more than one operation. Some utilities reported that their steps usually contained only one operation, but sometimes contained more.

Table 4-32
Number of Operations per "Step" of Written Instructions

Item III.6. Number of operations included in each written step (proportion of those responding)			
	Overall % (n)	Distribution % (n)	Transmission % (n)
One operation only	55 (157)	55 (53)	52 (83)
More than one operation	45 (157)	43 (53)	49 (83)

Identification of Steps

The proportion of those responding that each step in a switching order has a unique identification number was 65% overall and was virtually identical for both transmission and distribution switching. This is an area where there is no clear industry consensus.

Background Information Included in Switching Orders

Participants were asked which of a number of different items of background information were included in switching orders. We believe that the information items are often useful in allowing the field switchmen to evaluate the correctness of the instructions received, and thus help to identify errors in the instructions before they are acted upon.

Table 4-33
Background Information Items Included with Switching Orders

Item III.8. Information items included in written switching orders (proportion of those responding)			
	Overall % (n)	Distribution % (n)	Transmission % (n)
Purpose of job	83 (156)	83 (52)	82 (83)
Name of person writing switching order	90 (156)	88 (52)	92 (83)
Name of person(s) approving switching order	72 (156)	69 (52)	70 (83)
Name of the switchman	72 (156)	73 (52)	67 (83)
Name of clearance holder	89 (156)	75 (52)	86 (83)
Identification of steps to be performed via SCADA	71 (156)	75 (52)	65 (83)
Steps to be performed at all Field/substation locations	85 (156)	88 (52)	82 (83)
Expectations re 'as-found' status	40 (147)	44 (48)	37 (78)
Time each step completed	77 (156)	79 (52)	75 (83)

Finding: *A larger proportion of utilities in the low–error group than in the high–error group reported including the name of the switchman (79% vs. 54%) and the identification of steps to be performed via SCADA (90% vs. 71%) in their written switching orders.* Inspection of Table 4-34 suggests that the low–error utilities tend to be more likely to include almost all of the information items listed than do either the high–error group or the other utilities in the sample.

Table 4-34
Differences Between Low– and High–Error Groups in Background Information Items Included in Switching Orders

Item III.8. Information items included in written switching orders (proportion of those responding)				
	Low–Error % (n)	High–Error % (n)	Statistics Test df p	Excluded % (n)
Purpose of job	86 (28)	82 (28)	*NS*	82 (100)
Name of person writing switching order	93 (28)	82 (28)	*NS*	91 (100)
Name of person(s) approving switching order	86 (28)	64 (28)	*NS*	70 (100)
Name of the switchman	79 (28)	54 (28)	X^2 = 3.90 1 .089	75 (100)
Name of clearance holder	86 (28)	89 (28)	*NS*	90 (100)
Identification of steps to be performed via SCADA	96 (28)	71 (28)	X^2 = 6.49 1 .0.25	65 (100)
Steps to be performed at all Field/substation locations	96 (28)	86 (28)	*NS*	82 (100)
Expectations re 'as-found' status	52 (21)	36 (28)	*NS*	39 (98)
Time each step completed	89 (28)	71 (28)	*NS*	75 (100)

Situations when a Written Order is NOT Required

Responses to a question asking in what situations written instructions were NOT required indicated inconsistent practices across utilities. From the responses, transmission switching is somewhat more likely to be performed without a written switching order in each of the situations identified in the survey, except emergency switching. In emergencies, distribution personnel are slightly more likely to switch without a written switching order than transmission personnel. The negative wording of this question (situations in which an order is NOT required) may have influenced the way in which it was answered, although the responses for LTCs and capacitors are not out of line with the investigators' prior expectations.

Table 4-35
Situations for which a Written and Approved Switching Order is NOT Required

Item III.9. Situations in which a written and approved switching order is NOT required (proportion of those responding)			
	Overall % (n)	Distribution % (n)	Transmission % (n)
All switching performed from control center via SCADA	21 (159)	15 (54)	27 (83)
Adjustments to taps on LTCs or voltage regulators	70 (159)	65 (54)	72 (83)
Switching of capacitors via SCADA	66 (151)	60 (50)	74 (80)
Emergency switching	67 (156)	74 (53)	67 (81)

Number of Signatures Required Prior to Dispatching

The average number of signatures required for routine jobs prior to dispatching was 1.5. One utility in the transmission group required 6 signatures. Inspection of Table 4-36 below suggests that most of the signatures other that that of the person preparing the order are those of supervisory personnel. Most utilities require one or more dispatchers to review orders for accuracy and completeness prior to dispatching. While their initials may be required prior to sign-off by a supervisor, their reviews apparently are not counted as a formal sign-off.

Required Signatures

Generally, a system operator or dispatcher signature suffices for transmission switching, whereas the control center supervisor's signature is more likely to be needed for distribution switching.

Table 4-36
Approvals Required for Routine Switching

Item III.11. Approvals (signatures) required for routine switching (proportion of those responding)			
	Overall % (n)	Distribution % (n)	Transmission % (n)
Control center manager	6 (154)	6 (51)	5 (81)
Control center supervisor	31 (154)	41 (51)	25 (81)
System operator / dispatcher	75 (154)	69 (51)	79 (81)
Supervisor of persons performing work in the field	16 (154)	18 (51)	9 (81)

Use of Job Aids in Preparing Switching Orders

Job aids required to be used in preparing switching orders are shown n Table 4-37. Use of line or station prints in preparation of switching orders is required by 6 of 7 companies. Use of station operating instructions and relay diagrams are required by approximately 1/2 of the responding organizations. Use of software aids is required by very few utilities, and their use was reported as "optional" by only a few. We interpret these responses to indicate that those preparing switching orders are allowed a good deal of discretion in the materials to be used.

Table 4-37
Required Job Aids for the Preparation of Switching Orders

Item III.12. Aids **required** to be used for preparing/checking switching orders (proportion of those responding)			
	Overall % (n)	Distribution % (n)	Transmission % (n)
Previous or canned switching orders	8 (155)	6 (53)	9 (81)
Line/station prints	86 (155)	85 (53)	86 (81)
Station operating instructions	53 (155)	48 (52)	54 (81)
Relay diagrams	20 (155)	11 (53)	25 (81)
Software for checking switching orders	1 (155)	0 (53)	1 (81)

Time when Switching Instructions are Distributed to Switching Personnel

As shown in Table 4-38, the average number of hours in advance that a switching order is distributed is about 12 hours (lower for distribution than for transmission). But, as shown in Figure 4-9, the distribution is bimodal, with the most common responses being ZERO hours (instructions are dictated once the switchman is at the site) and 20-24 hours. The average in the table is slightly distorted by the inclusion of one utility that distributes the orders for routine planned switching one week in advance.

Table 4-38
Hours in Advance that Instructions are Distributed to Field Personnel

Item III.13. Hours in advance of the actual switching (H) that instructions are distributed to those who will perform the switching			
	Overall H (n)	Distribution H (n)	Transmission H (n)
Average hours in advance	11.6 (149)	6.2 (52)	15.3 (76)
Low value	0	0	0
High value	168	48	168

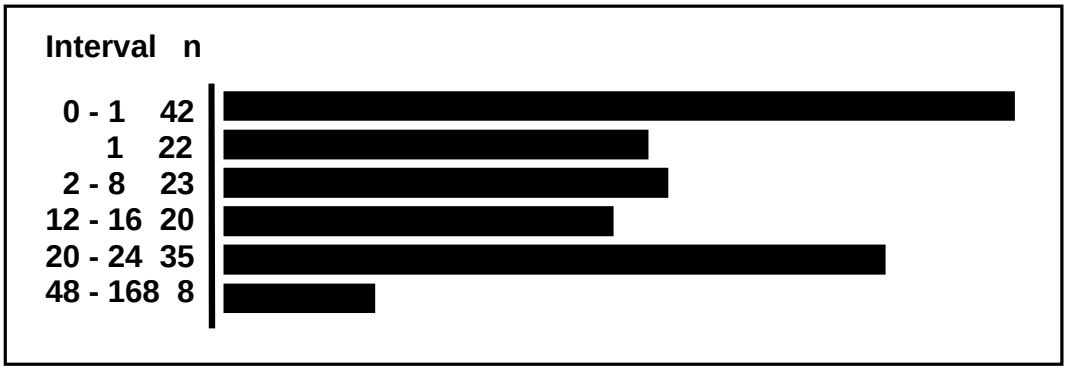

Figure 4-9
Number of Hours in Advance that Switching Orders are Distributed

Switching with Other Companies

Several respondents checked more than one type of procedure used when coordinating switching with other utilities, indicating that they often have discretion in the procedures to be used. Transmission operations were more likely to use special inter-utility procedures when interfacing with another system.

Table 4-39
Procedures used When Coordinating Switching with Other Companies

Item III.14a. Procedures used for notifying/scheduling the switching when switching involves another utility or customer personnel (proportion of those responding)			
	Overall % (n)	Distribution % (n)	Transmission % (n)
Our usual procedures	64 (158)	75 (53)	65 (83)
Their procedures	18 (158)	9 (53)	24 (83)
Special inter-utility procedures	44 (158)	26 (53)	51 (83)

Restore–to–Service Switching Orders

A clear majority of utilities, about 7 out of 8 (88%) do **not** rely on the practice of performing the opposite steps in the reverse order from the remove–from–service switching orders.

Table 4-40
Detail Provided in Restore–To–Service–Orders

Item III.15. Detail provided in switching orders for restoration to service following completion of scheduled work (proportion of those responding)			
	Overall % (n)	Distribution % (n)	Transmission % (n)
Same detail as in the remove-from-service orders	88 (156)	91 (53)	84 (82)
Written out in detail ONLY when restoration is NOT accomplished by performing the opposite steps in the reverse order from the remove-from-service switching orders	12 (156)	9 (53)	16 (82)

Finding: *All utilities in the low–error group provide the same detail in restore-to-service switching orders as they do in the remove-from-service orders, whereas 19% of the high–error group do not (*$\boldsymbol{X}^2$ = 5.70, df = 1, p = .023).

Changes in Switching Procedures

Overall, 30% of the respondents indicated that they were changing their switching procedures. Many different types of changes were identified. Most frequently cited responses and the number of respondents in each case are shown in Table 4-41. Several utilities also reported implementing multiple changes, often as a result of mergers or consolidation or centralization of operations from several geographically distributed control centers.

Table 4-41
Most Commonly–Reported Changes to Switching Procedures

Item III.16b.Describe any Changes to Switching Procedures	
	Number of respondents
Changes to increase standardization	15
Additional steps or greater detail in switching procedures	10
Greater advanced notice for routine switching	7
Introduction of computerized tools	6

Section IV: Implementing Switching in the Field

Required Practices for Switching in the Field

The responses summarized in Table 4-42 show a large measure of agreement on some switching practices (e.g., repetition of verbal instructions) with limited industry consistency in several other areas. Of particular interest here are the relatively low percentage of respondents (73%) that require that each step be checked off as it is performed. Overall, 42% require that an explicit self-verification routine be performed at each step. Note also that approximately twice as many utilities require the entire order to be read back *after* it is copied as require each step to be read back *as* it is copied. Variations between transmission and distribution switching are not pronounced, except that Distribution is somewhat more likely to require the use of a self-verification routine (50% vs. 35% for Transmission respondents).

Table 4-42
Practices Required When Performing Switching in the Field

Item IV.1. Proportion of those responding that persons performing switching in the field are required to always ("sometimes" responses are not discussed) follow the following practices			
	Overall % (n)	Distribution % (n)	Transmission % (n)
Use a phonetic alphabet for equipment nomenclature	22 (159)	20 (54)	20 (83)
Repeat all verbal instructions to sender	95 (150)	94 (50)	96 (78)
For a series of dictated steps			
a) Repeat each step as it is copied	49 (150)	46 (50)	37 (78)
b) Repeat entire order after all steps are copied	56 (150)	44 (50)	62 (78)
Review the work with dispatcher before beginning	39 (159)	41 (54)	33 (83)
Review appropriate prints before beginning the work	40 (159)	39 (54)	40 (83)
Walk down their portion of the work before beginning the work	35 (159)	28 (54)	37 (83)
Notify dispatcher if equipment not exactly as specified	96 (159)	98 (54)	94 (83)
Call in before beginning the job	89 (159)	89 (54)	92 (83)
Carry the order while switching	73 (158)	70 (54)	72 (83)
Check off each step as it is performed	73 (159)	78 (54)	69 (83)
Use explicit self-verification routine at each step	43 (155)	50 (52)	35 (81)

Finding: *Utilities in the low–error group were significantly more likely to report that field personnel were required to personally review the work with the dispatcher before beginning (46% vs. 18%), check off each step as it is performed (79% vs. 54%), and use an explicit self-verification routine while switching (54% vs. 28%).* Inspection of Table 4-43 reveals that the proportion of utilities in the low–error group reporting these practices is the same as that in the group of utilities excluded from the error-based comparisons. However, the proportion of utilities in the high–error group requiring these practices is less that of both the low–error group and the rest of the sample.

Table 4-43
Differences Between Low– and High–Error Groups in Practices Required for Switching in the Field

Item IV.1. Proportion of those responding that persons performing switching in the field are required to always ("sometimes" responses are not discussed) follow the following practices				
	Low–Errors % (n)	High–Errors % (n)	Statistics Test df p	Excluded % (n)
Use a phonetic alphabet for equipment nomenclature	39 (28)	25 (28)	*NS*	17 (103)
Repeat all verbal instructions to sender	100 (21)	89 (28)	*NS*	95 (101)
For a series of dictated steps				
a) Repeat each step as it is copied	48 (21)	43 (82)	*NS*	42 (101)
b) Repeat entire order after all steps are copied	67 (21)	54 (28)	*NS*	54 (101)
Review the work with dispatcher before beginning	46 (28)	18 (28)	X^2 = 5.24 1 .044	43 (103)
Review appropriate prints before beginning the work	43 (28)	25 (28)	*NS*	44 (103)
Walk down their portion of the work before beginning the work	43 (28)	39 (28)	*NS*	31 (103)
Notify dispatcher if equipment not exactly as specified	100 (28)	93 (28)	*NS*	95 (102)
Call in before beginning the job	89 (28)	100 (28)	*NS*	86 (103)
Carry the order while switching	75 (28)	64 (28)	*NS*	75 (102)
Check off each step as it is performed	79 (28)	54 (28)	X^2 = 3.90 1 .089	77 (103)
Use explicit self-verification routine at each step	54 (28)	21 (28)	X^2 = 6.08 1 .023	46 (101)

Coordination of Switching Activities

The great majority of coordination takes place through the control center. Those reporting that direct coordination between field supervisors or independent switchmen at different locations was allowed usually said that it was allowed under special circumstances.

Table 4-44
Coordination of Switching Activities at Different Locations

Item IV.2. Individual switchmen communicate to coordinate their steps if the switching involves switching at different locations (proportion of those responding)			
	Overall % (n)	Distribution % (n)	Transmission % (n)
Through the control center	96 (159)	93 (54)	100 (83)
Through the field operations supervisors	7 (159)	9 (54)	5 (83)
Directly between themselves	9 (159)	11 (54)	7 (83)

Policy for Issuing Clearances

The majority of utilities (2/3) issue one clearance to each work group, but significant minorities use other methods. Many respondents checked more than one response to this question, often mentioning flexibility in tailoring the style of clearance to the situation in the field.

Table 4-45
Policies for Issuing Clearances

Item IV.3. Utility policies in relation to issuing "clearances" (proportion of those responding)			
	Overall % (n)	Distribution % (n)	Transmission % (n)
Only one clearance is issued	23 (159)	26 (54)	20 (83)
One clearance to each work group	67 (159)	67 (54)	71 (83)
Master clearance with 'sub-clearances' for each group	17 (158)	13 (54)	17 (82)

Finding: *A greater proportion of utilities in the low error group than in the high error group reported issuing only one clearance to cover multiple work parties.* These data are shown in Table 4-46.

Table 4-46
Differences Between Low– and High–Error Groups in Policies for Issuing Clearances

Item IV.3. Utility policies in relation to issuing "clearances" (proportion of those responding)				
	Low–Error % (n)	High–Error % (n)	Statistics Test df p	Excluded % (n)
Only one clearance is issued	43 (28)	14 (28)	$X^2 = 5.60$ 1 .037	20 (103)
One clearance to each work group	75 (28)	68 (28)	*NS*	63 (103)
Master clearance with 'sub-clearances' for each group	19 (27)	14 (28)	*NS*	17 (103)

Method of Issuing Clearance

The majority of respondents reported that the clearance is issued orally. However, a point made by several respondents is that there are written clearance documents but the clearance is "issued" to those at the work site orally by the dispatcher.

Table 4-47
Method of Issuing Clearance

Item IV.4. Methods used to issue clearance (proportion of those responding)			
	Overall % (n)	Distribution % (n)	Transmission % (n)
A written document	22 (159)	17 (54)	20 (83)
Orally, by phone or radio	91 (158)	91 (53)	93 (83)

Inter–Utility Clearances

A high proportion of respondents provided an answer to this question. Several respondents did not answer, but made the point that only **they** could issue clearances to work on their systems, and that what was issued by adjoining systems was a "guarantee" rather than a clearance.

Table 4-48
Coordination of Clearances Involving Other Utilities

Item IV. 5. When another utility is issuing a clearance related to work on your equipment (e.g., opening their end of an interconnection), to whom does the other utility issue the clearance (proportion of those responding)			
	Overall % (n)	Distribution % (n)	Transmission % (n)
Your control center operator	94 (147)	85 (47)	93 (79)
Your field personnel	7 (147)	17 (47)	4 (79)

Releasing Clearances

A majority of the respondents (55%) reported that someone **other than** the clearance holder could release a clearance. Explanations were virtually all variations on the theme that the clearance holder's supervisor can release the clearance if the clearance holder is unavailable (e.g., absent or injured). In a few cases that supervisor must personally inspect the site; and one requires the release to be authorized by an area manager. This question may have been interpreted in terms of usual practices rather than policies, because the explanation given by the 55% answering in the affirmative is allowable under OSHA regulations, and a practical necessity [4].

Placement of Tags

Sixty-five percent (65%) of utilities reported that one tag was placed on each device switched. A distinction made by some respondents was that tags are required only on isolation points rather than on all devices switched. Thirty-four percent (34%) allowed each working group to place their own tags. The most interesting thing in the table that fewer than 2/3 (59%) reported placing tags on SCADA points.

Table 4-49
Placement of Tags

Item IV.7. Utility policies in relation to placement of tags (proportion of those responding)			
	Overall % (n)	Distribution % (n)	Transmission % (n)
One tag on each device	65 (158)	61 (54)	70 (83)
Each group places own tags	37 (158)	39 (54)	35 (83)
Tags placed on SCADA points	59 (158)	50 (54)	61 (83)

Clearance Holder's Name on Tag

Overall 60% of respondents stated that the clearance holder's name is always placed on the tag (56% for distribution and 62% of transmission). Some utilities reported that the clearance number rather than a person's name is placed on the tags. This is one of the few items on the survey where there was no clear majority practice.

Switching Records Retained

The major point of consensus with this item was the retention of the orders used by the dispatcher/system operator. We were surprised by the relatively high percentage who do not routinely keep the voice recordings; though some did say that they were kept only if there was a problem of some sort. Other materials mentioned by respondents included Day Logs and SCADA Logs.

Table 4-50
Records Retained Following Completion of Switching

Item IV.9. Types of switching documentation maintained in the records after switching is completed (proportion of those responding)			
	Overall % (n)	Distribution % (n)	Transmission % (n)
Switching orders used by dispatcher	95 (154)	94 (51)	98 (82)
Switching orders used by personnel in field	35 (155)	37 (51)	35 (82)
Recordings of communications between CC and field	58 (149)	57 (49)	64 (78)
Tags	32 (154)	35 (51)	31 (81)

Finding: *50% of respondents in the low error group reported retaining the switching orders used by personnel in the field, whereas only 21% of those in the high error group did so.* Inspection of Table 4-51 shows that a higher proportion of both groups reported retaining recordings of communications between the Control Center and personnel in the field than was the case among the rest of the sample.

Table 4-51
Differences Between Low– and High–Error Groups in Records Retained Following Completion of Switching

Item IV.9. Types of switching documentation maintained in the records after switching is completed (proportion of those responding)				
	Low–Error % (n)	High–Error % (n)	Statistics Test df p	Excluded % (n)
Switching orders used by dispatcher	93 (28)	93 (28)	*NS*	96 (99)
Switching orders used by personnel in field	50 (28)	21 (28)	$X^2 = 4.98$ 1 .050	34 (99)
Recordings of communications between CC and field	73 (22)	75 (28)	*NS*	50 (99)
Tags	32 (28)	32 (28)	*NS*	32 (99)

Section V: Incident Investigation and Reporting

Definition of Error

A consistent definition is necessary for error statistics to have any meaning. To determine the types of incidents commonly recorded as switching errors, the survey provided a list of five common kinds of incidents and asked respondents to check all that would be classed as "switching errors" in their utility. The responses shown in Table 4-52 below indicated a fairly strong consensus on all the actions/consequences included in definitions of error or incident, with the exception of mis-operation of equipment. There were few additions to the list, although several respondents differentiated between "errors" and "incidents," reporting that the term "error" was used only if there was a violation of a procedure. However, respondents indicated that all of the mishaps listed—regardless of the definition used—are considered cause for an investigation and appropriate follow-up action.

Table 4-52
Components of the Definition of Operating Incident or Error

Item V.1. Actions/consequences included in utility definitions of an "operating error" or "incident" (proportion of those responding)			
	Overall % (n)	Distribution % (n)	Transmission % (n)
Personal injury	85 (158)	89 (54)	88 (82)
Damage to equipment	84 (158)	85 (54)	87 (82)
Loss of service to customers	92 (158)	100 (54)	87 (82)
Violation of procedures	86 (158)	89 (54)	87 (82)
Mis-operation of equipment	75 (157)	72 (54)	80 (81)

Finding: *The proportion of utilities in the high–error group including mis-operation of equipment as a part of their definition of an operator error or incident was higher than among utilities in the low–error group (95% vs. 71%,* $\boldsymbol{X}^2 = 4.38$; df = 1; p = .078*).*

Near–Miss Investigation

Almost 2/3 of respondents reported that they attempted to collect near miss information: of those, 12 reported special forms (near–miss reports, "close-call cards") for doing so, and 3 reported "near–miss" programs. Most of the descriptions provided were rather vague and to the effect we will investigate *if* we hear about it.

Table 4-53
Collection of information on "Near-Misses"

Item V.2. Proportion of those responding that their utility attempts to collect information on "near misses"			
	Overall % (n)	Distribution % (n)	Transmission % (n)
Collect information on near-misses	64 (157)	64 (53)	62 (82)

Finding: *The proportion of utilities who report collecting information on near-misses is significantly higher in the low–error group than in the high–error group (79% vs. 54%: X^2 = 3.90; df = 1; p = .089).*

Models of workplace accidents suggest that the number of near misses is larger than the number of realized accidents or incidents by a factor of somewhere between 3 and 10. Sixty five (65) surveys (41% of the total sample) supplied both the numbers needed to calculated the ratio of reported near misses to the number of incidents (errors). As shown n Table 4-54, the average value of this ratio was 1.22. The data thus strongly suggest that most utilities are not picking up anywhere near the true number of near misses.

Table 4-54
Ratio of Reported "Near–Misses" to Errors or Incidents

Item V.3b. Ratio of reported near-misses to incidents*			
	Overall Ratio (n)	Distribution Ratio (n)	Transmission Ratio (n)
	1.22 (65)	1.53 (21)	1.10 (31)
Low value	0.00	0.00	0.00
High value	11.1	11.1	2.0

* Calculation does not include those who reported "near–misses" but no actual "errors or incidents"

Table 4-55 shows the average near-miss-to-incident ratios for the utilities in the low– and high–error groups. The average near-miss-to-incident ratio was 2.52 for the 9 utilities in the low–error group and 0.73 for the 13 respondents in the high–error group supplying the necessary numbers. Although the difference is dramatic, it fails to achieve statistical significance because much of the difference is due to one of the low–error utilities that had a very high near–miss to error ratio. The data do, however, suggest that, on average, the members of the low–error group who collect near–miss information do so more effectively than both the members of the high–error group and the utilities in the rest of the sample.

Table 4-55
Differences Between Low– and High–Error Groups in Ratio of Near–Misses to Incidents or Errors

Item V.3b. Ratio of reported near-misses to incidents							
	Low–Error Ratio (n)	High–Error Ratio (n)	Statistics Test	df	p		Excluded Ratio (n)
Ratio of near-misses to reported errors	2.52 (9)	0.73 (13)	t = 1.53	8.41	.162	*NS*	1.24 (43)

Error Trends

Utilities reporting decreasing errors (29%) outnumber those reporting increasing errors (19%). Some respondents checked two boxes, such as decreasing and steady (presumably to indicate "steady–to–decreasing"). Those responding for Transmission appeared to be more likely to report that errors were increasing than were their counterparts in Distribution.

Table 4-56
Trends in Errors/Incidents

Item V.3c. Reported trends in the number of errors/incidents (proportion of those responding)						
	Overall		Distribution		Transmission	
	%	(n)	%	(n)	%	(n)
Increasing	19	(146)	10	(49)	25	(75)
Decreasing	29	(146)	33	(49)	24	(75)
Steady	55	(146)	57	(49)	57	(75)

Investigative Procedures

Respondents were equally divided between those reporting informal or ad hoc investigation methods (55%) and those reporting following a formal written procedure when investigating switching incidents (55%). Many respondents reported they used both formal and informal investigations, depending on the judgment of the severity of the incident.

Table 4-57
Procedures Employed in Error Investigations

Item V.4. Reported methods of investigation (proportion of those responding)						
	Overall		Distribution		Transmission	
	%	(n)	%	(n)	%	(n)
Informal or ad-hoc procedure	55	(155)	62	(53)	50	(80)
Follow written procedure	55	(155)	47	(53)	60	(80)

Error Investigations

Responsibility for Investigation

Primary responsibility for investigating operator errors/incidents depends on where the error occurs:

- For errors or incidents occurring in the control center, control center supervision is almost always responsible.
- For errors or incidents occurring in the field, field supervision is responsible most of the time, usually with someone from control center supervision also involved in the investigation.

Investigation Team

If the incident investigation is performed by a team rather than a single individual, the composition of the team is highly variable. Control center supervision is included almost all of the time, with field supervision when field people are involved. Teams investigating incidents involving field personnel more frequently have safety department personnel and sometimes a union representative for the trades-people. One utility includes non-involved peers on the review teams.

Distribution of Incident Reports

As shown in Table 4-58, the groups most likely to receive incident reports are the managers of the individuals involved and the individuals themselves, either as a specifically target recipient (32% overall) or via department-wide distribution (58%).

The majority of utilities report that the purpose of error/incident investigations is to learn from their mistakes so as to prevent something similar from happening again. It is, at first glance, somewhat surprising that less than half of the respondents (43%) reported routinely sending incident reports to the Training Department. However, in most utilities the Safety Department provides a second channel of communications about incidents and steps to prevent their re-occurrence. Responses to Item V.5. suggest that the Safety Department representatives participate in most investigations of incidents involving workers in the field, but they were seldom mentioned as being involved in investigations of incidents that involved only control center personnel. Moreover, 58% report distributing incident reports to all personnel in the departments involved. This would tend to support the stated goal of using incidents as learning opportunities, either via "lessons learned' sections in the reports or by simply allowing personnel to draw whatever inferences may be applicable to their personal work situations.

Wide dissemination of incident information is a component of strategies for reducing them [5, 6]. The difference between the low– and high–error groups shown in Table 4-59 below was not statistically significant. The proportion of utilities in **both** groups distributing incident reports to all personnel in the departments involved with the incident (71% and 81% respectively) was larger than in the population of utilities excluded from the error comparison (47%),

Overall, 36% of respondents reported that error/incident reports were sent to senior (VP level) management. This proportion was slightly higher for distribution departments than for transmission operations. In many cases, routinely receiving individual incident reports may be the result of active participation by senior management in programs to reduce errors or incidents, and serves as a visible reminder of management's concern. In addition, the proportion of the low–error group sending reports to their VPs was larger than in the high–error group (57% vs. 41%), and larger than in the sample as a whole.

Table 4-58
Distribution of Incident Reports

Item V.6. Personnel to whom error / incident reports are routinely distributed (proportion of respondents)			
	Overall % (n)	Distribution % (n)	Transmission % (n)
Individuals involved [1]	32 (152)	38 (50)	30 (80)
All personnel in the departments involved [2]	58 (152)	48 (50)	64 (80)
Training department	43 (152)	34 (50)	45 (80)
Safety department	75 (152)	72 (50)	75 (80)
Managers of the individuals involved [3]	37 (152)	40 (50)	35 (80)
Vice president or above	36 (152)	44 (50)	34 (80)

[1] Only the individual involved and not other members of their departments (except their managers).

[2.] All members of the departments involved, including both the individuals involved in the incident and their managers.

[3.] Managers but not all personnel in the department.

Table 4-59 shows the responses to this survey item for the low– and high–error groups. Interestingly, these two groups again seem more like one another than either is to the remainder sample. As shown in the table, the proportion of utilities in both the low– and high–error groups distributing incident reports to their training departments (57% and 44% respectively) was somewhat larger than in the population of utilities excluded from the error comparison (38%).

Table 4-59
Differences Between Low– and High–Error Groups in Distribution of Incident Reports

V.6. Personnel to whom error / incident reports are routinely distributed (proportion of respondents)				
	Low–Error % (n)	High–Error % (n)	Statistics Test df p	Excluded % (n)
Individuals involved [1]	21 (28)	11 (27)	*NS*	40 (97)
All personnel in the departments involved [2]	71 (28)	81 (27)	*NS*	47 (97)
Training department	57 (28)	44 (27)	*NS*	38 (97)
Safety department	71 (28)	78 (27)	*NS*	75 (97)
Managers of the individuals involved [3]	29 (28)	15 (27)	*NS*	45 (97)
Vice president or above	57 (28)	41 (27)	*NS*	29 (91)

[1] Only the individual involved and not other members of their departments (except their managers).

[2.] All members of the departments involved.

[3.] Managers but not all personnel in the department.

Implementation of Recommendations

Overall, 42% of respondents reported having a formal mechanism for ensuring that recommendations resulting from the investigations were implemented. The values were 37% for distribution and 46% for transmission. In virtually all cases, managers of affected departments were responsible for implementing changes recommended by investigators (Item 7.b). Fifty Four percent (54%) of those in the low–error group reported some mechanism for implementing recommendations, as compared to 39% in the high–error group.

Accountability Policy

As shown in Table 4-60, 55% of survey respondents reported that their utility has a "personal accountability" policy whereby operators (and/or their supervisors) may be disciplined for errors/incidents. The proportion of those responding for Distribution only (63%) was higher than the proportion responding for Transmission only (47%). Virtually all such policies progressive discipline policies. A number of respondents indicated that although such policies were in place, they were followed inconsistently.

Table 4-60
Personal Accountability Policies

Item V.8. Accountability policies			
	Overall % (n)	Distribution % (n)	Transmission % (n)
Have "personal accountability" policy	55 (154)	63 (51)	47 (81)

Having a personal accountability policy is more common in both the low– and high–error groups than in the rest of the sample (71% vs. 54% respectively, compared to 50% of the 98 responses excluded from the comparison). The difference between the low– and high–error groups is not statistically significant.

5
IMPLICATIONS FOR SWITCHING PRACTICES

The survey provides summary data about a broad range of switching practices and preliminary analyses linking these practices to error rates. In this concluding section of the report, we use this data and literature drawn from other safety critical industries to take a first step toward the identification of "best practices."

As has been stated several times earlier in the report, the present data do not allow any firm conclusions to be drawn about practices that contribute to the mitigation of error when performing high voltage switching. But the data are often suggestive. In this section, we take another look at areas where a strong industry consensus about switching practices and information from the error analysis converge on candidate "best practices" for enhancing safety and reliability.

The first section describes our approach to identifying best practices and the rules of interpretation that we have used. This is followed by a summary of the candidates for best practices. Finally, we set these findings against the broader context of factors that contribute to human performance improvement in an organization. This leads us on the one hand to offer some cautions and recommendations concerning the ways in which readers should apply the results of the study in their own organizations, and on the other hand to suggest additional avenues of research for the future.

Toward Best Practices: The Approach

The initial purpose of the survey was to provide a description of the ways in which switching operations are conducted industry-wide. Such a description would enable individual utilities to situate practices in their own company against those used more broadly in the industry. More widespread information about how others do business might gradually lead to greater standardization across the utility industry—a result which is increasingly desirable given the frequency and extent to which boundaries between utilities are being redrawn. However, as the study proceeded and preliminary results became available, it was evident that the industry wanted more than a simple description of switching practices. They wanted to know which practices were effective in reducing error, and which of the practices were "best practices." Best practices may be defined as practices that appear to contribute significantly to the success of an enterprise. As used in the business literature [7, 8, 9, 10], the term encompasses a range of meanings, from individual procedures to essentially the entirety of the way an operating unit or company conducts its business. In this discussion, we will use the term in its narrowest sense, to refer to individual practices at the level of description used in the survey.

In this section, we approach the identification of best switching practices from three directions. These are: (1) areas of consensus across survey respondents; (2) correlation between specific practices and error rates as determined by the error analysis; and (3) theory and practice from other safety-critical industries as determined from the literature in the field.

Areas of Consensus

Areas of consensus provide the first suggestions of best practices. If the majority of the industry performs operations in a given way, then there may be some justification for concluding that this method of operation has stood the test of time and embodies the collective wisdom of the industry.

A dictionary definition of consensus is "collective opinion or general agreement." The dictionary gives no quantitative values, but a consensus is clearly much more than a simple majority. For the purposes of this discussion, practices used by 70% or more of survey respondents are considered areas of consensus[1]. Conversely, if 30% or less of respondents indicate use of a given practice, the non-use of this practice may also be considered to be an area of consensus (for example, non-use of relay prints when preparing switching orders). For questions to which respondents were asked to provide a numerical response (for example, number of hours of refresher training), a strong modal value or interval may also be taken as an area of consensus (for example, provision of refresher training at 12-month intervals).

Taken by itself, consensus is not sufficient as an indication of best practice. From the active interest shown by many utilities in this project and associated research, it is evident that the industry is also looking for better way. Consensus data must therefore be considered alongside other information.

Results of Error Rate Analysis

The error rate analysis methodology was described in Section 3 and the results were presented throughout Section 4. These results are referred to as findings. Where a particular practice is employed by significantly more members of the low–error group than of the high–error group, this indicates that the practice is used by those utilities that are more successful at error-avoidance. We take this to be an indication that it is a valuable practice and should be considered as a candidate for a 'best practice.'

Again, there is a need for caution in interpreting these results by themselves, since correlation does not necessarily imply a cause and effect relationship. For example, from the finding that a higher proportion of the high–error group appeared to have more aggressive use of testing in their qualification programs than members of the low error group, one would not wish to conclude that less testing is in some sense better. A more plausible alternate interpretation is that more extensive use of testing is provided to ensure the effectiveness of training in response to the higher incidence of errors.

[1] In the summary of areas of consensus that follows, practices have not been included where the agreement applied only to one sub-group (e.g., transmission or distribution) and the level of agreement only just reached the cut-off value of 70%.

In interpreting the finding in this example, we have recourse both to the literature of performance-based training and to experience in other industries. Consider, for example, the heavy emphasis placed on refresher training and formal qualification by safety critical industries such as the airline industry and nuclear power. Thus, the third strand to consider in this attempt to identify best practices is the understanding and experience that the literature of the field provides.

Literature Review

Section 6 provides a partial bibliography of studies and reports against which the particular findings of this study have been evaluated. The literature covers several different points of view (human factors, safety, human performance, training, organizational studies, benchmarking) and different critical safety industries (nuclear, petroleum, defense). Literature sources are referred to selectively in discussing individual results in the next section.

Rules of Interpretation

In reviewing the results of this study, we have used the following rules of interpretation:

- Where areas of consensus are supported by the error analysis, we postulate a best practice, particularly where these areas are also consistent with the literature of the field.
- Where an area of consensus conforms with the literature and is not contradicted by a finding, we consider it to be a candidate for best practice.
- Where the results of the error analysis are supported by the literature, but are not in agreement with the areas of consensus, we flag these areas as ‘low hanging fruit’ or potential areas for improvement industry-wide.
- Where the results of the error analysis are not supported by the literature of the field, we look for alternate interpretations or conclude that there is a need for further investigation.

With these rules in mind, the following section takes a further look at the survey results as presented in the last section. All major areas of consensus are discussed.

Switching Responsibilities

There is a consensus that control centers—not substation or line operations—have switching authority at both transmission and distribution voltages (Table 4-3). This result is consistent with a number of other areas of consensus throughout the survey that indicate the important central role that control center operators have in coordination of switching operations: for example, in coordinating switching and clearances and in incident investigation.

While there is a need for one position to have ultimate authority in any complex or safety-critical operation, it is also important for all those involved to have responsibility for successful task performance. At the 3rd Annual Switching Safety and Reliability Conference, several utility presenters stressed that each position should have the responsibility and be empowered to call a halt to an operation when safety or reliability was in question. The balance of authority and

responsibility between control centers and the field is an important area for future investigation but was not addressed directly in the survey.

Another area of consensus is that substation, maintenance and linemen/troublemen are allowed to perform switching on company equipment; customer personnel and contractors are not (Table 4-6).

Personnel Selection, Training, and Qualification

Selection and Retention of Personnel

The following are areas of consensus in relation to personnel selection:

- Utility field experience is required for selection as control center operator; college education is not required.
- Prior work experience in the electrical field is generally not required for entrance into training as a substation operator or field operator (lineman or troubleshooter). The work experience to operate independently is provided during the apprenticeship period, which is typically 4 years.

Trends in the industry suggest that, at least for transmission control center operators, the situation as reflected by this area of consensus is changing. Because of a shortage of candidates, control centers are being forced to recruit personnel without field experience. Also, more value is being placed on the education level of control center applicants.

The reported difference in years of experience between the low-error and high-error groups (which is statistically significant for substation personnel but not for control center or line personnel) suggests the importance of measures to retain experienced staff. This conclusion is supported by literature concerning the importance of case experience in development of expertise. In some cases, experience on the job can be replaced by ‘accelerated experience’ using carefully planned training simulations.

Training Programs

The survey indicated strong consensus concerning the provision of formal training programs (Table 4-11). The consensus covered each group of personnel (line, substation, and control center) and the two voltage levels (transmission and distribution). An interesting finding is that a higher percentage of the high–error than of the low–error group reported having formal training programs for line, substation, and control center personnel; although the difference did not reach statistical significance. Overall 75% of respondents have formal training programs with a range of 69-85% in the low-error group and 86-95% in the high error group. This result is surprising if the data are interpreted in terms of simple cause and effect. The finding would, however, be consistent with the use of formal training as part of a program to reduce errors or increase performance generally, though there is no means of determining this from the survey data.

Figure 4-5 indicated that the most common number of weeks of initial classroom training was between one and two weeks for both line and substation personnel with a greater spread of values for control center personnel. When considered in combination with the number of weeks of job experience that are required of these positions, the results indicate a strong industry consensus that the important learning for utility switching personnel is experience-based.

The training literature, while not disputing the importance of job experience, suggests that formalized training (in classroom or job setting) is essential for achieving required levels of employee performance. It is certainly difficult to understand how simple exposure to job experience can be regarded as adequate preparation for a formal qualification process, which, as the next item indicates, is a very strong candidate for best practice. The balance of theory (classroom) and practice (experience) in initial training is an area for further investigation.

Qualification

There was a consensus (or near consensus) concerning the requirement to complete an internal qualification or certification process for each group of personnel and each voltage level (see Table 4-14). This result is strengthened by the finding that the percentage of those with such a program was higher in the low error group for all three categories of personnel. The literature also strongly supports the practice of internal certification for critical job positions [11, 12].

Although the components of the training programs and the certification processes were not captured in detail by the present survey, and undoubtedly vary between utilities, it is clear that a strong commitment to personnel training and qualification is a common denominator among the utilities in the low-error group.

Refresher Training

In contrast to the consensus on provision of formal (initial) training, there was no consensus relating to the provision of periodic refresher training. Both common sense and the training literature suggest that refresher training is essential to sustain high levels of performance on the job. A possible explanation for the lack of consensus on the provision of refresher training is that the question was interpreted in terms of formal, off-site training, whereas much training—particularly for field personnel—may take place at safety meetings and other routine occurrences.

There was however a finding that the average interval between refresher training sessions for control center personnel for utilities in the high–error group was longer than that for the low–error group and far exceeded the 12-month modal interval for the industry as a whole. This is consistent with the known result that spaced repetition or practice provides for more effective learning than massed repetition.

The data also show that members of the low–error group with refresher training programs provided, on average, more than twice as many hours of training per year as the members of the high–error group. The difference, though impressive, was not statistically significant due to large variations within each group.

These findings, backed by the tenets of good training practice, point to higher frequency and more extensive (hours/year) refresher training as areas of best practice. Future investigations should focus on detailed practices in the area of refresher training.

Retesting

Concerning periodic retesting for maintenance of certification as a qualified operator, there is a consensus among survey respondents that retesting of qualified personnel is not required. This applies to each position and voltage level. This is an area in which the experience of other industries suggests there may be reason for the utility industry to change.

Planning Switching

In the survey results, the largest number of areas of consensus or near-consensus existed for activities related to planning switching and to the preparation of switching orders.

Advance Planning

The consensus value for the advance notice required for submitting switching requests was between 24 and 48 hours. There was a tendency for the low–error group to require greater advanced notice than the high–error group or the overall sample, though the difference did not achieve statistical significance.

This is an area that is changing with industry deregulation—particularly for transmission outages. In market environments, the operating rules generally require that longer notice be provided. In this respect, it is of interest that greater advanced notice for routine switching was also the third most common category (mentioned on 7 surveys) of changes being made to switching procedures (see Table 4-41). Further investigation is necessary before identifying a best practice.

Preparation of Switching Instructions

There is a consensus that control center operators, not supervisors and still less substation or line personnel, are responsible for the preparation of switching orders (Table 4-28).

Standardization of Switching Procedures

The use of standard switching procedures throughout the utility was an area of consensus for both transmission and distribution respondents 77% overall. In addition, the largest number (15) of reported changes to switching procedures (Table 4-41) were to increase the degree of standardization.

The value of standardizing terminology and switching procedures has been stressed at recent EPRI Switching Safety and Reliability Conferences, as has the potential for error when different terminology and operating assumptions co-exist within a company or within a region. A long-

range goal of this project is to work toward greater standardization of terminology and switching practices industry-wide, as a means of coping with the problems that arise when utilities merge and re-organize. As reported at the 3rd Annual Switching Safety and Reliability conference, one NERC region is taking serious steps to standardize terminology for inter-utility switching. Standardization thus emerges as a candidate for best practice.

Switching Steps Contained in Switching Procedures

There were very high levels consensus on eight of ten items relating to the content of written switching orders, as shown in Table 5-1 (see Table-4-31 for more details). For each item, there was consensus for both transmission and distribution switching. It is interesting that there was no such consensus for including the item 'applying and removing of portable grounds'. The need to track grounds carefully received attention at the 2nd Annual Switching Safety and Reliability Conference and the lack of a system for tracking grounds was cited recently in the report of a major industry event [13].

The second most cited category of changes made to switching orders (mentioned by 10 surveys) was the inclusion of additional steps or more detail in the written orders. The use of detailed switching procedures becomes a strong candidate for best practices. However, the desirability of providing instructions covering every detail of a job is a matter of debate in the literature [14, 15]. Some would argue that providing very detailed instructions tends to remove the element of professionalism from the employee's work, making the employee too reliant on external direction. Exactly what level of detail is desirable may depend on multiple factors such as the complexity of the electric system, experience of the operators and so on. It may also depend on the way in which responsibility is shared between control center personnel and line or substation personnel. In some utilities, relay adjustments and other operations at the station are performed locally and are not part of the standard communication between control center and field. This avoids the need for inclusion of these steps within the switching order.

Table 5-1
Areas of Consensus as to the Contents of Written Switching Procedures

Instructions	% Overall
Operating breakers	99
Operating disconnects	99
Operating ground switches	80
Disabling and restoring protective schemes	83
Placing tags	95
Checking open breakers	91
Disabling and restoring reclosers	92
Enabling and disabling local control	73

Background Information

As shown in Table 5-2 (see also Tables 4-33 and 4-34), there were also high levels of agreement as to virtually all background information items included in written switching orders. Here the consensus areas were reinforced by two findings: utilities in the low-error group are more likely to include the name of the switchman and steps performed via SCADA in their switching orders.

Table 5-2
Areas of Consensus as to Information Items Included in Written Switching Procedures

Practice	% Overall	% Low-Error Group	% High-Error Group
Purpose of the job	83	86	82
Name of the person writing the order	90	93	82
Name(s) of person(s) approving order	72	86	64
Name of the Switchman	72	79	54
Name of the clearance holder	89	86	89
Equipment to be operated via SCADA.	71	96	71
Steps to be performed in all field locations	85	96	86
Time each step completed	85	89	71

Helping personnel at all levels understand the big picture as well as the details of their immediate tasks is a characteristic of high reliability organizations [16]. Background information items are useful in allowing the field switchmen to evaluate the correctness of the instructions received, and thus help to identify errors in the instructions before they are acted upon.

Return to Service

There was a consensus that restore-to-service orders should be written in the same detail as remove from service orders (86% overall and 100% of utilities in the low–error group). This also constituted a finding with statistical significance and is therefore a strong candidate for best practice (see Table 4-40).

Use of Job Aids

Two areas of consensus were (1) the required use of line and station prints when preparing an order (86%) and (2) that previous or canned procedures are NOT required. On the second point, other data from the survey suggested that there are many divergent practices on the actual use of previously-prepared procedures (see Table 4-29). There was also a consensus that relay diagrams are not used in preparing either distribution or transmission switching. This is a somewhat surprising finding, given the importance of making appropriate adjustments to system protection when switching equipment in or out of service. Further investigation is required.

Implementing Switching in the Field

Areas of consensus in relation to practices required of field personnel are shown in Table 5-3 (See also Tables 4-42 and 4-43.). Of these, the requirement to check off each step as performed also emerged as a finding: those in the low error group were significantly more likely to use this practice.

Table 5-3
Areas of Consensus as to Practices Required of Switchmen in the Field

Practice	% Overall	% Low-Error Group	% High-Error Group
Repeat all verbal instructions to the sender	95	100	89
Notify dispatcher if equipment is not in exact condition anticipated	96	100	93
Call in before beginning a job	89	89	100
Carry order while switching	73	75	64
Check-off each step as it is performed	73	79	54

There were two items that provided findings in the error analysis but that did not achieve consensus or even a simple majority in the overall sample. These include requiring field personnel to personally go over the switching instructions with the dispatcher prior to beginning work (46% of the low–error group vs. 18% of the high–error group and 39% of the sample as a whole); and use of a self–verification routine (54% of the low–error group vs. 21% of the high–error group and 43% of the sample as a whole). Self checking [17] is a tool that has been employed for many years by several electric utilities [2] and is used widely in the chemical and petrochemical industries [5, 18] and commercial nuclear power plants [6]. The data therefore suggest that these practices offer opportunities for improving switching practices industry-wide.

Coordination of Switching

There is consensus that switching performed by different switchers in the field is coordinated by the control center operator for both transmission and distribution switching.

Issuing Clearances

Consensus practices in relation to issuing and releasing clearances are:

- Clearances are issued orally and not in writing. There are no findings to support or negate this practice, and the few write-ins suggest that the question was interpreted more literally than perhaps we intended, in that the final go-ahead to work is typically communicated to crews at or in route to the job site.
- Clearances issued by another utility are issued first to the control center operator and not to field personnel. This practice reinforces other data that emphasize the strong central role of the control center operator in all switching. The clear identification of responsibility is widely

recognized as an important component in a high performing organization and links to the accepted importance of individual accountability (see below).

- One clearance is issued to each work group. This was an area of near-consensus that appears to be strengthened by the negative consensus that two alternate practices (only one clearance or one master clearance with sub-clearances) are not used (23% and 17% respectively). The statistically significant finding that more companies in the low–error group than in the high–error group (43% vs. 14%) reported the practice of issuing only one clearance to cover multiple work parties is not interpreted as diminishing the desirability of this as a policy. The handful of write-in amplifications to responses for this item suggest, rather, that several utilities in the low–error group demonstrated a degree of flexibility in their clearance practices, using different kinds of clearance as required by the characteristics of the individual jobs.

Retention of Records

The majority of respondents (95% overall) reported that the written orders used by the dispatcher are retained in the records after the job has been completed. The retention of orders used by personnel in the field does not achieve consensus but does provide a finding: respondents in the high–error group are significantly less likely to retain switching orders used by personnel in the field (50% vs. 21%). Together, these results suggest the retention of records to be a best practice. Such retention also supports auditing for procedural compliance and the accountability of all parties and facilitates the process of incident investigation when errors occur. See Tables 4-50 and 4-51 for further details.

Incident Investigation and Reporting

Near-Miss Data

Overall, 64% of respondents reported attempting to collect information on near-misses: a clear majority, but not enough to qualify as a consensus practice. However, 79% of the low–error group attempted to collect such information, while only 54% if the high–error group did. As reflected in a higher ratio of reported near-misses to incidents, members of the low–error group also appeared to be more successful at collecting near-miss information than did members of the high–error group or the sample at large. The fact that norms for other industries suggest a much higher ratio of near-misses to errors than reported by respondents to this survey suggests that this is a candidate for best practice and an area for improvement in the utility industry.

Investigation Procedures

Although use of formal procedures in incident investigations did not achieve consensus levels (see Table 4-57), systematic investigation and root cause analysis of incidents is the norm in the commercial nuclear industry [6] and strongly recommended as a component of an overall error management program by guidebooks for other industries [5, 18].

Similarly, a program to ensure follow through on implementation of recommendations is generally recommended, but did not achieve consensus level in the responses. However, 71% of respondents in the low-error group did report such programs. This is another area for improvement in the utility industry.

Responsibility for Investigation

From the write-in responses provided in response to a question concerning responsibility for conducting incident investigations, there was a clear consensus that control center supervision or management is involved in nearly all incident investigations. Control center errors are investigated by control center personnel and essentially no one else, while errors in the field are investigated by field supervision, the safety department and, virtually always, control center supervision or management.

Distribution of Reports

Table 5-4 indicates areas of consensus relating to the distribution of incident reports (see also Tables 4-58 and 4-59). There is a consensus that incident reports are distributed to the individuals involved, to their managers, and to the safety department.

Table 5-4
Areas of Consensus as to Distribution of Incident Reports

Practice	% Overall	% Low-Error Group	% High-Error Group
Distribution to the individuals involved*	79	92	92
Distribution to all members of the departments involved	58	71	81
Distribution to the Safety Department	75	71	78
Distribution to the managers of individuals involved*	95	100	96

* Tabled values derived by adding distribution to individuals-only or managers-only shown in Tables 4-58 and -59 to those for distribution to all in the departments involved.

Although not statistically significant, the proportion of utilities in the low–error group sending reports to their VPs was larger than the proportion in the high–error group (57% vs. 41%), and the sample as a whole (36%). Routine distribution of incident reports to senior managers is a visible sign of the commitment from senior management that is an essential element of effective error management programs [5, 19].

Accountability Policies

A bare consensus (71%) of utilities in the low–error group reported having some form of personal accountability policy, as compared to 54% of the high–error group and 55% of the

sample as a whole. Personal accountability is considered to be a critical element of effective error management strategies by many managers [19].

Summary

Interpretation of the survey data with the help of applicable literature from other industries leads to the following summary of candidates for 'best practices' that may help to improve the reliability and safety of switching operations.

Switching Responsibilities
• Control Centers have switching authority. • Substation operators, maintenance personnel, and linemen/troublemen are allowed to perform switching on company equipment; customer personnel and contractors are not.
Personnel Selection, Training and Qualification
• Experienced personnel are retained in key operating positions. • Formal, structured training programs are provided for persons with switching responsibility. • There is a formal qualification or certification process for persons with switching responsibility. • Periodic refresher training is provided; intervals between training sessions are shorter (12 months or less) rather than longer (18 to 36 months).
Planning Switching
• Switching procedures are standardized within all areas and departments performing switching operations. • Switching instructions are prepared and approved by control center operators. • Station operating instructions and line and station prints are used when preparing switching orders. • Step-by-step information and background information as listed in Tables 5-1 and 5-2 are provided in written switching instructions or procedures. • Restore–to–service orders are written in the same detail as remove–from–service orders.
Implementing Switching in the Field
• Practices listed in Table 5-3 relating to the issuing of switching instructions are followed. • Field personnel are required to personally review switching instructions with the dispatcher prior to beginning work. • A self–verification routine is used by both dispatchers and field personnel when performing switching. • Clearances are issued orally. • Clearances from another utility are first issued to the control center operator. • Switching orders used by both the dispatcher and the switchmen in the field are retained in the records.
Incident Investigation and Reporting
• There is an effective program for collection and dissemination of information on near-misses. • Incidents are investigated in a formal manner and there is a process for following up on the recommendations. • Incident reports are widely distributed, including to managers and senior managers.

Applying Best Practices

The identification of 'best practices' is undertaken with the expectation that adoption of such practices by those that do not currently employ them may improve some aspect their own performance. The 'best practices' identified from the survey data, as reported in the previous section, provide a first step toward the eventual definition of a set of standard practices. However, the analysis of the data suggested many additional questions and the need for caution in applying the results.

Reasons for Caution

One area of concern is correct interpretation of the data. As indicated, several of the specific conclusions were ambiguous or call for further investigation. Examples are practices where the error analysis and industry consensus point in opposite directions. Some of these ambiguities may be the result of the lack of standard terminology (for example 'clearance') that led to different interpretations of questions on the survey form.

An underlying question is how similar practices may result in wide variations in performance as far as the incidence of errors is concerned. The answer, or part of it, may lie in the way in which respondents answered the survey questions. That is, many of the work practice questions could be answered at the policy level—what was supposed to happen (the 'ought')—as opposed to the practice level—how things are actually done most of the time (the 'is'). A policy or practice that would produce reliable results if followed closely, may have the opposite effect if it is widely ignored in practice. Such issues are the province of supervision and management. And managers at all levels are engaged in coping with a period of unprecedented changes in their organizations, changes that are competing for their attention with the critical task of overseeing daily activities.

Transferability of Practices

Practices Taken in Isolation

In deciding to apply the best practices that are identified here, the reader should consider the weight of the evidence provided and the applicability of a specific practice within the reader's own organization. There is a fairly large literature warning that simply importing bits and pieces of another's practices may not produce the hoped-for results. One reason is that a group of practices which, taken together provides an effective way of achieving safe performance, may when taken in isolation, lose their effectiveness or be incompatible with other practices. For example, the level of detail on a switching instruction may reflect the way in which responsibilities are assigned or the level of training that is provided to the operators. Another reason is that a 'best practice' identified in one industry or organization may not transfer seamlessly to another type of enterprise or to another organization within the same industry. Some of these relate to the institutional culture as discussed below.

General Policies vs. Specific Practices

When considering how to apply the results of this study, it may be helpful to distinguish general policies related to the management of human performance from specific practices related to the task of high voltage switching. In the former group are methods used to train and qualify employees and methods for incident investigation, such as are covered by Sections II and IV of the survey. In the latter group are specific details concerning the planning and implementation of switching identified in Sections III and IV of the survey.

The experience of other industries can be applied more readily to the management policies level items than to the specific details of switching. Even within an area such as training, we can more confidently identify best practices at a general level (there should be a formal training and qualification program) than the specific duration or frequency of such training (substation operators require so many weeks of initial classroom training).

In all areas, the generic under-pinning of a practice may be of more significance than the specific practice itself. For example, the level of detail that should be provided in a switching instruction may be of more interest than the specific items that are or are not included. Again, the fact that responsibilities for each switching-related task are clearly defined may be more important than the specific positions to which particular responsibilities are given.

Institutional Culture

Another often-cited reason for the limited transferability of best practices is that success in any undertaking is a joint product of both individual and easily identifiable practices, such as those cataloged by the survey, and the underlying institutional "culture." Although detailed treatment of the concept and subtleties of institutional culture is beyond the scope of this report, questions of culture are important to the transferability of practices between organizations. Institutional culture may be roughly defined as the sometimes unarticulated value system that determines the priorities observed and how people perform their duties, which may not be visible in a simple description of what is done [8, 20, 21]. For our purposes, two aspects of such cultures are worth noting. First, although it is common to speak of "corporate" cultures, important differences may also exist between operating units or functional departments within a given corporation, for example marketing and operations, or engineering and operations [1]. A second related observation is that professional groups within different corporations may have values more similar to one another than to the other groups within their respective corporations, i.e., an "occupational culture" that exists within the broader corporate culture.

The survey made no attempt to collect information on institutional cultures. However, utility operations departments share very similar responsibilities, goals, and working environments. Moreover, several aspects of the professional culture within such departments, notably a high value placed on safety and reliability, commitment, and communication, appear to be characteristic of a general utility "operator culture" [1] and more generally of organizations that must perform hazardous operations routinely [16, 22, 23]. Thus, in spite of the well-founded caveats regarding the prospects for success of practices adopted with insufficient consideration of the overall culture in which they appear to be successful, the shared missions and cultures of utility operations departments may be expected to allow maximum transferability of practices.

Indeed, over the several years of EPRI investigation of this subject, the investigators have found that the communications among utilities at conferences and other gatherings have contributed both to an increased understanding of these cultural values and gradual convergence in ways of thinking about safety problems.

Additional Considerations

Partly as a result of careful analysis of the survey results—including the still unanswered questions about what practices are most effective—and partly due to issues that have surfaced at annual conferences and in response to industry events since the survey was initiated, we have identified a number of areas for future investigation. Several of these relate to the ways in which performance is managed [24] and the organizational processes and programs that support switching activities. Many of these areas would benefit from a careful look at how utilities with the best operating records, perform these functions.

Supervisory Practices

Effective supervision is the key to ensuring that policies and practices are implemented as intended. Operations managers and supervisors at utilities face many challenges to-day, including:

- Effective oversight of a workforce that is often geographically distributed, and in many cases includes many new people.
- Integration of different operating units as companies merge and operating boundaries are re-defined.
- Implementation of policies and priorities in the face of changing messages about company priorities from the corporate level, and in particular the demands of competition and the new rules of a de-regulated industry.

The questions to be answered include:

- How do utilities formulate and communicate priorities to operating personnel?
- What methods are used to audit work performance? What feedback is provided? What are the consequences of non-compliance?
- What steps are taken to ensure that the institutional culture supports compliance with documented policies and work practices?
- What policies are followed in relation to accountability and responsibility?

Incidents and Near-Misses: Promoting Institutional Learning

A second area that would benefit from further investigation is how to facilitate institutional learning from errors and incidents. Learning from near-misses is particularly problematic, but potentially rewarding because they are thought to outnumber realized errors by a factor of ten or more, and may involve the same conditions that are involved in serious incidents or accidents.

Typically, business measures do not support the goal of measuring near misses; utilities report many barriers to documenting and learning from them, including disciplinary policies and lack of open communication between management and operating personnel.

Questions to be answered include:

- How should 'Error' and 'Near Miss' be defined? What methods are being used to track and record near misses? What are the barriers to success of these programs? What are the benefits and limitations of different approaches?
- What methods are used to investigate and follow-up on incidents? How effective are they in identifying and responding to the root causes of events? What techniques are used to ensure effective measures that are not cost-prohibitive?
- How do excellent companies respond to errors? What is the response of management? Is it to blame the operators on the spot or is there a commitment to accepting management's ultimate responsibility for the conditions that lead to errors?

Training, Job Aids, and Operator Qualification

Formal training and qualification programs for all groups of operators have been identified as best practices, without any agreement on the details. Training provides the knowledge and skill the operator needs to perform switching safely and reliably, but there are also non-training methods for supporting operator performance, such as use of effective procedures and job aids. Respondents to the survey reported little or no use of job aids for switching. And anecdotal data supports the position that procedures for electric system operation (compared for example to those for nuclear power) are generally poorly written and not implemented in a consistent manner.

Questions to be answered include:

- What is the detailed structure and format for initial and continuing training at companies with excellent switching records? What is the basis for the training design? How effective has it been? What is the balance of classroom training and job experience?
- What type of qualification test is provided? What is the basis for these tests? How well does performance on the test correlate with subsequent performance on the job?
- What job aids are used to support performance? In what ways could job aids, including the new generation of software, be used to support improved operational performance?
- What is the format for refresher or continuing training? What is the mix of formal training periods and on-going coaching, safety meetings, and so on? Which mix of activities works well for companies with excellent performance records? Which methods are effective in improving performance of companies experiencing excessive operator errors? To what extent is refresher training used to prevent rather than to respond to problems?
- How effective are operating procedures in supporting operator performance? How is the information communicated to operators? Are procedural requirements followed routinely in the work situation? What balance between procedural directives and reliance on operator judgement (or professionalism) most effective in promoting excellent performance?

6
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A
APPENDIX A – MEMBERS OF THE STEERING COMMITTEE

Members of the Steering Committee Following 1997 Conference

Earl Cass	Western Area Power Administration
Dennis Caufield	Houston Power & Light
Chris Cooper	Ontario Hydro
Jim Daly	Tennessee Valley Authority
Richard Dearman	Tennessee Valley Authority
Paul Dessureau	EPRI Energy Delivery and Utilization Division
James Edwards	Oregon Trail Electric Co-op
Wade Miller	Pacific Gas & Electric
Dave Shypulski	Northern States Power Co.
Sarah Lutterodt	Quality Training Systems
Arthur Beare	Beare Ergonomics

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B
APPENDIX B – SWITCHING PRACTICES SURVEY

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Switching Safety and Reliability Project Survey

Survey of Switching Practices

Instructions:

1. *Please answer all items with respect to **either** transmission **or** distribution operations. **All** answers should be for the voltage levels identified in the box below. If you are responding for your company for both types of operation, please use a separate survey form for each.*

Responses provided on this survey form apply to:	
Transmission Operations	☐
Distribution Operations	☐
Voltage Levels Covered	_____ to _____

2. *Where there are check boxes, please check **ALL** that apply. Checking a box is saying YES to the question.*
3. *Note that many of the questions are answered by check boxes arranged in multiple columns, e.g., for **line (L), substation (SS),** or both **(L/SS),** and **control center (CC)** personnel. Please be sure you understand the answer format before answering each question.*
4. *Where the answer is in the format Y / N, circle either Y for 'Yes' or N for 'No'.*
5. *Where there is a blank line, please enter the appropriate information.*
6. *Please write in a clarification for any answer that you feel is not adequately captured by the alternatives presented. If necessary, attach extra sheets **clearly** indicating the item(s) that your comments address.*

I: Respondent and Organizational Data

Utility: _____

Your name: _____

Your job title: _____

Your phone number (very important): _____

E-mail: _____

1. My responsibilities in relation to switching include:
   - Control center operations ..... ☐
   - Switching in substations ..... ☐
   - Line switching ..... ☐

2. For the voltage level for which you are responding, who has switching authority on the system?
   - Control center ..... ☐
   - Substation operations ..... ☐
   - Line operations ..... ☐

3. a. Approximately how many switching requests (***not*** individual control actions) are processed by your utility each year?
   _____

   b. Approximately how many of the above requests involve other utilities or non-utility (customer/contractor) personnel in execution of part or all of the switching? _____

4. Categories of personnel authorized to perform switching on equipment in the field:
   - Substation operators ..... ☐
   - Maintenance personnel ..... ☐
   - Linemen / troublemen ..... ☐
   - Generating plant personnel. ..... ☐
   - Customer personnel……. ..... ☐
   - Contractors……. ..... ☐

	L/SS	CC
5. Does your utility keep a list (by name) of those persons qualified to do switching?	Y / N	Y / N

II: Personnel Selection, Training, and Qualification

1. a. Briefly describe type and length of work experience required for control center operators: _____
   _____

   b. Briefly describe type and length of work experience required for field (substation, maintenance, or line) switching personnel: __
   _____
   _____
   _____

	L	SS	CC
2. a. What is the average or typical years of experience of present personnel in their current jobs?	____	____	____
b. What is the expected percentage turnover of switching personnel in next two years?	____%	____%	____%
3. a. Is there a formal training program for persons with switching responsibilities?	Y / N	Y / N	Y / N
b. If the answer is 'Yes' in 3.a above, what is the length of initial classroom training (in weeks)?	____	____	____
4. What is the minimum time required on the job before individuals can perform switching on their own?	____	____	____

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	L	SS	CC
5. a. Are the personnel performing switching on the electric system required to complete an internal qualification/certification process?	Y / N	Y / N	Y / N
b. If 'Yes' to 5.a, what types of testing are used?:			
Written test	☐	☐	☐
Oral board	☐	☐	☐
Formal job performance test	☐	☐	☐
Informal on-the-job observation	☐	☐	☐
Simulator test	☐	☐	☐
Other (describe): _____			
6. a. Are switching personnel required to complete periodic refresher training in switching procedures?	Y / N	Y / N	Y / N
b. If 'Yes' to 6.a, approximately how many hours of training are required?	_____	_____	____
c. If 'Yes' to 6.a, what is the frequency of refresher training courses/activities (approximate interval in **months**)?	_____	_____	____
7. Is periodic formal re-testing required?	Y / N	Y / N	Y / N

8. a. Are customers, contractors, or other non-utility personnel allowed to perform switching on equipment that is under the jurisdiction of your utility? ..... Y / N

b. If 'Yes' to 8.a, briefly describe any training or qualification requirements for non-utility personnel allowed to switch your equipment: _____

_____

_____

_____

_____

_____

_____

III: Planning Switching

1. How many hours in advance of the scheduled time of the switching are requests for routine switching (e.g., for maintenance or testing) required to be submitted? _____

2. Who is responsible for preparing the step-by-step written instructions for switching equipment (i.e., switching orders)?
   - Control center supervisor ..... ☐
   - Control center operator ..... ☐
   - Substation/line supervisor ..... ☐
   - Substation/line operator who will perform the switching. ☐
   - Other (describe): _____

3. Does the company use a database of 'canned' switching orders?
   - Yes, whenever possible ..... ☐
   - Yes, but only for the most routine switching ..... ☐
   - No, never ..... ☐
   - Yes, but only for (list situations below) ..... ☐

4. How standardized are switching order forms and associated procedures within your utility?
   - Standardized throughout the utility ..... ☐
   - Different between control center and field operations ..... ☐
   - Vary between departments and districts ..... ☐
   - Vary between generating stations and field ..... ☐

5. Which of the following instructions are included in written orders for switching?
   - Opening / closing breakers ..... ☐
   - Opening / closing disconnects ..... ☐
   - Closing / opening ground switches ..... ☐
   - Applying / removing portable grounds ..... ☐
   - Bypassing / restoring protective schemes ..... ☐
   - Applying / removing tags ..... ☐
   - Applying / removing locks ..... ☐
   - Checking open breakers ..... ☐
   - Disabling / restoring reclosing ..... ☐
   - Enabling / disabling local control ..... ☐
   - Other (describe): _____

6. How much information is included in each of the written steps?
   - One operation only ..... ☐
   - May include more than one operation ..... ☐

7. Does each step in a switching order have a unique identification number? ..... Y / N

8. Which of the following information items are included in written switching orders?
   - Purpose of job ..... ☐
   - Name of person writing switching order ..... ☐
   - Name of person(s) approving switching order ..... ☐
   - Name of the switchman ..... ☐
   - Name of clearance holder ..... ☐
   - Identification of steps to be performed via SCADA ..... ☐
   - Steps to be performed at all field/substation locations ..... ☐
   - Expectations re 'as-found' status (e.g., energized or not) .. ☐
   - Time each step completed ..... ☐
   - Other (describe): _____

9. In what situations, if any, is a written and approved switching order NOT required for switching:?
   - All of the switching is performed from the control center via SCADA ..... ☐
   - Adjustments to taps on LTCs or voltage regulators ..... ☐
   - Switching of capacitors via SCADA ..... ☐
   - Emergency switching ..... ☐
   - Other (describe): _____

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10. What is the number of approval signatures required for routine jobs prior to dispatching? _____

11. Whose approval (signature) is required for routine switching?
- Control center manager ☐
- Control center supervisor ☐
- System operator / dispatcher ☐
- Supervisor of persons performing work in the field ☐
- Other: (describe): _____

12. Aids used for preparing/checking switching orders include:

	required	optional
Previous or canned switching orders	☐	☐
Line/station prints	☐	☐
Station operating instructions	☐	☐
Relay diagrams	☐	☐
Special software for checking switching orders	☐	☐

Other (describe): _____

13. For routine switching, how many hours in advance of the actual switching are instructions distributed to those who will perform the switching ? _____ hrs.

14. a. When switching involves another utility or customer personnel, what procedures are used for notifying/scheduling the switching?
- Our usual procedures ☐
- Their procedures ☐
- Special inter-utility procedures ☐

b. Who schedules the switching with the other utility or customer?
_____

15. How much detail is provided in switching orders for restoration following completion of scheduled work?
- Same detail as in the remove-from-service orders ☐
- Written out in detail ONLY when restoration is NOT accomplished by performing the opposite steps in the reverse order from the remove-from-service switching orders ☐

16. a. Has your utility changed its switching procedures in the last two years, or is it planning such a change? Y / N

b. If so, briefly describe the nature of the changes and the reasons they were necessary: _____

IV: Implementing Switching in the Field

1. Persons performing switching in the field are required to:

	always	sometimes
Use a phonetic alphabet when communicating equipment nomenclature	☐	☐
Repeat verbal instructions back to the sender	☐	☐
When a series of steps is dictated, repeat back:		
Each step as it is copied	☐	☐
The entire order after all steps are copied	☐	☐
Personally review the work with the dispatcher before beginning the job	☐	☐
Review appropriate prints before beginning the work	☐	☐
Walk down all of their portion of the work before beginning the work	☐	☐
Notify the dispatcher if equipment status or nomenclature is not exactly as specified	☐	☐
Call in before beginning the job	☐	☐
Carry the order while switching	☐	☐
Check off each step as it is performed	☐	☐
Perform an explicit self-verification routine such as "the Six Steps of Switching" (see box below) when performing each step	☐	☐

Other (describe): _____

"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.

2. If the switching involves switching at different locations, how do the individual switchmen communicate to coordinate their steps?
- Through the control center ☐
- Through the field operations supervisors ☐
- Directly between themselves ☐
- Other (describe): _____

3. What is your utility's policy in relation to issuing "clearances" (notification that it is safe to do work on the system) for a given outage?
- Only one clearance is issued ☐
- One clearance to each work group ☐
- Master clearance with individual 'sub-clearances' for each work group ☐
- Other (describe): _____

4. How is clearance issued within your utility?
- Written document ☐
- Orally, by phone or radio ☐
- Other (describe): _____

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5. If another utility is issuing a clearance related to work on your equipment (e.g., opening their end of an interconnection), to whom does the other utility issue the clearance?
   - Your control center operator ☐
   - Your field personnel ☐
   - Other (describe): _____

6. a. Can anyone **other than** the clearance holder (e.g., the clearance-holder's supervisor) release a clearance? Y / N

   b. If 'Yes' to 6.a, please explain: _____

7. What is your utility's policy in relation to placement of tags?
   - One tag placed on each switching device ☐
   - Each working group places their own tags ☐
   - Tags placed on SCADA points ☐
   - Other (describe): _____

8. Is the clearance holder's name always placed on the tag? Y / N

9. Which of the following are maintained in the records after switching is completed?
   - Switching orders used by dispatcher ☐
   - Switching orders used by personnel in field ☐
   - Recordings of communications between CC and field ☐
   - Tags ☐
   - Other (describe): _____

V: Incident Investigation and Reporting

1. How does your utility define an "operating error" or "incident"?
   - Personal injury ☐
   - Damage to equipment ☐
   - Loss of service to customers ☐
   - Violations of operating procedures ☐
   - Mis-operation of equipment ☐
   - Other (describe): _____

2. a. Does your utility attempt to collect information on "near misses," i.e., errors or incidents that almost occurred but were caught before the wrong actions were taken? Y / N

   b. If 'Yes' to 2.a, please describe: _____

3. a. Approximately how many errors or incidents are reported each year? _____

   b. How many near misses a year? _____

   c. What is the trend in the number of errors/incidents?
      - Increasing ☐
      - Decreasing ☐
      - Steady ☐

4. What process is used for investigating incidents?
   - Informal or ad-hoc ☐
   - Follow a formal (written) in-house procedure ☐
   - Other (describe): _____

5. a. Who has primary responsibility for investigating errors/incidents by operators when an error or incident occurs in . . .
   - The control center? _____
   - The field? _____

   b. If the incident investigation is performed by a team rather than a single individual, what is the composition of the team?

6. To whom are error / incident reports distributed?
   - Individuals involved in the incident ☐
   - All personnel in the departments involved ☐
   - Training department ☐
   - Safety department ☐
   - Managers of the individuals involved ☐
   - Vice president or above ☐

7. a. Is there a formal mechanism for ensuring that recommendations resulting from investigations are implemented? Y / N

   b. If 'Yes' to 7.a, please describe: _____

8. a. Does your utility have a "personal accountability" policy whereby operators (and/or their supervisors) are disciplined for errors/incidents? Y / N

   b. If 'Yes' to 8.a, please describe: _____

VI: Other Concerns Related to Safety and Reliability

On a separate piece of paper, please identify any issues related to switching practices that you think may affect safety and system reliability, and should have been addressed in this survey.

C
APPENDIX C – UTILITIES PROVIDING THE DATA ANALYZED FOR THIS REPORT

1st Energy

Alabama Electric Co-op

Alabama Power Co

Allegheny Power

Alliant - IES Utilities, Inc

American Electric Power

Arizona Electric Power Cooperative

BGE

Bonneville Power Administration

Boro of Chambersburg

Boston Edison

Board of Public Utilities

Cajun Electric Co-op

Clarksdale Public Utilities

CLECO

CONVEX-Northeast Utilities

CP&L

City Public Service of San Antonio

City of Columbia MO water & Light

City of Lodi Electric Utility

City of Palo Alto

City of Tallahassee

City of Thomasville

Clallam County PUD

Colorado River Commission

Conectiv

Connecticut Light and Power

Consumers Energy

Crawfordsville Electric Light & power

Dairyland Power Cooperative

Decatur Utilities

Detroit Edison

Duke Energy Corp

Duquesne Light Co

ENTERGY

East Kentucky Power Co-op

El Paso Electric Co

Electric Power Board of Chattanooga

Electric Energy Inc.

Empire Electric Association

Farmington Electric System

Florida Power & Light

Florida Power Corp

GPU Energy

Georgia System Operations Corp

Georgia Power Co

Georgia Transmission Corp

Groton Utilities

Hawaiian Electric Co

Hetch Hetchy Water & Power, City of San Francisco

Hoosier Energy

Illinois Power & Light

Idaho Power Company

Illinois Power Co

Imperial Irrigation District

Jackson Co. REMC

Jackson Utility District

Jacksonville Electric Authority

Johnson City Power board

Kansas City Power & Light

LGE Energy

Lansing Board of Water & Light

Lincoln Electric System

Long Island Lighting Co

Longmont Power & Communications Co.

Loup River Public Power District

Memphis Light Gas & Water

Menasha

MidAmerican Energy Co

Minnesota Power Co.

Minnkota Power Co-op

Mississippi Power Co

Modesto Irrigation District

Montana Dakota Utilities Co.

Morristown Power System

Northern Indiana Public Service Co.

New York Power Authority

New York State Electric & Gas

Nashville Electric Service

Nebraska Public Power District

Nevada Power Co

Niagara Mohawk Power Corp

Northeast utilities

Northern States Power

Northwestern public Service

OG&E Electric

Ocala Electric Utility

Omaha Public Power District

Orange & Rockland Utilities

Otter Tail Power

Pacific Gas and Electric

Potomac Electric Power Co

PECO Energy Co

Pennsylvania Power & Light

Pierce-Pepin Electric

Portland General Electric

Public Service Company of New Mexico

Public Service Company of Oklahoma/CSW

Public Service of Colorado

Public Service Electric & Gas

PUD#1 of Chelan County

Puget Sound Energy

Reedy Creek Energy Services

Richmond Power & Light

Roseville Electric

Salt River Project

San Diego Gas & Electric

Santee Cooper

Snohomish PUD Everett, WA

South Carolina Electric &Gas Co

Southern California Edison

Southern Indiana Gas & Electric Co.

Tampa Electric Co

Tennessee Valley Authority

The Illuminating Co (First Energy)

The Montana Power Company

Tri-State Generation-Transmission

TU Electric

United Illuminating

United Power Association

USBR Hoover Dam

Vermont Electric Power Co.

Western Area Power Administration

Westfield Gas & Electric

Wisconsin Electric

Wisconsin Public Service Corp.

Canadian Utilities Included in Analysis

BC Hydro

Manitoba Hydro

New Brunswick Power

Ontario Hydro

Sask Power

Trans Alta Utilities

Foreign Utilities Excluded from Analysis

Electric Supply Board of Ireland

Powercor (Australia)

Transener (South Africa)

Target:
Substation Operation and Maintenance

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