CAUSE AND PREVENTION OF HUMAN ERROR IN ELECTRIC UTILITY OPERATIONS

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ABSTRACT

Trends in the electric utility industry have increased the chances and costs of errors by power system operators. Competition is dictating that more be done with available assets. There are fewer field personnel. Cost, rather than reliability and ease of operation is taking priority in new power distribution equipment. Computers, which can be used to simplify work , are installed primarily to process more information and allow the operator to do more.

Although this study touches on many aspects of electric operations, it focuses on errors committed by the people running the nerve center of the industry, the power system dispatchers or operators. By the nature of the job, these people are the most visible when something goes wrong. The effects of their mistakes are immediate and potentially costly. This is in contrast with engineering or management mistakes which might never be detected even though things later goes awry because of them.

Even though errors are taken seriously by the industry, little has been done to formally track and reduce their occurrence. The two cases found relied on the principle that lack of concentration was the primary cause of mishaps. In other words, the dispatcher must be "fixed" if the situation is to improve. This theory is in contrast with other process industry and manufacturing approaches to prevent errors, defects and accidents.

This study started with a survey of dispatchers from 18 utilities representing nearly 2000 years of operating experience. Operators identified underlying error causes and suggested improvements. In addition, other fields were examined to find ways to track and reduce errors. Quality management and reliability engineering principles were found that apply to error reduction. The cognitive science and industrial safety professions also have concepts that prove useful in understanding and eliminating mistakes.

This paper should provide a better understanding of human error. It is intended to give practical information to operating personnel. It offers suggestions, tools and a plan that any utility can use to reduce the likelihood of errors in its control centers, power plants and out in the field.

It's been said that those who cannot remember the past are doomed to repeat it. If we learn from others, we need not commit the same mistakes. Not only must dispatchers learn from their coworkers, but companies should share information for everyone's benefit. That is why this paper also recommends the establishment of a utility error database.

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INTRODUCTION

Background

At this moment, a network of dispatchers is operating the most complex machine ever built, the national electric power system. This task is accomplished through the coordinated effort of more than 200 energy control offices across the country. Each office serves as the nerve center for a segment of the interconnected generators and transmission lines that deliver power to every home, business and factory. The system operator, or dispatcher, is responsible for the safe, reliable and economic operation of his or her cog in this "national engine".

As part of this job, giant circuit breakers and switches are operated to control voltage, direct power flows and permit routine maintenance. Thousands of these devices across the country are switched each day either remotely by the dispatchers or locally by field personnel under the operators' orders.

Because humans are involved in the process, mistakes will be made. The most serious consequence of an error by a system operator is the death or injury of a person working in the field. Less serious mistakes can ruin equipment worth hundreds of thousands of dollars. Localized blackouts can also occur that affect thousands of people.

The indirect costs associated with an error can dwarf the equipment damage that occurs. A failed main transformer at a power plant can render the entire station useless for the duration of the repair, which can be months. In addition, a plant outage can significantly reduce a utility's ability to import power from neighboring companies. The result is that a single event at a large power station could cost a utility many millions of dollars.

For the purposes of this study, an operating error is defined as an action or significant omission by a dispatcher that results in one of the following:

- equipment damage.
- a loss of customer load.

- improper protective zone for field work.

These are the most serious mistakes made by the operator. They occur while "switching" on the transmission system.

What Can Be Done?

If the electric power industry is to maintain its safety record in a higher risk environment, it must take an honest look at its performance and also learn from lessons in other fields. Telling the operator to “try harder” while increasing workload is a formula for failure. To succeed, both management and operators must share the responsibility to improve. Each must be taught how to avoid risks. Finally, proven preventative and corrective measures must be applied to the problem.

This thesis provides the tools any utility can use to not only maintain, but also improve its safety performance. It contains practical operating tips collected through surveys from scores of operators. It provides the cognitive science theory needed to understand the causes of human error. Finally, it presents quality management techniques that can lead to improved safety.

Increased Concern

There has been a growing concern with human error. Our high tech world has increased the magnitude of recent mishaps. The single words TMI, Bhopal, Challenger, Valdese and Chernobyl bring vivid images of man's failures. They have been a driving force in the growth of literature in this previously obscure field.

In the past, the consequences of errors were usually confined to the immediate vicinity of the error. With increased technology, the impact can be felt across continents and generations. The disasters listed above bear witness to this.

Until recently, it was unlikely a power system error would cause an incident on a the scale of the events mentioned above. Larger areas are now controlled by individual operators. Deregulation has forced the power system to operate closer to its limits. Combine this with society's dependence on continuity of power, and errors now have a greater impact. Electric utilities should learn the lessons of other industries.

This paper looks to several fields of study to attack the problem of errors. It weaves together the areas of cognitive science, industrial safety, quality management/control along with observations of power system operators. Two of these areas in particular have not been explored by utilities to improve operations.

Cognitive science offers insight into the workings of human mind. There has been recent growth in this field, especially in understanding the underlying factors that cause errors. The problem is that this field has not offered much in ways to prevent mistakes.

The quality control profession has worked toward the prevention of defects (production errors) for over 50 years. It has a great deal to offer in the practical aspects of error prevention.

Objectives

The goals of this study are to:

- Analyze specific operating errors that occurred over several years at a major utility.
- Through surveys of system operators, identify error causes and obtain suggestions for improvements.
- Compare utilities to identify significant differences.
- Make recommendations to reduce the number of errors.
- Develop a system to track errors in order to spot problems and trends.
- Provide a plan and the tools needed for any utility to implement their own error reduction program.
- Recommend a format and provide the mechanism to establish a utility wide error data base.

To make this a useful document, specific suggestions will be made as they apply to the topic at hand. These **OPERATING POINTERS** (☛) will both reinforce the information and also provide tips to improve a company's operations.

Significance

This study should provide system operators and managers valuable information to reduce the number of operating errors. Some of the potential benefits would be:

- increased safety of field personnel.

- reduction in equipment damaged due to errors.
- improved system reliability.
- reduced customer dissatisfaction from outages.
- fewer customer damage claims because of power interruptions.
- increased worker satisfaction by directly involving them.

The principles in this paper would apply to error reduction in other industries.

Operating Error Overview

Many people in the industry commit errors. The dispatcher is, however, the most visible. Due to the nature of the job, he or she has the most opportunity to make errors. Maintenance, testing and construction personnel also make mistakes. They, along with others, will be included indirectly in this study.

Job responsibilities for the system operator vary from company to company. Smaller utilities typically have smaller staffs. This means each person must perform a wider range of duties. In general, the tasks done by an operator include:

- operate the transmission and/or distribution system.
- dispatch electric generation for economics and reliability.
- make short and intermediate term electric load forecasts.
- respond to system problems.
- buy and sell power with other companies.[1]
- call out work crews after normal working hours.
- monitor other services (gas, water).
- control waterways (hydroelectric generation).
- run computer studies to accomplish the above.

As this study focuses on switching errors, this portion of the job will be discussed in more detail.

Types of Switching or Operating

The dispatcher performs his or her job in different "operating states". These coincide with the condition of the power system. The switching that takes place in these states can be divided into four categories. Although common mistakes can occur in each, the underlying causes of errors vary. This is due to the condition of the power system and the working environment of the operator.

Scheduled Switching

Scheduled switching involves work that has been previously requested by other groups (maintenance, line workers, etc.). A dispatcher has sufficient time (one or more days) to study the outage's effect on the power system, write up the procedure to be followed, schedule manpower and take care of any coordinating details. Most switching falls in this category. Because scheduled switching is done the most, the majority of errors occur doing it.

At some companies, the preparation of scheduled switching is done by someone other than the "real time" dispatcher. This reduces the workload and distractions of the operator and allows him or her to concentrate on the task at hand. It also ensures at least one extra person has reviewed the sequence beforehand.

☛ **Operating Pointer:** If there is no separate outage coordinator, the switching procedure should be reviewed by another person. This quality check would help prevent errors due to following an incorrect procedure.

PCs are also proving useful in storing switching procedures. "Good" procedures and useful notes can be saved. This builds a knowledge base that dispatchers can draw on in the future.

☛ **Operating Pointer:** Word process switching procedures and save them. If this is not feasible, make copies of hand written procedures for future reference.

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[1] This responsibility is changing to one of monitoring and approving transmission usage as mandated by the Federal Energy Regulatory Commission (FERC).

Routine Switching

Routine switching encompasses the normal, day-to-day actions taken to prod the power system in the right direction. It is repetitive and uncomplicated in nature. Examples are cutting capacitors and reactors in and out to control voltage. Usually no documentation takes place. Because it is easily done, it tends to be rushed compared to other jobs. This is where the person "just operates the wrong device". A later discussion on human reliability will show that this occurs at a predictable rate.

☛ **Operating Pointer:** The dispatcher should always slow down, take a deep breath to focus on the task at hand and take a second look before operating any device.

☛ **Operating Pointer:** If you operate capacitors and reactors off special CRT displays with only these devices, you will never accidentally open a line circuit breaker by mistake.

Unscheduled Switching

Unscheduled switching involves unforeseen situations that arise while running a power system. Defective equipment is found by field personnel. Unexpected opportunities to work on "hard to get out" items come up. Communication breakdowns or lost paperwork result in surprises when crews call in asking why their requested outage hasn't happened.

A red flag should come up in the operator's mind in these situations. Even though it is important to have a cooperative "can do" attitude, it can easily cause trouble. Less time is available to write up and prepare for these jobs. The procedure doesn’t go through a “quality review” by other operators. Errors will happen because the operator overlooks something or tries to do too many things at once. It will be seen later that an unscheduled job is roughly 25 times more likely to go awry than a scheduled one.

☛ **Operating Pointer:** Whenever someone calls to request an unscheduled outage, always break communication (tell them you will call them back), take the time to write the procedure and have someone review it. If there is any doubt about taking the equipment out of service, don't.

Emergency or Forced Switching

Emergency or forced switching occurs the least. The weather is the major cause of transmission and distribution lines tripping out of service. Equipment failure, animals contacting equipment in substations, and relay misoperations are among the other causes of system disturbances.

During such times, priorities must be established and acted on. The operator must be both a communicator and troubleshooter. Steps must be taken decisively to restore and ensure the security of the system. Records must also be kept. This flurry of mental activity occurs in an instant after periods of relative quiet.

The key to preventing errors in emergency situations is training and information. Training forms the basis of the operator's response. Job aids (memory joggers) can be useful guiding people through the proper steps.

Trends in the System Operator Job

The factors that have the greatest impact on the system operator job are advancements in computer technology, utility deregulation and a resulting change in "political" environment. These three factors are closely intertwined.

In years past, the priorities of the system operator were clear. They were (in order) personnel and equipment safety, system reliability, and finally economics. Competition has blurred the distinction between reliability and economics. The operator is charged with assuming more risk and reducing operating costs where possible. Systems in the field are less redundant and rely more on operator action.

Deregulation has also allowed customers within a utility's boundaries to look elsewhere for service. The dispatcher is often the one who must account for the power that is brought into his or her system. Also the number of power contracts and companies the operator can deal with has increased exponentially. This bartering and accounting can demand a significant portion of the operator's attention.

Competition and the FERC

In 1996, the Federal Energy Regulatory Commission (FERC) mandated open access of the national grid. This has brought non-utility marketers into the picture. The marketers have no inherent stake in maintaining the reliability of the system. Their primary interest is “moving” power. This is causing the grid to operate closer to its limits. A system operating closer to its threshold is more susceptible to failure. Large power transfers over long distances were identified as a contributor to the August 10, 1996 outage that interrupted 7.5 million customers and shut down 15 major power plants in the western United States[2].

In an attempt to ensure equal access of the transmission system to all players, the FERC also forced utilities to physically move their merchant activities out of the transmission control rooms. This means the system operator no longer performs this function. The utilities are therefore adding staff to perform this important marketing function.

Because system operators have experience in energy transactions, both utility and non-utility marketing groups are hiring dispatchers. Due to demand and the potential returns, the marketing positions pay more than dispatching jobs. This has drained experienced operators from the control centers.

This turnover means there is now a less experienced dispatching force than before the FERC order. It will be shown later that there is a strong relationship between experience and error-free operation. Utilities need to mitigate this increased risk if they want to preserve the reliability of their operations.

Computers

Computer advancements allow the operator to control more equipment and process more data. The result is dispatchers are monitoring wider territories. Because more information is being processed, the

[2] WSCC Final Report on the August 10, 1996 Disturbance, North American Electric Reliability Council (http://www.nerc.com/), October 30, 1996.

dispatcher has more to decipher. Situations that he or she can observe today that put them in the alert state may have gone unnoticed in the past.

Changes at this study’s host utility exemplify the increased demands. Since the mid 80's, the area controlled by transmission operators has nearly tripled. It was expected to increase again under a proposed merger. In fact, the accounting consultant that studied the merger suggested operating the future utility’s five state transmission system from one location.

From an operator’s perspective, computers can be used for two primary purposes, work expansion or work simplification. Even though computers can make the operators' present job easier, the above discussion demonstrates this doesn't happen. The majority of new applications are to permit more to be done. New energy management systems (EMS) are being installed to allow the operator to monitor a million or more pieces of data. Intuitively, effort should also be put in simplifying the work if the goal is to reduce the number of errors.

Changes in the Operators

The age, background and experience level of operators is changing. An Electric Power Research Institute (EPRI) study on human factors[3] noted that the traditional hiring pool (substation operators) for dispatchers was almost gone. In addition, most utilities have since implemented early retirement programs. This was done to reduce budgets and make companies more competitive. Finally, FERC Orders 888 and 889, which are driving the deregulation of the transmission system, have led marketing organizations to hire a significant number of dispatchers. The net result is that operators are younger, less experienced and with a more diverse background.

The risk vs. experience factor was mentioned earlier. This should be of concern to utilities. The changes in age and background are beyond the scope of this study. Hopefully the diversity of skills will increase the abilities of the dispatcher pool.

[3]Koenig, D., Frank, C., *Human Factors Review of Electric Power Dispatch Control Centers*, Electric Power Research Institute, October 1982.

COGNITIVE SCIENCE AND THE THEORY OF ERROR

Introduction

There are several problems encountered with an attempt to study errors. Experts in this field have divergent opinions on what constitutes an error. This leads to differences in estimates on the frequency of mishaps. It is reported that anywhere from 4 to 90 percent of industrial and systems failures are due to human error[4]. Because of this wide gap, the costs and impacts of errors are hard to pinpoint. Finally, there are general misunderstandings, particularly among decision-makers on what causes errors, and therefore, what should be done about them.

Problems Defining Errors

The leaders in the field do not have a general agreement on the definition of an error. Some believe an error is the same as an accident. Others include the concept of "intention" as a criteria. Still others have their own working models to describe subsets of errors. Different observations and conclusions will result from different definitions.

Problems with Error and Safety Data

Depending on the source, the available figures on error rates are often subjective. Many times they are based on opinions of experts. Data based on observations are often simulations. People perform differently when being observed. Since the damage from some errors doesn't occur until months or years after the initiating action many go uncounted. Finally, people detect many of their own errors and correct them before they have an observable effect. Such errors never come to light. The net result is that real error rate will be greater than what is reported.

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[4] Cohen, H. , Cohen, D. "Myths about human mistakes", *Professional Safety*, October 1991.

Difficult to Quantify Error Costs

Some attempts have been made within the electric utility industry to identify the costs associated with errors. An Electric Power Research Institute (EPRI) study on errors in power plants suggests 20-25% of power plant failures were due to human error[5]. The report noted 30 million Megawatt-hours of generation is lost annually due to these mishaps. A rough estimate of the increased cost of replacement power for the lost generation is $10/Megawatt-hour. If the equipment damage and injury related costs associated with these accidents are included, the sums are significant. This represents only one facet of the utility workforce.

The people that operate processes or equipment are typically the ones associated with error. Designers, managers, builders and maintainers also make mistakes. Insurance, injuries and damage expenses could be considered one estimate of the costs incurred due to "non-operators". The FERC reports that investor owned and public utilities paid $1.31 billion for property insurance, injuries and damages in 1995[6].

Myths Associated with Errors

Any accident can be said to be due to human error. If someone had done something differently, the accident would not have occurred. For example, if equipment failed, the designer and manager could have chosen a better device. However, when a report is filed on an error, it is typically by a manager that says that an accident was caused by an operator or maintenance person.

Human error encompasses widely different phenomena, each of which calls for different corrective measures. There is little in common between those accidents that occur because someone did not know what to do, those of omission, those due to inability and those that occur because someone forgot.

A common theme in the two error reduction programs found was that "lack of awareness" was the primary cause of operator errors. This conclusion is nearly identical to those in the earliest published accident reports. It is hard to argue with this concept. However, to say that all errors are due to a "lack of awareness" is

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[5] Weiss, J. *The Role of Personnel Errors in Power Plant Equipment Reliability,* EPRI TPS 77-715 & AF-1041.

similar to saying all trips and falls are due to gravity. The conclusion can't be disputed, but it offers no practical cure.

Action is needed to prevent an accident from happening again. It may be training, better enforcement of procedures, or changes in designs or work methods to reduce the likelihood of errors. An error reduction program that relies solely on the "try harder" approach will offer little results. No one wants to make mistakes. They were probably trying at the time.

Errors are Multidimensional

A simple example can be used to demonstrate the many forces that can interplay to cause an error. To show that errors are not strictly due to a lack of concentration, give several people 20 seconds to look at the following sentence and have them count all the "F's" it contains.

FEDERAL FUSES ARE THE RESULT OF YEARS
OF SCIENTIFIC STUDY COMBINED WITH
THE EXPERIENCE OF YEARS

Even though everyone was given the same task under the same conditions, there are typically many different answers. Some of the things that can affect the outcome of this test include:

- **Experience and Training.** Some of the people may have seen a similar example in the past. They would likely do better.
- **Skill.** Some people have a "knack" for a given task.
- **Time Available.** If people were given 40 seconds to read the sentence, the chance of getting the correct answer increases.
- **Distractions.** If you talk to the people while they are taking this test, not only would they become annoyed, they would also make more mistakes.
- **Time of Day.** Studies show that errors are more likely at certain times of the day. This will be discussed later.
- **Communications.** It is possible that someone distracted or hard of hearing could misunderstand the instructions and count the "S's".

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[6] 1995 FERC Form 1 data.

- **Personal Factors.** People's performance is affected by several internal factors that they bring to work each day. These include: their state of health, the amount of sleep they had, personal problems, etc.. Some of them are within the control of the individual, some are not.
- **Incorrect or Unclear Instructions.** What if the real goal of this test were to count the number of WORDS THAT CONTAINED the letter F? The answer could be different.

From the perspective of a manager or an outside observer, it often doesn't matter what was the underlying cause for a mishap. The thing that stands out is that a mistake was made. That is why the operator typically will be found at fault even though there may be things beyond his or her control. A method will be discussed later for looking deeper to identify and remove underlying causes of errors.

Finally, for the curious, there were 6 F's in the example.

Error Classifications and Definitions

Before we look at how a person performs a complex task we must understand the terms that will be used. This includes how errors are classified and how they are defined. Figure 1 shows the relationship between the types of errors.

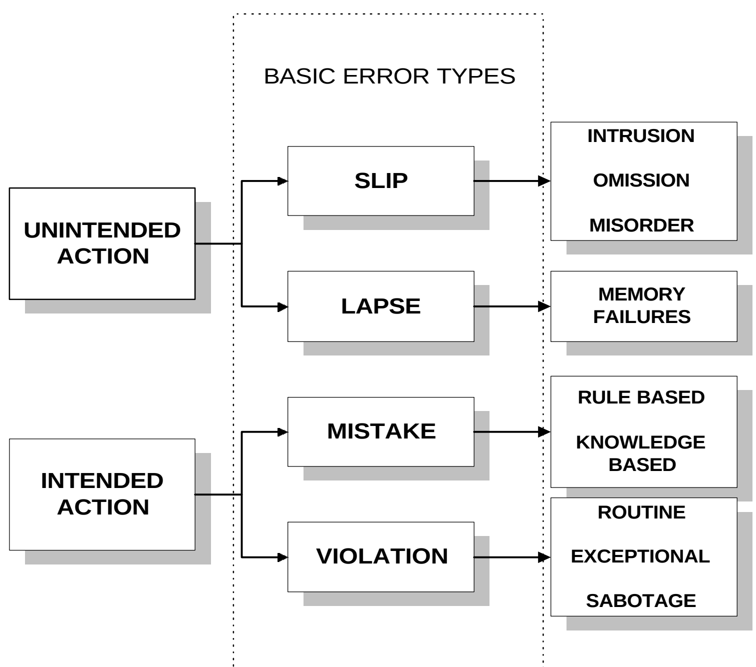

Figure 1. Error Types

Two Broad Categories

As shown in Figure 1, errors fall into two major groups. They are unintended actions and intended or planning failures. In other words, the person:

- did something he or she didn't want to do (action/omission error).
- did what they set out to do, but it wasn't the right thing (planning mistake).

Definitions

Accident: An unintended event with sad consequences.

Active error: A mishap with an immediate impact. They are usually committed by front line or operating personnel.

Error: A human action or omission not intended by the actor; not desired by a set of rules or an external observer, or that let the task or system move outside its acceptable limits.

Lapse: An omission from an original plan that causes undesirable results.

Latent error: An error with delayed consequences. They occur after something is done that sets a trap that waits for the right conditions to combine to cause a failure. Latent errors often are the most costly and are typically associated with disasters. Most of them are made by non-operators (designers, maintenance personnel, construction crews, managers, etc.).

Mistake: A planning failure where actions are taken as intended but the plan is flawed.

Operating Error: An action (or significant omission) by a dispatcher that results in equipment damage, a loss of customer load or improper protective zone for field work.

Sabotage: An intentional act with the expressed purpose of causing damage.

Slip: An error of action, such as operating the wrong device.

Violation: An intentional act that deviates from accepted rules.

Importance of Operating Error Definition

In order to identify and track anything, it must be observable and identifiable. Although several of the surveyed utilities tracked “errors”, each had different definitions. The three factors (load loss, damage and safety breeches) were common to all. They are not likely hidden, overlooked or forgotten. The fact that all three are severe events in the eyes of utilities and operators leads to the second justification for the definition.

Nearly everyone born before 1960 can remember where they were November the 22nd, 1963 (the date of John Kennedy's assassination). The previous generation can recall their surroundings December 7, 1941. These significant emotional events ingrain a great deal of information in people's long term memory.

Most people quizzed cannot recall what they had for dinner two nights ago. It's likely that those who do remember have a weekly dining pattern. On the other hand, dispatchers that have erred while switching are able to note the time of day, the location and device, coworkers involved and contributing factors of the event five to ten years later. The reason is the errors were "significant emotional events". This allows a utility to gain valuable information on their operations through surveys (as in this study).

Levels of Performance

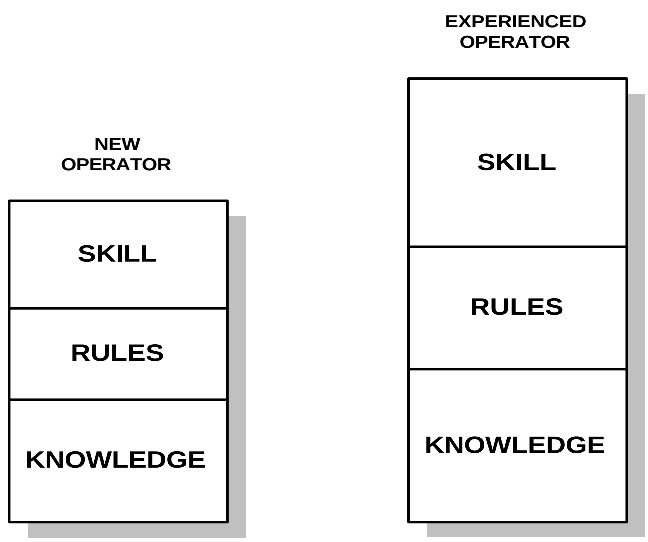

Figure 2 Levels of Performance

To understand the different types of errors, it's important to first look at the different "modes" in which people perform the thousands of tasks of every day life. Cognitive scientists have found that people perform at three separate levels. Figure 2 shows the three levels along with a comparison of an experienced and new operator.

Skill Based Performance

Skill Based Performance can be thought of as the use of mini computer programs (subroutines in programming jargon) that the mind stores by repeatedly doing a task. These programs are called into play without much thought and are done automatically.

Consider the example of a small child learning to dress. A great deal of effort and attention is expended fastening buttons and tying shoes. Performance at first is very slow.

With time, this task of getting dressed becomes automatic. Several subroutines are linked into one. "Get dressed" combines putting on socks, tying shoes, buttoning a shirt, tying a tie, etc. This larger subroutine (get dressed) is done without much thought.

When we are developing a skill, we start by ignoring all but one facet of the task. Driving a car with a stick shift is an example. We initially focus on shifting, ignoring speed, lane position, even other cars. Over time, the remaining skills are added to the subroutines, giving us smooth control of the vehicle. These skill based subroutines can be considered "autopilot" operation.

This autopilot mode of performance is not bad. It frees our mind to plan while allowing us to accomplish a myriad of tasks that face us each day. If every act required the same effort as that of a child dressing, we would likely never even get to work.

Slips (operating the wrong device) and lapses or omissions are the major forms of error in this mode of performance.

Rule Based Performance

The mind calls "Rule Based Performance" into play if the situation cannot be handled automatically by a stored skill. The rules are guidelines held in the person's memory store. An example of an operating rule is: if voltage is low, put in a capacitor. Rules can also be verbal (guidance from your supervisor or another operator) or written (instructions and procedures). Rule based mistakes (selecting the wrong rule or misapplying a good rule) cause trouble in this performance mode.

If the situation is resolved by applying a rule, the operator reverts back to skill based performance. If, however, there is no direct rule that can be applied, or if the problem can't be corrected by applying known rules, the operator must step up to the next level of performance.

Knowledge Based Performance

Knowledge Based Performance is where the person brings to bear all the concepts (as opposed to skills) that have been learned in order to come up with a solution. During knowledge based operations, the only real way forward is through trial and error. Success depends on defining the goal correctly, taking action, then recognizing and correcting deviations from the desired path.

Knowledge-based operations come into play in novel situations where actions must be planned in real-time. It uses conscious analytical processes and stored knowledge. Errors at this level are due to limitations in ability (called bounded rationality by cognitive scientists) and incomplete or incorrect knowledge.

As knowledge-based actions are taken, the situation either gets worse (an error has occurred), improves, or is solved. If the situation improves, a check is made to see if any rules apply. If so, they are attempted. If not, the problem stays in the knowledge based realm. The above cycle is repeated until the situation is “normal” and operator returns to skill-based performance. Because risk and effort is highest in the knowledge based area, the ultimate goal of human nature is to solve the problem at hand and return to the least-effort skill based level of performance.

Performance Levels Applied to Operations

When a dispatcher is first hired, he or she brings limited knowledge of the job and few skills. They follow written procedures and guidance of other operators. With more time on the job, the operator's skill set increases. He or she can do these things more or less automatically. They travel “up and down the ladder” to rule based and knowledge based operations as problems arise and back down as they solved.

The EPRI study on power plant errors[7] gives the impression that all mistakes are due to "lack of operator awareness" and working on autopilot. If operators did not spend the majority of their time in the skill based arena, very little would get done. The challenge is actually to instill good operating practices, simplify tasks and make the work environment less error prone.

> *"It is a profoundly erroneous truism...that we should cultivate the habit of thinking what we are doing. The precise opposite is the case. Civilization advances by extending the number of important operations which we can perform without thinking about them."* A.N. Whitehead

Major Error Types

Errors tend to take a surprisingly limited number of forms. Cognitive scientists identify three major types of errors. These coincide with the different modes of operating. They are:

- skill based slips.
- rule based mistakes.
- knowledge based mistakes.

Slips

A slip is an "action error" where the person does something they didn't set out to do. Operating the wrong circuit breaker is an example of a slip. The effects of a slip are usually immediate.

The likelihood of having a slip as opposed to other errors increases with experience. This is because slips occur in the skill based mode of performance. Experienced operators spend most of their time in the skill based mode. Overconfidence may also feed this. An error free record of a few years might cause a dispatcher to rush relatively simple jobs.

In most cases where a slip occurs, something has captured the person's attention while they are performing a familiar (skill based) task. The mechanism behind this will be discussed in the section on "the Human Action Model". The different types of slips are described below.

☛ **Operating Pointer:** Just before operating a piece of equipment, take a breath, reread the device label and verify it is the device you want.

[7] Weiss, J. *The Role of Personnel Errors in Power Plant Equipment Reliability*, EPRI TPS 77-715 &

Strong habit intrusion

When we operate in the autopilot mode and receive the proper stimulus while distracted, we tend to the things we do most often and those things we've done recently. A few everyday examples are:

- You are driving on a day off along the same road you normally travel to work. You catch yourself taking the work exit.
- The phone rings as you walk in the house after a busy day at work. You answer with your work greeting.
- You're a passenger in a car and suddenly a vehicle in front of you stops. Your right foot stomps on a non-existent brake.
- Next January, you will write the wrong year on your checks.

An interesting example can demonstrate strong habit intrusion. Figure 3 lists several words that are printed in different colored ink. The goal of the test is to quickly state, from top to bottom, the COLOR OF INK in which the words are printed. The person should NOT read the words. If they read any words, they have committed an error through strong habit intrusion. They did the thing they do most often, i.e. read the text.

Red
Yellow
Green
Blue
Red
Blue
Yellow
Green
Blue

Figure 3 State the Colors of the Text

AF-1041.

Preoccupation

James Reason demonstrated this error mechanism with a simple test similar to the one below[8]. Tell one or more people you will ask them seven questions. They should respond quickly. You can make this a challenge by awarding one point for each question to the person who responds first. You may help them with the first two answers, but don't do so beyond that. The questions, along with the likely responses are as follows:

1. What type of tree grows from an acorn? (Oak)
2. Who is Pepsi's® biggest competitor? (Coke®)
3. What do we call a story with a funny ending? (Joke)
4. What do we call the white of an egg? (Yolk) This is incorrect, but don't stop the exercise.
5. What do we call the white of an egg? (The response will likely be "Yolk" again).
6. What do we call the white of an egg? (The response might be "White", Yolk or perhaps silence)

There were not seven questions. Saying there were seven questions forced people to "think ahead" and become preoccupied with the ultimate result. For reasons to be discussed in the section on "the human action model", words in the people's memory store that ended with an "oke" sound were activated. A quick association was made between eggs and words that ended with "oke".

The net result is that because they were preoccupied, they slipped by giving a response related to something they do most often (yolk is a more common word than albumen, the correct answer).

Omitted Checks

The autopilot feature of the human mind helps us perform a myriad of tasks daily. The price we pay is that slips can occur when we are preoccupied at a key moment. The ☛ **Operating Pointer:** The "six steps of switching" described later, acts against this error mechanism.

Over-Attention

On the other side of the spectrum, over-attention can lead to errors. If you were to actually give thought to what your feet are doing while walking down steps, the chance of a fall would increase.

Another example from the sporting world is the standard football tactic when a critical field goal is attempted. The defensive team will call a time-out in order to make the kicker "think" about a normally automatic task.

Preventing Slips

Slips occur when attention is captured by distraction or preoccupation at a key moment while performing a routine task. This statement points to several strategies to prevent them.

- Reduce distractions to help prevent "capture" at key moments.
- Technology can prevent or eliminate slips. Examples in everyday life are spell checkers on word processors and stopper valves on drip type coffee makers.
- Installing a "barrier" between the operator and the risk. Putting all capacitor controls on a special CRT page will prevent an operator from dropping load when trying to switch a capacitor.
- Slips can also be overcome by taking personal steps to force more frequent checks (dropping out of autopilot) or causing a check to be made before a critical step. Using the earlier example of driving on your day off, if you take a different lane, you give occasional thought to why you're there. This will reduce the chance of you inadvertently taking the work exit. The "operating pointer" below outlines a similar strategy for switching.

☛ **Operating Pointer:** A recent EPRI study on switching safety[9] found that 67% of reported field errors were due, at least in part, to slips (failure to check or operating the wrong equipment). It recommended operators follow a 6 step procedure to prevent these mishaps. The procedure is applicable to people in control centers as well as those in the field. The procedure can be recalled by using the mnemonic TOEPOT:

1. **Touch** the label of the device to be operated.
2. Check your **orders** to ensure you have the correct device.
3. Is the device in the **expected** position (if not, question the orders).
4. **Perform** the operation.
5. **Observe** the change of status of the equipment.

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[8] Reason,J.T. *Human Error*. Cambridge University Press. 1990. p. 101.

6. Record the **time** of the operation.

In summary, skill based errors cannot be eliminated by simply asking people to "try harder". If slips are to be reduced, the work situation must also be redesigned[10].

Lapses or Omissions

Lapses are the other skill based problem. An everyday example is forgetting to pick up a gallon of milk on the way home from work. An operating example is missing a step in a procedure.

Lapses are most likely to occur when a job is interrupted. Control center operators (who are subject to interruptions because they often switch several jobs simultaneously) are more susceptible to lapses than field personnel. Similarly, since maintenance work also involves frequent interruption, omissions are a common form of error among testing and maintenance personnel[11].

EPRI study WO2944-10 reported that 25% of field errors and 33% of control center mishaps occurred, at least in part, because of omissions. Interruptions, distractions and workload were reported as contributors to the oversights.

☛ **Operating Pointer:** When returning to a job that has been interrupted, always back up a few steps and ensure each has been completed before proceeding.

☛ **Operating Pointer:** An important, yet overlooked responsibility of operators is to see that even small problems are fixed. Print errors, phone problems, loose switches, burned out indicator bulbs, etc. , can and do lead to future operating mishaps through interruption, misinformation and miscommunication.

Rule Based Mistakes

Mistakes are more complex and less understood than are slips. They are harder to detect and often lie dormant, waiting for the right conditions to come together to cause a future failure. Our consciousness is geared to pick up departures from an intended path. Even when detected, abnormal situations can be debated. The quality of the plan is often a matter of opinion. Another problem is that defective decisions based on

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[9] Beare, A. Taylor, J. *Field Operation Power Switching Safety*, WO2944-10, EPRI. 1996.
[10] Kletz, T. *An Engineer's View of Human Error.* New York: VCH Publishers. 1991. p. 2.

misinformation and/or poor judgment sometimes lead to successful results. Finally, a mistake might never see the light of day.

Rule-based performance involves the tackling of familiar problems by using stored rules. A mechanic's example is to turn bolts clockwise to tighten and always tighten them snugly. The mind applies this rule to everything that resembles a bolt. The problem is, not every bolt tightens clockwise and some bolts shouldn't be tightened snugly.

An operators' example is; if voltage goes low, put in a capacitor. This works in almost all cases. However, the operators responding to solar magnetic disturbances in Ontario found that doing this damaged transformers and capacitors[12]. Another problem with following this simple rule is where the capacitor hasn't discharged from its last use. This can blow fuses and damage equipment.

A rule based mistake occurs while trying to follow a procedure that has worked for the person in the past. Some of the major forms rule based mistakes take are:

- using the wrong rule.
- missing a step (or switching steps) in a rule.
- misapplying a good rule.

Rule based mistakes can be prevented by training and improving the accessibility and quality of rules. Job aids and "memory joggers" to assist the operator can prevent such errors. Putting good practices in writing and making them easily accessible can help the dispatcher. "Task outlines" as found in the *Tools* section of this paper, can be used for both training and for reference while operating. In summary, for rules to be effective[13], they must:

- be recallable (or readily available).
- be applicable to the current situation.
- have some expected value.
- be simple.

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[11] Rasmussen,J. "What can be learned from human error reports?". In K.Duncan, M. Gruneberg & D. Wallis (Eds.) *Changes in Working Life*. London: Wiley, 1980.
[12] "Magnetic storms could hit utilities hard in 1991", *Electrical World,* December, 1889.
[13] Reason,J.T. *Human Error*. Cambridge University Press. 1990. p. 49.

Knowledge Based Mistakes

A knowledge based mistake occurs when an operation is performed as intended but the desired goal is not reached. This is, in effect, a planning error. Knowledge based performance is really akin to "trial and error". The person performs an educated act, watches the result, and then moves to the next step.

Knowledge based performance takes place in new situations. A plan is developed and steps are taken. If an action moves the system in the wrong direction, the step is typically undone. This assumes the problem is detected. Oftentimes a knowledge based mistake plants a problem to trap someone else down the road.

James Reason identified four factors that contribute to knowledge based failures[14]. They are:

- bounded rationality (something beyond the training or ability of the operator).
- an inadequate mental model of the system.
- confirmation bias (fixating on a cause or problem and overlooking or neglecting other valuable information).
- overconfidence.

These factors suggest that a prevention strategy is to first realize that everyone involved in the process is fallible. Teamwork, training and process improvement will reduce the number and severity of these errors.

Training

Knowledge based performance is actually intelligent problem solving. It is the justification for having human operators in an automated system. As a system becomes more complex, there is an increasingly important challenge to keep the operator's knowledge base updated.

Mistakes can be reduced by training. This provides more problem solving tools. Training also increases the skill and rule based space, meaning they don't have to step up to the troublesome knowledge based mode as often.

☛ **Operating Pointer:** Shift partners should pose questions to each other to develop troubleshooting skills and also to offer potential action plans should the unexpected occur.

[14] Reason,J.T. *Human Error*. Cambridge University Press. 1990. p. 87.

Drills and Exercises

Emergency management experts have found that conducting drills improves performance when disasters occur. Exercises point out flaws in processes and problems with equipment. It also refreshes seldom used skills. Even though a drill might not parallel the next real emergency, it gives the participants more "tools" with which to respond. An exercise builds both an individual's and the organization's performance base.

☛ **Operating Pointer:** The Federal Emergency Management Agency (FEMA) and individual states' emergency management divisions conduct drills to respond to natural and man-made disasters. They also provide tools and training that organizations can use to run internal drills and exercises. Utilities are welcome and should participate.

Operations in Complex Systems

Operators will not likely be replaced. The main reason for a human's presence in complex systems is the power of knowledge based reasoning to respond to system emergencies[15]. Technology, will however, force people to control larger and more complex processes. There will be greater and more hazards concentrated under the control of fewer operators.

Chernobyl and Bhopal were impossible events 50 years ago but may be dwarfed by future disasters. This means the impact of an operator's error has grown and so should the attention paid to preventing errors.

The same discussion applies to power system operations. Technology will allow operators to control wider territories. The drawback in this economy of scale is that the effects of mistakes in the future will be more widespread and costly. As part of deregulation of the industry, proposals are being made for "independent system operators" responsible for regions that cover several states. There are wide differences of opinion in the scope of responsibility for these operators. The decision of that scope will in part be made by people removed from actual operating experience. One thing is likely true. The more control given to these operators, the greater the cost of a human failure.

The strategy used to prevent failure in complex systems is a "defense in depth". The goal is to prevent any single error from breaking down the system's safety features. Analysis of major events shows failures of multiple parties (operators, maintenance, engineering and management). This means everyone must be involved in maintaining and improving the process. This will be discussed more fully in the section on "Industry's Perspective on Human Failure".

Violations

A violation can be considered an error in judgment. Driving through a yellow light is an everyday example. People know it is wrong, but the apparent benefits (saving time) outweigh the perceived cost (small chance of a ticket or accident). The risk is accepted in a quick decision because the act was successful in the past. If a low probability event is carried out enough times however, the "gambler" will eventually lose.

People don't intentionally try to hurt themselves or others. Trevor Kletz noted that people violate safety practices when the practices get in the way of doing the job[16]. In many industrial situations, safety is the stated priority while production receives the greatest amount of resources and management attention.

In some cases, the operator of a system is faced with what James Reason calls "double binds". These are tasks that make violations inevitable, no matter how well intentioned the operator. Chernobyl and the Zeebrugge ferry disaster were two examples of this[17].

The solution to violation errors can be summarized as follows:

- there must be a trusting work environment.
- management must not turn a "blind eye" to violations and safety problems.
- management and operators must work together to fix problems.
- management and workers should be accountable for their part of the process.

Where hazards have been identified, there should be at least two safeguards (defense in depth). Skill and training are only one safeguard. Analysis of past problems and near misses can show where additional "barriers" are needed.

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[15] Reason,J.T. *Human Error*. Cambridge University Press. 1990. p. 93.
[16] Kletz, T. *An Engineer's View of Human Error.* New York: VCH Publishers. 1991. p. 57.
[17] Reason,J.T. *Human Error*. Cambridge University Press. 1990. p. 196.

Latent Errors

Slips typically take the form of active errors where the effect is felt immediately. They receive widespread attention. Latent errors fall on the other end of the effects spectrum. Their precursors lie dormant in a system. The effect is not felt until the initial error combines with other factors to breach a system's defenses. Designers, management, construction and maintenance personnel are major contributors to latent failure. In general, the higher the level in the organization such an error is made, the higher and more widespread the cost.

Incidents such as Three Mile Island, Bhopal, Chernobyl and Challenger have shown that latent errors pose the greatest threat to the safety of a complex system. In the past, reliability analyses and accident investigations have focused on the operator and equipment failures. While operators do make errors, many of the underlying causes of emergencies are usually present within the system long before the active errors were committed.

The delays associated with latent errors can be very long. James Reason noted a 2 year delay at TMI and a 9 year lag for the Challenger disaster[18]. This implies there is time available to fix imbedded problems. There needs to be, however, a process in place to root them out. Later discussions on the "accident pyramid" and quality control will show how this can be done.

It's impossible to quantify all the costs associated with latent errors. One partial measure would be the claims utilities pay to customers for injuries and damages. These payments should be associated with failures from all aspects of the industry (management, design, construction, maintenance and operations). Investor owned and public utilities paid $827 million in 1995[19] for these problems. Similar outlays are likely for substation equipment damage, power plant failure and increased production costs.

The events that led to the failure at Three Mile Island give an indication of the impact of latent failures. The elimination of any one may have prevented the accident. A summary of the sequence was:

- a faulty seal leaked a cupful of condensate water into the plant's instrument air system. This had occurred before*.

[18] Reason,J.T. *Human Error*. Cambridge University Press. 1990. p. 188.
[19] 1995 FERC Form 1 data.

- this tripped the plant's feedwater pumps.
- the backup feedwater system had valves erroneously shut (maintenance error)*.
- the turbine tripped and the reactor scrammed.
- reactor decay heat caused the pressure operated relief valve (PORV) to open.
- the PORV stuck open*.
    - indication was incorrect. Indication was a control signal not actual valve position*.
    - this had occurred at other plants*.
- the reactor core became uncovered.
- other problems.
    - maintenance deficiencies found*.
    - no check of systems at shift change*.
    - lack of followup from previous problems*.
    - equipment was not marked*.

Action taken on any one of the items marked with an * could have mitigated or perhaps prevented the mishap.

Error Detection

The impact of a slip is generally felt immediately and almost always detected. On the other hand, latent errors by the very nature of their delayed impact, are usually unnoticed. The greater the number of latent problems that are detected and eliminated, the lower will be the ultimate consequences.

There are three ways an error is detected.

- The perpetrator finds it through self checking.
- The environment makes it clear.
- Someone else finds it.

What is the likelihood of detecting an error? A few studies provide useful estimates.

- Given unlimited time, computer novices detected 84% of the database errors they committed[20].

[20] Rizzo,A.Bagnara,S.,& Visciola,M. "Human error detection processes". In G.Mancini, D. Woods & E. Hollnagel (Eds.) *Cognitive Engineering in Dynamic Worlds*. Ispara, Italy:CEC Joint Research Centre, 1986.

- In production simulation, experienced steel mill operators corrected 78% of their errors[21].
- Quality inspectors find 70% of the defects in an inspected lot[22].
- Nuclear operators detected one-third of their errors during simulated plant failures[23].

These estimates have important implications for power system operation. If a detailed switching procedure is prepared by an operator, there is a good chance it contains an error of some type. Assume one error in twenty is a critical one (resulting in loss of load, equipment damage or safety breach). If all jobs were done "on the fly" with no other person checking the procedure, there would be 1-2% chance that any job will result in an operating error. Note: This situation would be the case anytime someone calls on the phone with a request to remove equipment immediately.

Following this logic, if 1000 jobs were switched at an operating desk in a year, 10-20 errors could be expected because procedures were written incorrectly. Remember, this would be the case if jobs were done strictly "on the fly". All offices do a better job of planning work than this.

If, however, a procedure is written beforehand and is subject to a second review (ideally by an experienced operator), critical errors will be detected. In addition, if on the day of the requested outage, the night shift operator reviewed that day's switching along with a review by the person actually doing the job, the procedure would be subject to 4 inspections prior to implementation. This would give an error probability (due to errors in the written procedure) of:

0.05 [probability of a critical error]
x 0.3 x 0.3 x 0.3[each review finding 70% of the errors]=0.0013.

If 1000 jobs were switched in a year, there would be around one error annually due to incorrect procedures. The net result is that the chance of an error while switching an unscheduled or unreviewed job is around 25 times greater than one thoroughly checked.

☛ **Operating Pointer:** Whenever someone calls to request an unscheduled outage, always break communication (tell them you will call them back), take the time to write the procedure and have someone review it. If there is any doubt about taking the equipment out of service, don't.

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21 Reason,J.T. *Human Error*. Cambridge University Press. 1990. p. 166.
22 Juran, J. *Quality Control Handbook*, New York: McGraw-Hill, 1988. p 18.86.
23 Reason,J.T. *Human Error*. Cambridge University Press. 1990. p. 60.

☛ **Operating Pointer:** Switching procedures should go through an independent review in addition to those done by the shifts that prepare for the outage. Companies that have experienced problems with incorrect procedures should have the reviewers sign or initial the procedure to verify the check was made.

Rule based and knowledge based mistakes are the least likely to be detected by their perpetrators. A separate set of eyes is needed to find the problem. The stuck valve that caused the Three Mile Island accident was discovered two and a half hours into the incident by the oncoming shift supervisor. Even though dispatchers take pride in the quality of their work, they must realize that they can sometimes have "tunnel-vision". We should be in the habit of talking and asking questions in order to :

- allow each operator to better know current system conditions.
- refine/improve procedures.
- clear up oversights and misconceptions (no one has all the answers).

☛ **Operating Pointer:** Operators should be in the habit of questioning each other. This shouldn't be considered second-guessing, but an application of "two heads are better than one".

Performance Level Summary

Figure 4 summarizes the discussion on the levels of performance and associated errors. This table draws on the theories of Jens Rasmussen[24] . The key things to remember are:

- risk is greater as you "move up the performance ladder".
- increase an operator's skill set (training and experience) to reduce errors.
- provide easy to access information to move knowledge level tasks down to the safer rule based area.
- since experienced operators spend most of their time at the skill based level, slips (operating the wrong device) will be their most likely error.

Performance Level	Skill Based	Rule Based	Knowledge Based
Effort	Small	Moderate	High
Error Probability	Low	Moderate	High
Time Spent Here	High	Moderate	Low
Damage Caused	Low	Moderate	High
Error Type	Active	Both	Latent

[24] Rasmussen, J. *New Technology and Human Error (*68)

Who's Most Susceptible	Skilled Operators	Newer Operators	Newer Operators

Figure 4 Operating Level Summary

Human Action Model

Background

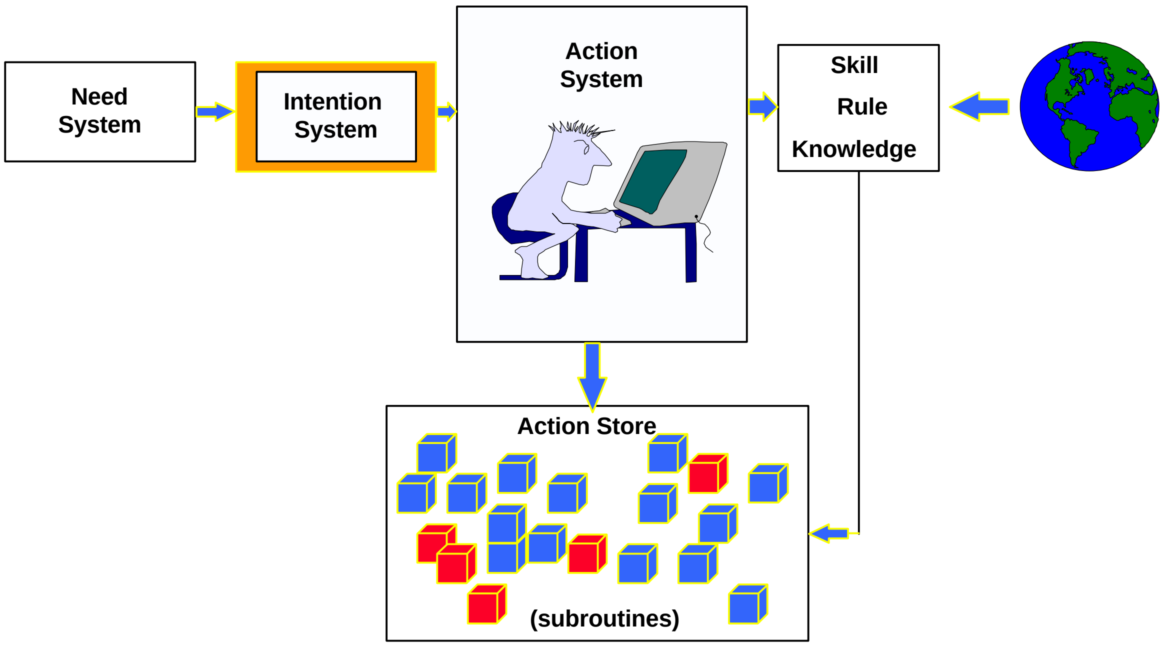

Figure 5 Human Action Model

Cognitive scientists have developed models to demonstrate how the human mind works to accomplish the multitude of tasks a person encounters every day[25]. Figure 5 and the following discussion is a condensation of these theories. The model provides a framework for understanding the mechanisms that cause errors. This is needed to develop strategies to prevent mistakes.

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[25] Reason, J.T.,*Absent-minded? the psychology of mental lapses and everyday errors*, Prentice-Hall, Englewood Cliffs, NJ, 1982. p. 48.

Components

Need system

Abraham Maslow found that human actions are motivated by needs that follow a specific priority[26]. In other words, a person's highest priority needs must be met before they are motivated by the next priority need. These needs, in order of highest to lowest, are simplified as follows:

- survival.
- safety.
- security.
- social acceptance.
- self fulfillment.

The need system sets priorities for the next system (intention system). If your house is on fire (survival), not much thought goes to getting ready for work (security). If it is a normal day, however, and you wake up late, the penalty of your boss' wrath might be worse than the hunger from missing breakfast.

Intention System

The intention system can be thought of as a scratch-pad or "to-do" list. The action system takes input from the need system and compares it to the present state of affairs. It spots changes and plots an appropriate course of action. The plan is then placed on the intention system's "to-do" list. The plan is designed to achieve the highest priority unfulfilled needs. The scratch pad is used to guide the actions of the action system. Examples of items on the pad when waking up on a workday would be; clean up, get dressed, drive to work, take care of unfinished project.

An important point to remember about the intention system is that the scratch-pad can hold only a limited number of "to-dos". Five to ten items are about the limit of what can be kept on the pad. A higher priority need that arises unexpectedly will push something else off the list. This means an

[26] Maslow, Abraham, Motivation and Personality (3rd ed., 1987), p16

important future task can be forgotten because something caused a distraction or became a higher priority at a critical time.

Forgetting to carry out an intended task at the proper time and place is one of the most common forms of human error. The idea of tying a string around your finger to remember something is actually a valid strategy to prevent forgetting an important, yet delayed task. A more modern example would be to place something out of the ordinary on your dashboard to remind you to pick up a gallon of milk on the way home.

☛ **Operating Pointer:** A dispatcher should keep a pad of paper readily available at all times. A one-word note will later remind them to complete a task that can't be done immediately.

Action System

The action system can be thought of as the "master controller" for the process. It compares the present situation with the intention system's plan. The controller then selects the appropriate skill or response from the "action store" to move the intention system's plan along.

The action system will first apply skills to handle the situation. This can be thought of as "autopilot" performance. If this doesn't work, it slows down and attempts to use a rule. If a rule doesn't apply, it moves up to the more difficult knowledge based performance to get the job done.

Action Store

Every skill we have mastered is kept in the "action store". The neuron interconnections in the brain are similar to the subroutines or mini-programs that computers use to complete complex tasks. The action system selects the appropriate subroutine at the proper time to allow a person to complete the next task.

The number of subroutines available grow as the person has more skill. The "size" of the subroutine also increases with practice. For example, "get dressed" entails putting on undergarments and socks, zipping pants, buttoning shirts, tying ties and shoes. A youngster could not perform these as a unit and there are likely some steps the child can't do.

How the action system makes the selection depends on whether or not the job is skill based. A great deal of feedback is required in knowledge based performance. The action system performs a step, checks results, verifies the plan, performs another step, checks results, etc.. On the other end of the spectrum, skill based performance is autopilot in nature.

The action system/action store operate similar to a warehouse. Frequently used subroutines are "kept up front". Those routines used recently are also kept handy. They are kept "active" for a period of time. This is very efficient but it is also the underlying reason for skill based slips. This will be seen later.

"Autopilot" Operation

Little feedback is involved when the action system is performing skill based tasks. Individual acts are performed with minimal thought. The action system is very effective at selecting the proper subroutine at the proper time. Autopilot operation is possible because the appropriate subroutines are "activated" before they are needed. This is shown graphically as the red subroutines in Figure 5.

As individuals, our ears "perk up" when we hear our name or something is mentioned that interests us. Something similar happens to the subroutines in our action store. Whenever you get in your car, all the subroutines associated with driving a car become activated (as depicted by the red colored subroutines). Also, those subroutines used most often are closest to the front of the action store. Now it is an easy matter for the action system to "find and quickly grab" the appropriate response. The completion of one subroutine (depress clutch) is the trigger for the next (downshift).

A driving example demonstrates the common error mechanisms associated with skill based performance. Assume you are a passenger (not the driver) in a car. The car you are in is traveling 30 mph down a street lined with parked cars. Suddenly a ball comes bouncing in front of you from between the parked cars. What do you do?

Most people try to stomp a non-existent brake. This is because when you entered the car, all driving subroutines were activated. Even though you were a passenger, your action system grabbed the most appropriate active subroutine (hit the brakes) in the limited time.

A similar driving example takes place when the car next to you moves while you are waiting at a stoplight. If you are daydreaming and therefore in autopilot, your action system grabs the most appropriate active subroutine (let go of the brake) when triggered by the movement of the car next to you. If the light is still red, you've committed an error.

The earlier examples to "State the color of the text" and "What do we call the white of an egg?" were demonstrations of autopilot slips.

To review, the main traps of skill based (autopilot) performance are:

- we do the things we do most often (slip).
- we do the things we've done recently (slip).
- we forget to perform a delayed task (lapse or omission) when our attention is captured elsewhere.

Some people might feel that autopilot performance is undesirable. Consider the price of the autopilot error committed in the driving example (reaching for a non-existent brake as a passenger) versus the cost of not being able to automatically applying the brake when you are a driver. The benefits of skill based operation far outweigh the costs.

Managers and operators must realize that skill based performance is desirable and inherently reliable. Occurrences of slips should be reviewed and, if possible, the particular work situation should be made less error prone. Repeat errors, such as dispatchers opening line breakers when they attempted to switch capacitors point to problems with displays, not necessarily the operators. This will be covered more in the section on human reliability.

Operators should be aware of high risk moments where slips can cause switching errors. They need to slow down and take more time during critical moments to ensure they are performing the correct action.

☛ **Operating Pointer:** Before operating a device, issuing orders, or repeating back actions completed, stop and take a deep breath to collect your thoughts and "drop out of autopilot".

Human Variability

Error can be thought of as one side of a coin called human variability. No two people are the same. Everyone has different experience and skills. Any time there is a mismatch between the person and the task at hand, an error usually results. It is therefore necessary to understand human variability in order to understand errors.

Target Example

Consider a rifleman firing at a target. Any shot missing the bulls-eye can be considered an error. The dispersion pattern of the bullets is caused by several factors. Some of the contributors would be:

- trigger squeeze.
- breathing techniques.
- wind.
- sight adjustment.
- quality of the ammunition and rifle.
- eyesight and steadiness of the marksman.

The apparent random variability of the shot pattern is due to the combined effects of the factors above. Quality control experts call this “common cause variation”. The greater the number of contributors, the greater the variation. The sum of all these factors lowers the marksman’s performance.

The implication of the discussion is that elimination or reduction of individual contributors will improve performance. Identifying and working on the largest problems will pay the most dividends.

Human error is one side of the human variability coin. No two people are alike. One of the first things a new dispatcher observes is that none of his or her coworkers attack a particular task exactly the same way. Given the same set of circumstances, one operator will make a mistake while others in a group may not. The important thing is to not make the same mistake twice.

A traditional “fix” reported by utilities is to counsel the operator after a mishap. On the surface, this seems an effective strategy. The operator does not commit the error again. The logic is flawed, however. The operator has already learned the lesson. In addition, there is evidence to suggest that people who receive negative feedback after a mistake tend to make fewer decisions[27]. The real corrective action is to share information so others learn about the problem and also to pursue solutions to prevent the same situation from arising.

The Other Side of the Coin

The other side of the variability coin is creativity and skill. Because every individual is different, we each bring something special to a job. We can and should learn from each other The key is to make a conscious effort to take the best of each person to improve the performance of the group.

> *"Knowledge and error flow from the same mental sources, only success can tell one from the other."* Ernst Mach (1905)

Problems in Complex Systems

Complex systems such as the interconnected electric grid offer specific challenges to operators. Studies have found flaws in the ways people react in complex situations. Among the most significant findings to electrical operators are:

- people think and respond linearly, while complex systems react exponentially[28].
- over-control occurs as stress increases.
- people are interested in how things are now, not how they are trending[29].
- people dwell on small details.

A few implications for improving operations can be made from these points. Prioritized alarms and “rate of change” indication would help operators in emergency situations.

[27] Dorner, D. “On the Difficulties People Have in Dealing with Complexity”, *New Technology and Human Error.* New York: John Wiley & Sons, 1987.
p. 102.
[28] Brehmer,B. Models of diagnostic judgements. In J.Rasmussen,K.Duncan & J. Leplat (Eds.), *New Technology and Human Error*. London: Wiley, 1987.
[29] Doerner,D. “On the difficulties people have in dealing with complexity”. In J.Rasmussen,K.Duncan & J. Leplat (Eds.), *New Technology and Human Error*. London: Wiley, 1987.

How People Make Observations

People's observations are shaped by their interests and experiences. Pieces of data are fit together to make the whole. We try to recognize patterns [30]. Once we "home in" on an answer, conflicting information is often ignored or discounted. Figure 6 demonstrates this phenomenon. The reader should quickly show the cards one at a time to another person and have them write down the card they saw.

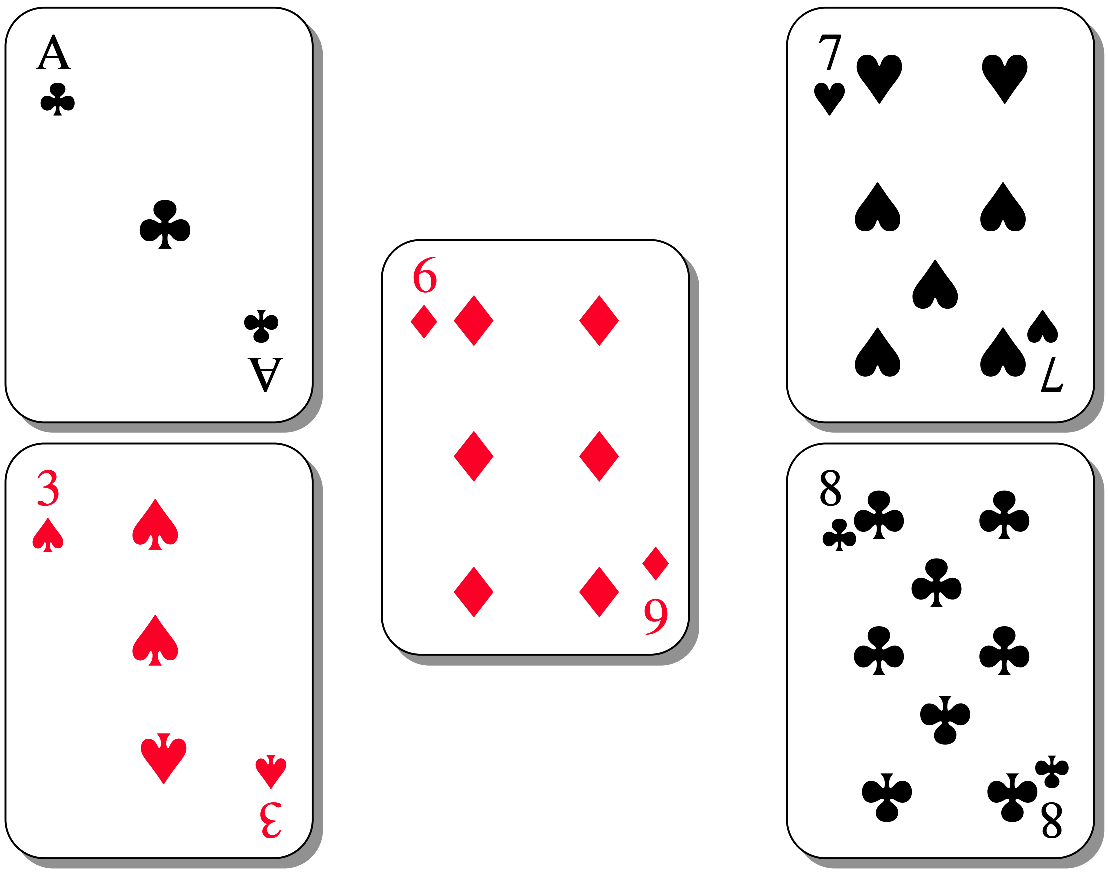

Figure 6 Identify the Cards

The most important detail about a playing card for most people is color. Next is the pattern of spots or the number (depending on player experience). The shape of the particular spot is considered last. A spade and a heart have similar shapes. In this example, the difference was discounted because the color was given more importance in the observer's mind.

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[30] Reason,J.T. *Human Error*. Cambridge University Press. 1990. p. 65.

Keeping in mind the idea of human variability, a colorblind person would perform the task just demonstrated better than a person with normal color perception. This drives home the point that everyone brings something special to the job and has something to contribute.

Some of the recommendations that can be drawn from this are example:

- be wary of disregarding information that doesn't fit what you expect to find. Confirm or disprove it.
- don't discount the opinions of others. They may see things you don't.
- a fresh set of eyes might find the problem. Ask for help when in doubt.

Problems with Communication

Operators spend a significant amount of time communicating information, issuing orders, recording data and giving direction. Problems with communications can lead to errors. Besides the obvious importance of the quality of the medium (radio, phone, electronic), other communication problems can set traps.

Under-specification

When given limited information, the mind will fill in details according to what is expected. Military history abounds with cases of disaster from following inadequate or unclear orders. Figure 7 provides a simple example. Although the center character is the same in both "words", most people will read the figure as "THE CAT". The mind fills in the details to make this happen.

Figure 7 "The Cat"

Operating instructions and orders should be simple and to the point. In cases where verbal orders are issued, they should always be copied by the receiver and read back to the sender. Even when "hard copy" orders are issued, they should be discussed by sender and receiver prior to switching. Although this is generally accepted practice among utilities, it requires constant enforcement.

"There is a universal failure [in this command] to repeat oral orders back. This failure is certain to result in grave errors" GEN George S. Patton

There is one additional strategy operators should use to improve communications and reduce errors. If all the passengers in a car know the destination, the likelihood of getting there without taking a wrong turn is increased. The same is true in switching.

☛ **Operating Pointer:** Before issuing switching orders, dispatchers should conduct a "tailgate session" to let field personnel know the goal of the orders. The field crews have valuable experience and can see things the dispatcher can't. Everyone knowing the goal increases the chance of getting there without a mishap.

Lost Details

Most people are familiar with the children's party game where a story is relayed from person to person until it comes back to the original sender. The final product is nothing like the message originally sent. Details are lost or twisted with every transmission. Figure 8 is an example.

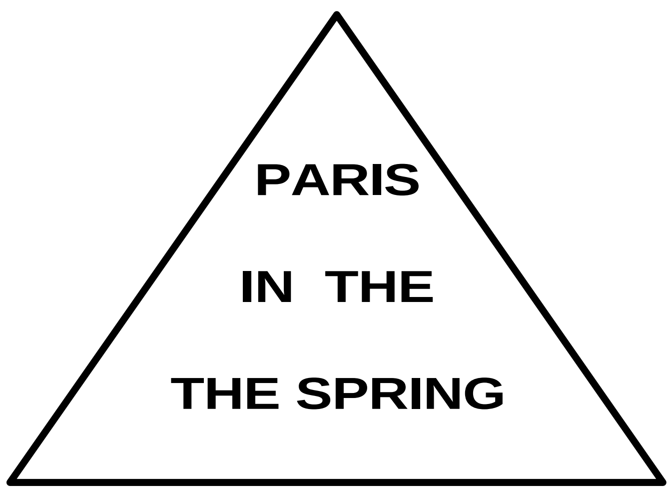

Figure 8 Lost Details

The reader typically "drops" the second "THE" in the pyramid. A detail is overlooked and lost. The more complex the message, the more likely something will be left out. Orders and instructions should be simple and to the point. Written instructions should be concise with key information highlighted.

INDUSTRY'S PERSPECTIVE ON HUMAN FAILURE

Introduction

Electric utilities can learn from other industries and fields of study to improve their operations. Quality Control / Quality Management, Human Reliability and Industrial Safety offer useful information and concepts. Other process industries encounter the many of the same operating problems. Why not look to them for solutions?

Quality Control/Quality Management

Beginning around 1980, there was a renewed interest in the use of statistical tools for quality control. This movement, called "Statistical Process Control" (SPC), concentrated on the use of control charts to distinguish statistically significant variations from those which were not. The same movement included training of supervisors and workers in basic statistical tools.

Who is Responsible for Errors?

A quality control study of six machine shop departments was done to identify errors (chronically high scrap and rework rates) and their causes[31]. The effort found that 68% were management controllable. The study results brought about agreement on the focus of a subsequent improvement program. The company saved over $2 million in one year and reduced production backlogs.

Many quality experts agree that the majority of defects are management controllable[32]. Even though the data points to this fact, most industrial managers don't know this or are unable to accept it. Their long-standing beliefs are that most defects are the result of worker carelessness, indifference and even sabotage. This,

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[31] Juran, J. *Quality Control Handbook*, New York: McGraw-Hill, 1988. Table 17.2.
[32] Rao, A., Carr, L. *Total Quality Management: A Cross-functional Perspective.* New York: John Wiley & Sons, 1996. p. 233.

no doubt, is the reason for the popularity of worker-motivation schemes to improve performance. These efforts generally result in limited, short-term improvements.

Two Types of Errors or Defects

Quality specialists have identified two causes of variation or errors. They are called common cause and special cause. The source and remedies for each are different.

Common cause defects are caused by what can be thought of as a "sea of variables" that surround the operator. This is depicted in Figure 9. The variables come together at times to produce errors at a random rate. For example, the operator could be given a procedure that was written incorrectly on a day with a heavy workload. Under normal situations, the dispatcher might have caught the problem with the procedure. Due to the conditions that day, he or she didn't catch it and an outage occurred.

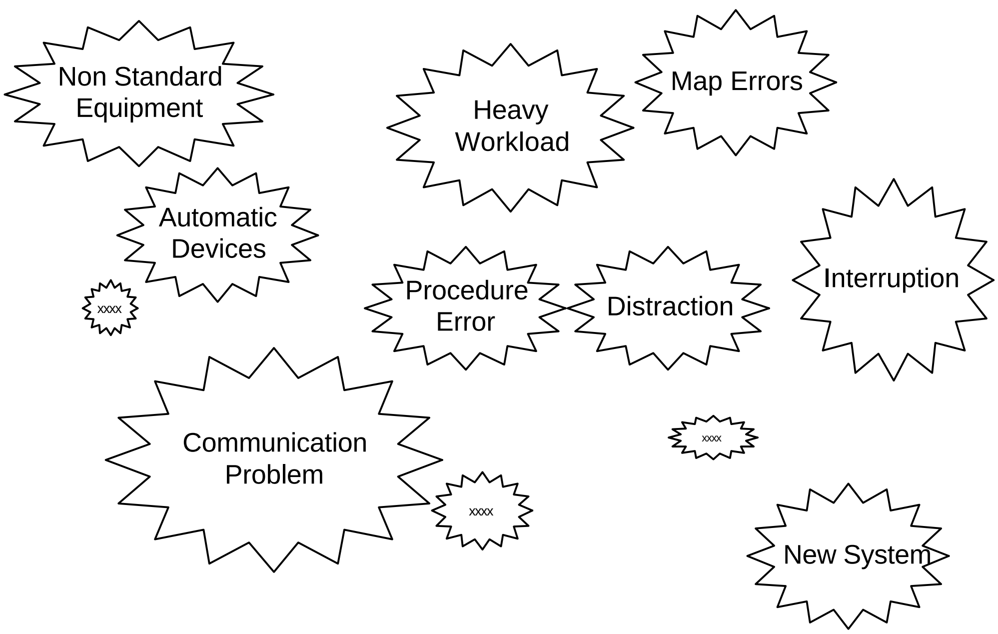

Figure 9 Sea of Variables

The idea of a "sea of variables" that combine randomly to cause problems parallels the theory of "resident pathogens"[33] used by cognitive scientists. Many major accidents occur when several small and/or

[33] Reason,J.T. *Human Error*. Cambridge University Press. 1990. p. 197.

repeat problems combine to produce the events needed to trigger the catastrophe. “Weeding out” small problems will not only cut down on typical mishaps, they can also prevent major events.

It is generally accepted that common cause errors are "management controllable". In other words, management has the tools and resources needed to reduce and prevent these defects. They provide the direction and guidance to fix the problems.

Special cause errors occur when there is a significant change in the working environment or process. This is signaled by a measurable shift (either up or down) in the number of errors that occur over a period of time. The people closest to the work can usually find and correct a special cause event.

An operating example occurred at the host utility. A few years ago, a new design relay was installed in the company’s electric distribution system. It was intended to protect long feeders against faults on the remote end by detecting an unbalance in current in the three phases. It was quickly found that these relays caused inadvertent trips whenever load was switched from one feeder to an adjacent one. A "special cause" of errors had therefore been installed in the system. The dispatchers, along with relaying personnel, were able to work out a solution to prevent future mishaps.

Another simple example can be used to clarify the common cause/special cause discussion. Figure 10 shows data a manager collected on her five employees (all do word processing). She identified four error types (A-D) and tabulated the number of mistakes each worker made.

Error Type	Sam	Fred	Bill	Sally	Kelly
A	1	2	1	0	0
B	0	3	1	0	0
C	2	4	2	2	0
D	1	3	0	1	0

Figure 10 Error Cause Example

One of the principles of process improvement is “management by fact”. Data is used to identify problems and to point to solutions. A first glance of the table above might lead to the impression that Kelly should be given a raise, while Fred should be counseled on his poor performance. The manager should be careful.

Kelley and Fred are both "special cause" situations. Their performance is different, but why? Since this a special cause situation, the workers would likely be able to come up with the underlying reasons. Possible explanations could be:

- Kelly does little work or was on vacation during the rating period.
- Kelly is the only one with a spell-checker.
- Kelly has a knack or special skill (use Kelly to train others).
- Fred missed the training on the new word processing program.
- Fred does twice as much work as the others.

There are other things that can be learned from the data with a closer look. Figure 11 compares the data from two directions. Fred and Kelly are identified with a # to denote their special cause status. A review of the number of occurrences of error type C shows it is a problem to nearly everyone. There is a "common cause" that contributes to the group' s problems.

Error Type	Sam	Fred	Bill	Sally	Kelly	Total
A	1	2	1	0	0	4
B	0	3	1	0	0	4
C	2	4	2	2	0	10 *
D	1	3	0	1	0	5
Total	4	12 #	4	3	0 #	23

Figure 11 Common Cause/Special Cause Example

The manager should spend her time working on a solution to problem C. This will pay the most dividends. Workers do have the responsibility to call management's attention to problems and to offer potential solutions, but supervisors have the underlying charge of removing common cause variation. But whether the situation is common cause or special cause, solid facts are needed to make informed decisions. Table 1 summarizes this.

Table 1 Defect Cause Summary

TYPE	IDENTIFIED BY	CAUSED BY	WHO'S RESPONSIBLE
Common Cause	Normal Variation	"Sea of Variables"	Management
Special Cause	Step Change or Trend	Change in Process	Workers

Process Variation and Improvement

A deck of cards can be used to explain the quality control concepts of process variation. Assume a deck of cards represents the current operating environment for employees at a particular company. The deck reflects the workload, risk, employee training, experience level, etc. of the utility. One card is drawn each month. The number of errors that occur in that particular month vary as follows:

♣--0 errors.

♦--1 error.

♥--2 errors.

♠--3 errors.

A quick calculation shows a standard deck contains 78 errors. The average number of errors that occur from a draw would be 1.5. This company could expect 18 errors/year. It is possible to get more or fewer errors with 12 monthly draws, but the average over many years with the same deck would be 18.

Quality specialists have shown that we are not forced to accept a particular level of performance. The idea behind process improvement is to continually find ways to better the job performance. Many small enhancements over time will keep increasing the process performance.

Going back to the deck of cards, a process improvement is the equivalent of pulling out one or two "bad" cards (♠,♥) and substituting better cards(♦,♣). Even if 5 or 6 improvements were made to the deck, it is still possible to draw 12 cards over the year and come up with 18 or more errors. However, over time, there would be fewer and fewer errors seen by making continuous improvements. You might have a few bad draws in a row, but the deck is improved. Performance will improve.

Quality specialist have developed charts that track a process over time and "raise a red flag" when a significant change has occurred. These SPC charts are described in most quality control texts. A detailed explanation is beyond the scope of this paper. It is enough to say that these charts can detect when such a condition arises. Appendix 1 describes a PC based program a company can use to track errors and spot process changes.

Human Error and Remedies from a Quality Perspective

Table 2 is a summary drawn from information in Juran's *Quality Control Handbook*. It lists the types of errors committed and remedies used in the industrial world. One point needs to be mentioned regarding the last error type listed. Conscious errors are those made by a worker who is aware of it and intentionally makes it. Cognitive scientists call this a violation. An example would be when a machinist has a production goal of 1000 parts per day. There may be a desired specification (a particular dimension for example) that the operator's experience has proven is not important. If meeting that specification slows his or her production, a conscious error is likely to occur (the spec will be ignored).

Due to the seriousness of an electrical operating error, it is unlikely that conscious errors would ever occur. This information can however be applied to the other tasks that dispatchers perform. It is included as a troubleshooting aid to improve other aspects of the operator's job.

Table 2 Quality Related Errors and Remedies

Type	**Remedy**
Misinterpretation	Precise definitions and glossaries Checklists Examples
Inadvertent errors	Aptitude testing Reorganize work to reduce monotony Fail-safe designs Redundancy Error-proofing (masks, templates, etc.) Automation Reorganization of work Sense multipliers
Lack of technique	Discovery of knack used by skilled workers Retraining
Conscious errors	Remove atmosphere of blame Action on suggestions or explanation of why not Depersonalize orders Establish accountability Provide balanced emphasis on goals Conduct quality audits Create competition and incentives Reassign the work

Useful Quality Control/Quality Management Tools

The field of quality management makes extensive use of graphic and statistical tools to represent data and process performance. The tools are not goals in themselves, they are used to provide understanding. A picture can say a thousand words. A few of the basic QC aids are described below.

Pareto Charts

This tool is named after an economist who studied the distribution of income in Italy. He found that majority of the wealth was in the hands of a small number of people. His studies have developed into a business axiom that states 80% of the results of any endeavor will come from the first 20% of effort. There will be diminishing returns after this point.

A Pareto chart is nothing more that a bar chart that displays the problems associated with a process. By definition, the problems are suppose to be arranged in descending order. The reason is to reinforce the "Pareto Principle" that initial effort applied to the biggest problem will pay the most dividends.

This means that once a process' problems are identified, the largest one should be attacked first. With some effort, the first problem is likely no longer the largest. The company should move on to address the next problem. The steps above are then repeated down the chart.

Because of software limitations, it might not be possible to easily arrange charts in descending order. The concepts can still be effectively applied. Figure 12 summarizes error data supplied by companies that responded to this study's survey. It also compares the total error data. The error causes as reported by the operators are:

D-Distractions.
C-Communication problems.
U-Unscheduled jobs.
W-Job **w**ritten up incorrectly.
P- Mistake in a **p**rocedure led to an error.
I- I just operated the wrong device (slip).
T-Trying to do too much at one time.
A-An **a**utomatic device operated unexpectedly.

O-Other.

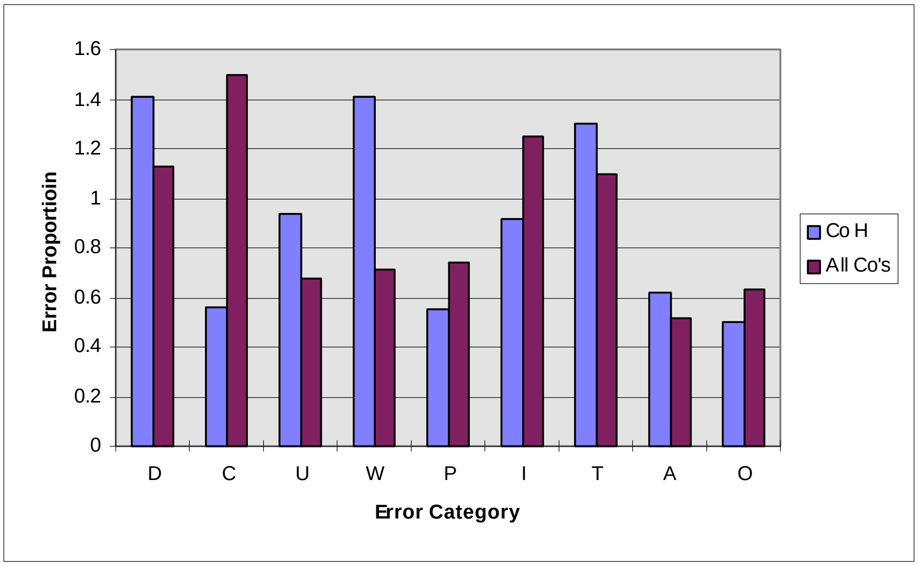

Figure 12 Error Causes Reported by Operators

If company "H" were to apply the Pareto concepts, it should first address office distractions (D) and mistakes in switching write-ups (W). It should then do something about workload (T) and unscheduled jobs (U). These improvement efforts can occur simultaneously, but the graph shows what efforts will pay the most dividends.

The graph is useful for another purpose. The other companies provide a "benchmark" of error causes. Company H has more problems with incorrect switching write-ups than other utilities. It should find out the methods the other companies use. Conversely, other companies could learn something from company H's communications procedures.

Cause and Effect Diagrams

Cause and effect or "fishbone" diagrams are useful for graphically representing the factors that lead to process problems (errors). Survey data (operators remember factors that led to errors for a long time) can be combined to diagram the sea of variables that cause problems. Brainstorming can identify other causes. Finally, analysis of actual events and near misses can be used to add information to the diagram.

Figure 13 is an example of a cause and effect diagram of factors that lead to operating errors. The value in creating such a diagram is to study and communicate a problem. It also suggests fixes.

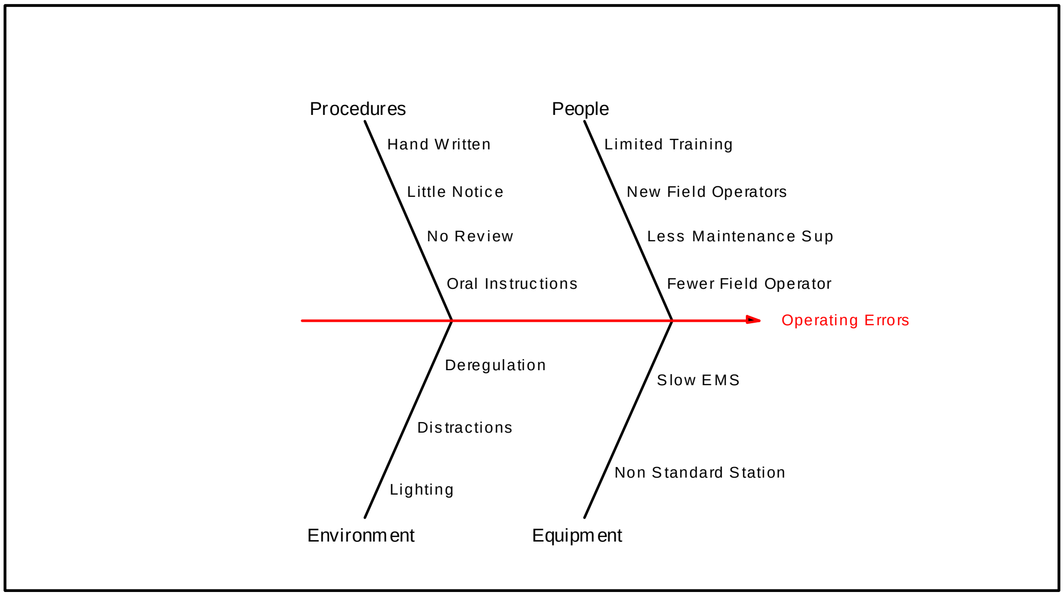

Figure 13 Cause and Effect Diagram

Human Reliability

Human Reliability is a branch of the Industrial Engineering field. It is based on the concept that human error can be reduced or mitigated based on an understanding of the nature, frequency, and effects of errors. Workers' attitudes will be more positive if management's emphasis is changed from one of motivating people to "try harder" to one of involving them in finding and correcting error causes[34].

One reason errors seem to be so frequent is that in almost any work situation, many people are doing a multitude of tasks over a long period. The Ford Motor Company estimates that it experience about 3 billion opportunities for assembly error each day[35].

From a human reliability perspective, the main approach to reducing errors is by improvements in:

- the system to be operated.
- tools to work the system.

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[34] Meister, D., "Reduction of Human Error", *Handbook of Industrial Engineering*.
[35] Rigby,L., Swain,D.,"Effects of Assembly Error on Product Acceptability and Reliability", *Proceedings, 7th Annual Reliability and Maintainability Conference*, ASME, New York, July 1968.

- drawings and instructions.
- procedures.
- work environment.

Identifying, eliminating (or reducing) error contributors in the areas above will result in a safer process. This idea parallels the continuous improvement principle of Quality Management.

Error Estimates

Several references[36] [37] [38] [39] were found that contained error estimates in industrial settings. A summary can provide both insight and direction to prevent accidents. The most significant estimates and implications are described below.

General Error Probabilities

- Workers average one 1 error per 1000 acts in a normal industrial setting (skill based performance).
- Errors can be reduced to 1 error in 10,000 acts in a well designed system.
- There are about 1 error per 100 actions where attention is required.
- One error per 10 acts occur for non-routine activities (knowledge based performance).

We cans see that skill based performance is very reliable. Training can provide experience that will increase the proportion of skill based performance. This should significantly improve a company's safety.

The above estimates can be applied to power system operation. If, on the average, 2-3 devices are operated per switching job, 2-4 errors per 1000 jobs would be expected (the same number of devices are operated to restore equipment, but the procedure has been proven because the steps to remove the equipment was successful). A superior company might have 1 error per several thousand jobs.

Inspection

- Inspectors will find 70-80% of the errors of others.

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[36] Rigby,L., Swain,D.,"Effects of Assembly Error on Product Acceptability and Reliability", *Proceedings, 7th Annual Reliability and Maintainability Conference*, ASME, New York, July 1968.
[37] Kletz, T. *An Engineer's View of Human Error.* New York: VCH Publishers. 1991. p. 91-111.
[38] Cohen, H. , Cohen, D. "Myths about human mistakes", *Professional Safety*, October 1991.

- Intense inspection can detect 80-98% of all defects.

All switching procedures should undergo a second review. No person can see everything. Be open to the suggestions and observations of others.

Control Layout

- The probability of selecting and depressing the wrong push button is 1 in 150.
- Operating miniature vs. larger (>0.5") buttons is 5 times riskier.
- Selecting the wrong device on a cluttered layout (5-10 buttons vs. less than 5) is twice as likely.

Operating displays should follow a simple, standard format. Displays should not be cluttered. Changing the characteristics (shape or color) of special devices will help differentiate them.

Distractions

- The chance of an error in a busy vs. a quiet control room is 10 times greater.

Noise and distractions in operating areas should be kept to a minimum.

Stress and Time Available

- The chance of a high stress error (dangerous activities happening rapidly) is 1 in 4 acts.
- If less than one minute is available to make a high stress decision, there is a 99% chance of it being wrong.
- If 30 minutes are available for a high stress decision, there is a 10% chance of failure.
- If given 120 minutes to make such a decision, there is a 1% chance of failure.

Potential ways to prevent high stress errors:

- perform risk assessments beforehand to come up with fixes.
- use emergency shutdown devices and interlocks.
- have simple, clear information systems.
- conduct tabletop emergency drills to train people and improve plans.

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[39] US Atomic Energy Commission, *Reactor Safety Study-an assessment of accident risk in US nuclear power plants*, 1977.

Industrial Safety

An accident can be thought of as an error with unfortunate consequences. A review of safety principles can support and reinforce error reduction practices.

Most serious accidents are preceded by several contributing events. This parallels the quality management concept of the "sea of variables" and the cognitive scientists' "resident pathogens" theory.

The events that led up to the 1987 fire at King's Cross Railway Station in England demonstrate this[40]. A match thrown on an escalator ignited dirt and grease on the running track, eventually killing 31 people. Contributing causes were:

- a missing cleat that prevents objects from getting beneath the track.
- the sprinkler system didn't work automatically.
- manual sprinkler valves were unlabeled.
- running tracks were not cleaned regularly.
- workers had no formal training in emergency procedures.
- 20 fires/year that had occurred from '58-'67 were not of concern.
- no smoke detectors.

It is quite possible that the correction of any one of the contributing factors may have prevented the accident. One of the primary jobs of an operator is to spot problems (even small ones) and initiate corrective action.

Management must continually focus on safety. Due to the continuous changes in most operating offices, other priorities ask for attention. Supervisors must have a means to frequently remind them to examine the impact of their decisions on safety. "Safety is our highest priority" must be more than a slogan.

Who Contributes to Errors in Other Industries?

A study of errors at nuclear power plants[41] sheds light on the causes behind the scenes. Although 92% of all root causes were man-made, only a small proportion were initiated by front line operators. Most originated in either maintenance related activities or in bad decisions within the organization.

Human error has been attributed for anywhere from 4 percent to 90 percent of industrial accidents. Even though managers, designers and maintainers all contribute to the problem, they seldom are the focus of attention. Safety specialists give four reasons for this[42]:

- it is human nature to blame what appears to be the active operator when something goes wrong.
- our legal system is geared toward the determination of responsibility, fault and blame.
- it is easier to focus on the worker than to acknowledge the workplace, procedure or environment needs improving.
- the forms used in accident investigations are modeled after the "unsafe act/unsafe condition" dichotomy.

Table 3 Contributors to Major Accidents

	TMI	Bhopal	Chernobyl	Total
Design	2	6	3	11
Maintenance	1	5		6
Management	5	25	5	35
Operator	2	2	2	6
Procedure		1		1
Regulatory	2	3		5
Training	1			1

The data in Table 3 is taken from case studies[43] involving three of the most significant accidents in recent history. Although they are all attributed to human error, the perception is that they are the fault of operators. The table is not intended to focus blame on any one group. It should be used to drive home the point that many underlying problems exist before an accident. Perhaps if only one or two of the underlying "pathogens" were removed beforehand, one or more of them might never have occurred. How many others are waiting, needing only one or two more of the right conditions to push them over the edge? The need for continuous improvement should be obvious.

[40] Reason, J.T. *Human Error*. Cambridge University Press. 1990. p. 194, 257.
[41] Reason, J.T. *Human Error*. Cambridge University Press. 1990. p. 187.
[42] Cohen, H. , Cohen, D. "Myths about human mistakes", *Professional Safety*, October 1991.
[43] Reason, J.T. *Human Error*. Cambridge University Press. 1990. p. 251-255.

Accident Frequency

The consequences of human error from a safety perspective range from unsafe acts and near misses up to serious injuries and fatalities. Knox[44] represented the number of incidents compared to their seriousness as a pyramid. Figure 14 displays the relative frequency of these events.

Companies can apply the pyramid concept to estimate the relative safety of their work environment. If the unsafe acts and near misses are reported and tracked (which can only happen in a trusting workplace), the progress of the company's safety efforts can be monitored. The lesser events can also be analyzed to weed out the sea of variables that would otherwise combine at some future time to cause injury and/or equipment damage.

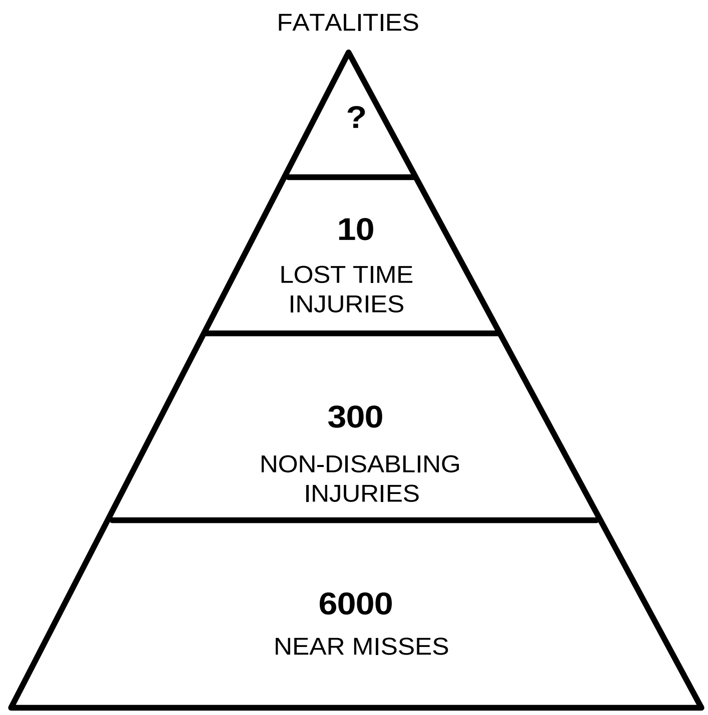

Figure 14 Accident Pyramid

Care should be taken when keeping safety and error statistics. What appears to be a pattern might only be random events. Due to the chance nature of errors, people could make more than their fair share

[44] Knox, B.J. Safety Standards-a Time for Change. Piper Alpha, Lessons for Life-Cycle Safety Management. I.Chem.E Symposium Series No. 122, pp.77-81. 1990

of errors just due to the "luck of the draw". Trevor Kletz [45] uses an example where 675 equally safe people work for a company. If 370 accidents happened in a given period:

- 11 people would have 3 accidents each.
- 1 or 2 people would have 4 accidents.
- every 6 or 7 periods, one unlucky soul would have 5 accidents.

This does not mean they are unsafe workers, it is just chance.

On the other hand, a good short term safety record does not imply a safe working environment. Remember the earlier deck of cards example. Just because a company hasn't experienced a serious accident in a long period, doesn't mean it has been operating safely. There is a randomness to these severe events.

Accident Reports and Analysis

Jens Rasmussen noted the problem with accident reports is that they are mostly concerned with assigning blame[46]. They can be inaccurate and incomplete, even when prepared by experienced, unbiased investigators. They never uncover all the facts. The investigator has much more time to think through the event than was available to the operator. Things always seem so much clearer in hindsight.

Any accident can usually be traced to a complex series of events that come together to cause trouble. If more "fish" swim in the "sea of variables", more accidents will happen over time. If, on the other hand, problems are found and removed, the operating record of the organization will continuously improve. The key is to learn and act on not only major events, but also the day to day problems.

One concern in the flatter organizations that exist in today's utilities is that there is less supervision and fewer safety specialists. A simple method is needed for "in house" analysis of near misses and errors.

It is a cumbersome process to draw out all the items in the chain of events that lead to a near miss or accident. The value of searching out each minor factor is questionable. A simplifying assumption can

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[45] Kletz, T. *An Engineer's View of Human Error.* New York: VCH Publishers. 1991. p. 64.
[46] Rasmussen, J. Approaches to the control of the effects of human error on chemical plant safety. Professional Safety , December 1988

be made to identify the “top three” factors that contributed to the mishap. Figure 15 could be used as a “fill in the blank” analysis form that could be filled out by the investigators.

This *Error Analysis Diagram* can be thought of as a flowchart. The three major events that led to the error are displayed. The predecessors to these events could also be added if they can be determined. If effort is applied to fixing one or more of the factors (to cut off the flow at points identified by the vertical lines) future events could be prevented. The farther down the process (the closer to the error) the more effective will be the fix.

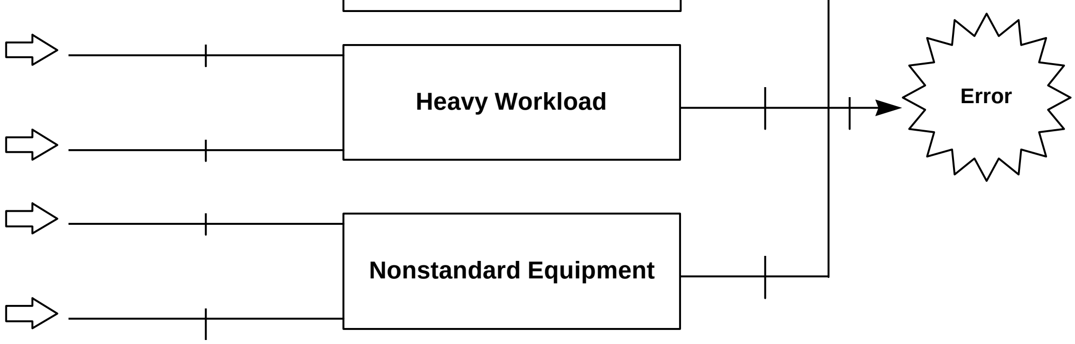

Figure 15 Error Analysis Diagram

Ideally, the form would be filled out by the person involved in the error and their supervisor. The back side of the diagram or an attached page could contain a brief description of the event. This tool could then be used for a few purposes. These are described below.

Remedial Action

Unless something is done to correct the factors that led to an accident, it likely will happen again. The steps that were taken to prevent future events should be noted right on the diagram.

"Those who cannot remember the past are doomed to repeat it". George Santayana

The traditional "fix" to prevent future errors has been to counsel the operator. This seems to be effective, because the person never does the same thing again. The problem with this logic is that the person has already learned the lesson. This leads to the next use of the diagram.

Training

These forms should be required reading for all people that do the same or similar job. They should be saved and used as part of a training program for new people.

"*I prefer to profit by others' mistakes and avoid the price of my own*". Otto von Bismarck

Process Improvement

Assume that a company wanted to improve its present working environment. Because operating errors happen infrequently, the utility shouldn't wait for them to occur and address each individually. A great deal of information can be gathered by having all operating personnel fill out forms for errors that happened to them in the past. Operators can vividly remember the significant details of their mishaps.

Everyone's diagrams (along with suggested fixes) could be collected. The information from all the forms could be combined into Pareto charts and "cause and effect" diagrams that could serve as a starting point for process improvement. Corrective measures that are simple and that address most prevalent problems should be initiated. The assembled forms on past events could also be circulated for their training value.

SURVEY RESULTS

Introduction

Data for this study was collected from three primary sources. They were:

- surveys of dispatchers from 18 utilities.
- four years of operational history from the author's company.
- existing literature on errors and related subjects.

This section summarizes the findings of the study. Supporting and conflicting information related to the specific error causing factors will be included for comparison. Finally, operators' suggestions to prevent errors of a particular type will be included.

The Survey

A survey was used in this study to gather error information from operator at 18 utilities. Error causes were divided into 9 categories. The dispatchers were asked to assign by weight the cause(s) of their last 2 errors. They were also asked for recommendations to prevent such occurrences in the future.

The categories chosen as cause contributors are by no means perfect. But choosing them allowed "slicing" the operators' environment into smaller segments. These segments can then be prioritized by how often they cause problems. An attack plan can then be developed to reduce the number of errors.

Although there may be some bias included in the survey responses, there is also a great deal of valuable information. This is highlighted by the fact that the results represent nearly 2000 years of operating experience. Refer to Figure 17 to review the error categories.

Cautions Interpreting the Data

1. The operational data is from one company only. It may not fairly represent other utilities.

2. The specific operating data covers only four years.
3. Because the surveys were voluntary and address a sensitive topic, they may not form a true picture of the total population. Those with a better track record would probably be more likely to respond. The total response rate was about 30% of the dispatchers from the companies that participated.
4. Subjective judgments were made when simplifying the data. Suggestions offered by dispatchers did not always fit neatly into the categories picked for analysis.
5. Some assessments were made on the personal observations of the author and his workgroup. They may not be true for other companies.
6. Due to the particular staffing and organization at each utility, one company's dispatcher may be more exposed to error situations (they may only be involved in switching and not spend time in other positions).
7. Because the data covers the operators' entire career, some problems that cause errors at a particular utility may no longer exist.

Summary Results

The working history of the dispatchers was compiled. The "average" system operator:

- had 10.8 years on the job.
- had 10.7 months of training before going on shift*.
- had 0.252 errors/year.
- had 21.5 years of operating experience.
- more had been power plant operators than other occupations.

* One company had an apprenticeship program that lengthened this time. The typical training time was 6-8 months.

Error Rate

The error rate of the responding companies is shown below. The rate is the average number of errors per year for each operator of the particular utility.

One point should be mentioned. Among the four lowest error rates, two of the reporting companies had had only 3 senior people submit surveys . One other "low" company did little SCADA switching. Most operations were performed by personnel in the field.

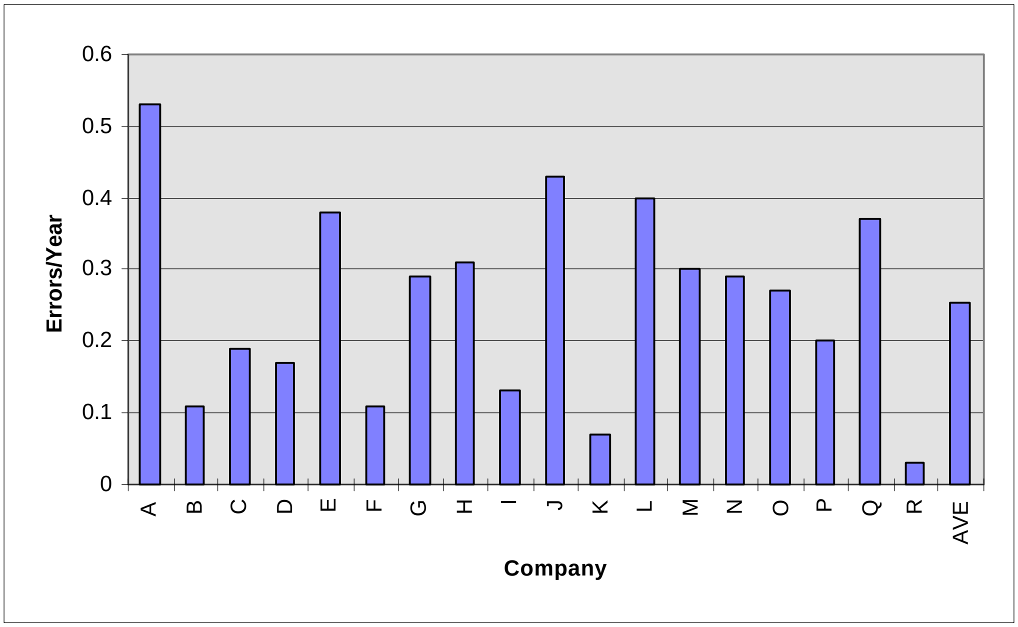

Figure 16 Error Rate of the Responding Companies

Reported Error Causes

Figure 17 shows a graph that was seen earlier. It contains the underlying causes for the errors committed by the surveyed operators. The categories of the causes are:

- **D-D**istractions.
- **C-C**ommunication problems.
- **U-U**nscheduled jobs.
- **W-**Job **w**ritten up incorrectly.
- **P-** Mistake in a **p**rocedure led to an error.
- **I- I** just operated the wrong device (slip).
- **T-T**rying to do too much at one time.
- **A-**An **a**utomatic device operated unexpectedly.
- **O-O**ther.

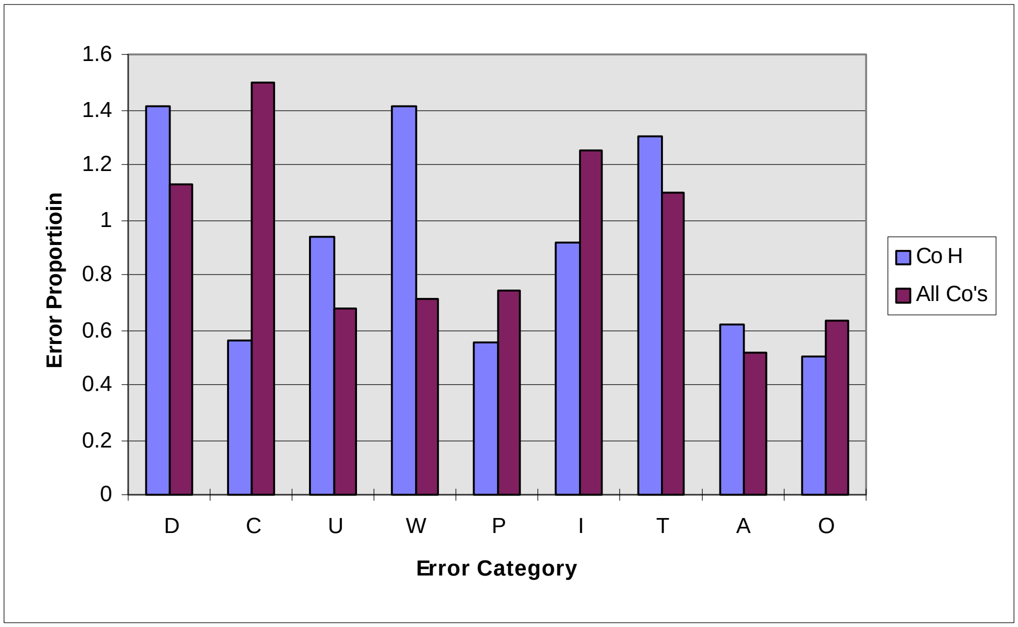

Figure 17 Reported Error Causes

Errors vs. Workload

Switching workload varies both by day of the week and by season. Most work occurs Monday through Friday. The yearly pattern is governed by weather. Less field work is done during extremely warm and cold periods. Figure 18 shows a month's switching workload at one operating desk, while Figure 19 is a year's switching for a control center at the host utility.

A correlation was done to test for a relationship between switching workload and errors. Eighteen months were divided into two categories, those months with more than the average number of scheduled switching and those with less than the average number of jobs.

There was a moderate positive correlation (+0.40) between the number of scheduled jobs and the number of errors. This supports the hypothesis of a link between workload and mistakes. This measurable increase in errors occurred even though the difference between a heavy and light workload equated to about an average of 1 additional switching job per operating desk per day.

As an interesting side note, the only error committed by the transmission operators at the host utility during the study window occurred on a day where the operator had 7 switching jobs (see Figure 18).

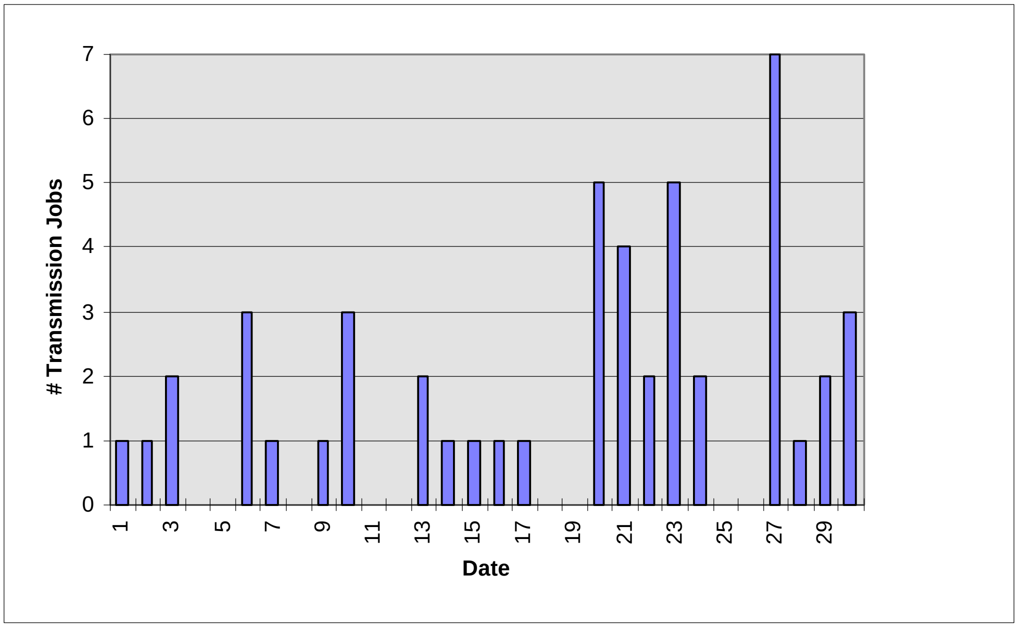

Figure 18 April Switching Workload

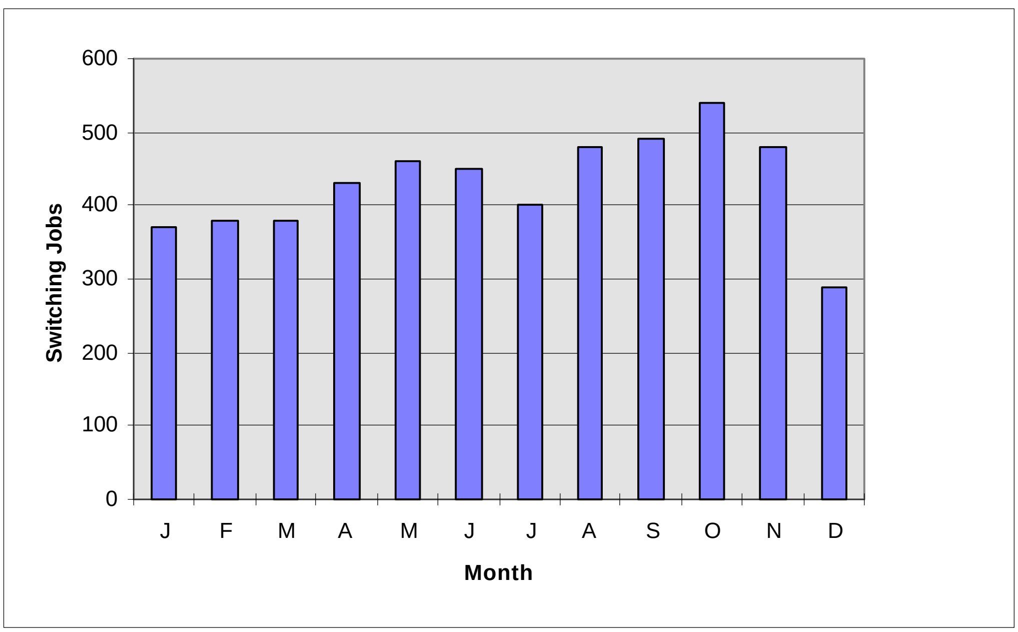

Figure 19 Yearly Switching Workload

Survey Response

Trying to do too many things at one time was the fourth leading cause of dispatcher's errors. It accounted for 13% of all the mistakes noted in the surveys. The operators' suggestions to prevent workload errors are in Appendix 2.

Related Study

NASA conducted an interesting study of process operators and their responses in situations that are likely to cause errors[47]. The study centered around operators controlling a computer simulation called PLANT. Figure 20 represents the system that the study subjects controlled.

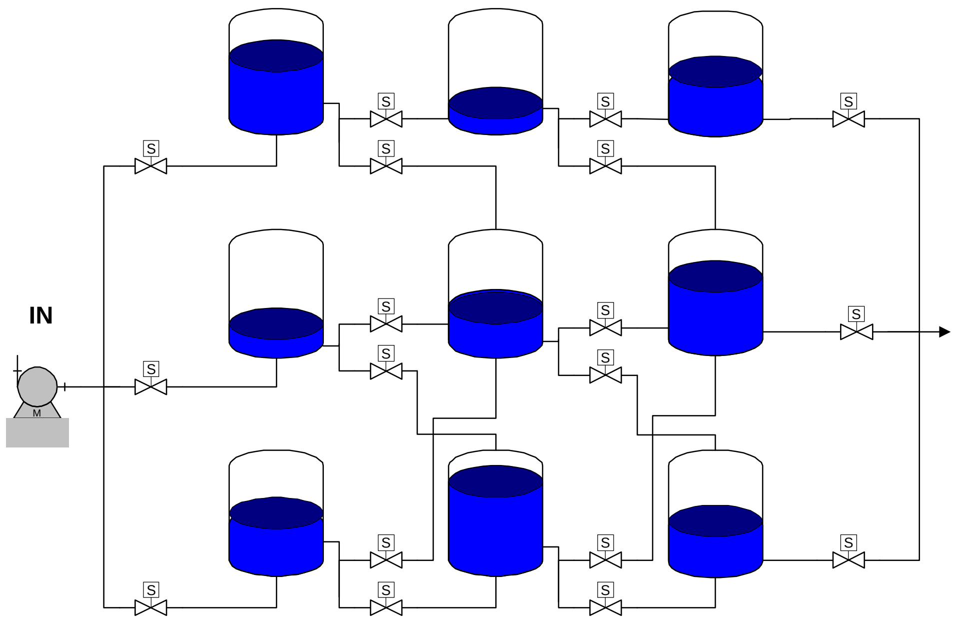

Figure 20 NASA Simulation

The simulation is a generic production facility. Operators control the flow of fluid through a network of tanks interconnected by pipes. Flow and fluid levels can be monitored in the system. Pumps can be started and valves opened and closed via computer commands to produce an unspecified product at the outlet. Workers can also be dispatched via the computer terminal in order to repair failed components. Production is the primary

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[47] Morris, N., Rouse, W. , "Human Operator Response to Error-Likely Situations in Complex Engineering Systems" *NASA Contractor Report # 177484*, August 1988.

goal. Secondary concerns would be system instability (tanks emptying or overflowing) and correct troubleshooting (fault detection and correction). Both of these would also impact production.

To study error likely conditions, the researchers set up a combination of conditions:

- **Keyboard Compatibility**. In one situation, the keyboard mirrored the graphics display of the plant. In the second set, the keys were not arranged in any relationship to the plant design.
- **Work Pace**. In half the situations, the operators could control the amount of input to the PLANT. In the other half, the computer controlled the input to the facility.
- **Type of Failures**. The operators' responses to both simple and complex failures were studied.

The researchers used a subjective measure to monitor the "mental workload" of the operators. The subjects wore headsets and microphones. At regular intervals, the computer asked them to report their level of effort (on a scale of 1 to 10). A speech recognition device recorded their response.

Interesting Findings

Operators responded by performing fewer commands in difficult situations (when the computer set the work-pace and during complex failures). This implies that when a person has less control of what is happening around them, they are more cautious.

Production was actually higher when the operators took fewer actions. Individual strategies that the people thought would increase production, didn't do so. This points to a need for using data to optimize a system. What we think is happening isn't always the case.

The above observation is not totally surprising. Most operators are aware of the fact that a "quiet process" is the most productive. A good operator anticipates changes in order to make fewer, smaller and earlier changes which allows the system to run itself.

Problems with the NASA Study

The study didn't specify consequences for committing errors. Production was the primary goal. The operators actually received a bonus for increased production. There was no direct penalty for loss of stability (spilled product, equipment damage, etc.) other than a loss of output. There was no safety implication. Since there were no significant or long term penalties for committing errors, these operators would probably take more chances than those in real production facilities.

Was NASA measuring workload? The researchers did not find a relationship between "mental workload" and errors. The problem might not be with their hypothesis, but with their measure of workload. Remember, this was a subjective judgment of the operators on a 1-10 scale. NASA did note that high mental workload was reported in situations where the operators were confused about the system state and also when they observed signs similar to situations that caused them problems in the past. This could mean that their "mental workload" might actually be more a measure of stress than the amount of work the operators were performing (both mentally and physically).

NASA appeared to overlook a significant piece of information in their data. This could be seen in situations where operators performed the most physical tasks (what they called "simple scenarios"). In these cases, the operators did the most "tweaking" of the system. When more commands were issued, significantly more errors occurred. The comparison is seen in the table below.

Table 4 NASA Study Summary

	Commands Issued	Errors
Simple Failures Scenarios	425	42
Complex Failures Scenarios	305	25

The table shows a 39% increase in commands issued resulted in a 68% increase in errors. If a computer command is caused by a conscious decision (which requires mental effort) followed by action (physical effort), perhaps the number of commands issued would be a better measure of workload.

If NASA would have used the number of keyboard commands as a measure of workload, they would have found a correlation with errors. They may have also observed other patterns in the study.

Errors vs. the use of Planners

Some responding utilities had support staff who did not perform real time operations, but whose primary job was to write up and coordinate future work. A test was made to determine the value of having an outage coordinator in reducing errors.

The hypothesis was tested by means of correlation. Using the entire sample population, there was not sufficient evidence to support the claim that having a planner would reduce errors. Intuitively, it would seem that there would be a lower rate by removing this added task from the real time operator. There could be other factors masking the effectiveness of a planner.

There was a correlation between companies that had planners and the length of their operators' shift week. Companies with shorter shift schedules were more likely to have planners. It may be that the shift schedule forced these companies to have planners because of the reduced day to day continuity of their workforce.

A test of the value of outage coordinators was made from another perspective. The effect of having a planner was tested against the population of "new" operators. These were people with less than four years on shift. In this case there was evidence (F = 13.5, R square = .771) to support the claim that a planner will lower error rate.

The second test would suggest that a company with higher turnover (low average time on the job) or is about to bring on several new operators, might consider the addition of a planner to reduce errors. From another perspective, newer operators should avoid secondary tasks that take their attention from switching.

Errors vs. Company Size

A test was done to check for a relationship between errors and the size of the utility. This was done by dividing companies into three size categories (based on peak demand):

- < 1000 Megawatts.
- 1000-5000 Megawatts.
- > 5000 Megawatts.

A regression found a slight negative relationship between size and error rate (-0.165, p=0.04). This implies smaller companies had a slightly higher error rate. This may occur because smaller companies typically have their operators perform a wider variety of tasks.

Errors vs. Experience

A linear regression was performed to test for a relationship between experience and errors. There was a strong link suggested (R square = 0.819, F = 113, p =.0001). This suggests that nearly 82 % of the errors appear to be linked to experience (or actually lack of it). The relationship is apparent from Figure 21, which mirrors a typical learning curve.

The model identified by the regression was:

Error rate (per year) = .139 + .833*

* (if < 4 years experience).

The second term of the equation only applies if the operator has less than 4 years on the job. This means the "typical" error rate for a new operator would be about .972 per year. This number decreases rapidly with experience. For an seasoned operator it would be .139 per year.

This model could be applied to a pool of operators in an office to come up with an estimate of what to expect. This would be done by taking a weighted average of the dispatchers' experience. An office of 12 veteran operators could expect about 2 errors per year. Remember, however, errors follow a probability distribution that results in some variation.

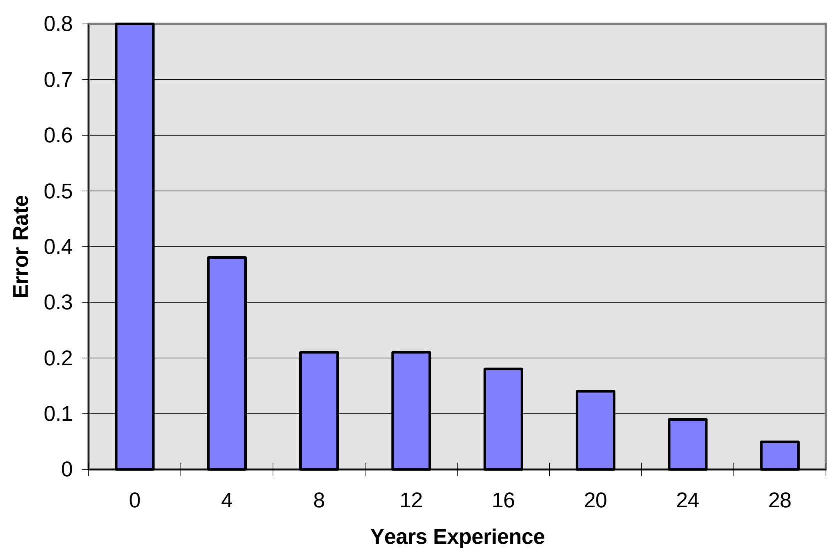

Figure 21 Error Rate vs. Experience

Note: The experience values noted on the graph are “midpoints”. In other words, the first bar represents 0-2 years, the second over 2 but less than 6 years, etc..

This experience relationship suggests two things to reduce error rate:

- reduce the turnover in your staff.
- find a way to build experience more quickly (training and expert systems).

Related Study

A 1988 study prepared for the U.S. Bureau of Mines, looked at 338 accidents in 20 mines over a 20 month period[48]. Nearly 50 percent of the accidents involved workers with less than three years’ experience in their job. This supports the idea of a strong relationship between inexperience and errors.

Errors vs. Training

There were wide differences reported in both the duration and type of training operators received. Smaller companies generally provided less training time before an operator was placed on shift. Many relied solely on on-the-job (OJT) training. The largest companies were most likely to mix OJT, simulator use and classroom training.

A statistical test to identify a relationship between the amount of time an operator spent as a trainee vs. error rate failed to establish a link. If some means could be developed to measure the QUALITY of training as opposed to the time spent training there may be a different result.

Shift schedule-Errors vs. Day of the Workweek

There was no direct way using survey data to test for a relationship between the errors and the part of the workweek. Each company had their own shift rotation. Because these positions are staffed 24 hours a day, the “workweek” for an operator continually moves.

A test was attempted at the host utility by studying those people worked primarily Monday-Friday (testers, electricians and construction). Their performance over a one year period was examined. Remember

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[48] Cohen, H. , Cohen, D. "Myths about human mistakes", *Professional Safety*, October 1991.

that these people are not the target population for this study. There should, however, be similarities between them and operators.

Of the 7 errors that occurred during the year, 3 happened on Monday and 2 on Friday. A closer inspection showed one of the remaining two mishaps took place the day before Thanksgiving. This day was therefore the end of the work week.

A "binomial distribution" table can be used to predict this probability (that 6 of 7 random events would occur on the start or end of the workweek). The chance of seeing this at random is less than 2%. This is considered statistically significant and does support the hypothesis that there is a difference in error rates between days of the week.

Alternate Analysis

It wasn't possible to directly collect information on what days the surveyed operators experienced errors. There was, however, an indirect way to check for a relationship between workdays and errors.

Consider a company whose operators work a 7 day rotating shift vs. one that works a 4-5 day shift week. Assume that no matter how long the normal shift is, the first day is a "Monday" and the last day worked is a "Friday". Over a year, a dispatcher that works a 7 day rotation will have few "Mondays" and "Fridays".

A variable can be derived that is equal to 1 ÷ (# of days in a shift week). This variable would be proportional to the number of "Mondays" and "Fridays" a dispatcher experiences in a year.

An analysis showed there was a positive correlation between this variable and error rate (0.222, p=0.04). There was also a reduced "time to the first error committed" with more "Mondays and Fridays" (-0.298, p=0.02). This supports the concept of a link between the day of the week and the likelihood of mishaps. It also suggests a company might improve is safety record by adjusting its shift schedules.

Related Study

A recent EPRI study on switching safety listed the fatalities of electrical workers that occurred in utility substations from 1989 through 1993[49]. Figure 22 shows the days of the week on which these accidents occurred.

It can be seen that the greatest number of fatalities occurred on Friday. The data can be adjusted to provide additional insight.

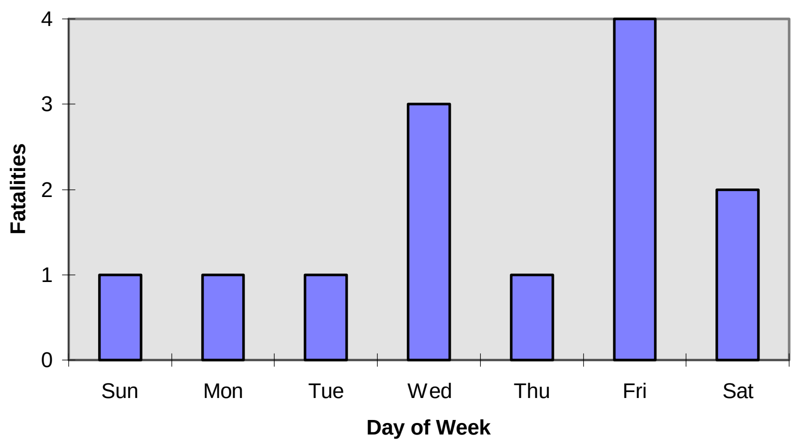

Figure 22 Electrical Substation Fatalities by Day of the Week

People familiar with utility operations know that the vast majority of field work occurs during the normal workweek. It is likely that over 90% of the jobs are done from Monday through Friday. Work scheduled on weekends is typically overtime.

The accident data could be modified using the simplifying assumption that an overtime Saturday job would be the person's last workweek day and that a Sunday job would be a person's first workweek day.

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[49] Beare, A., Taylor, J. *Field Operation Power Switching Safety*, WO2944-10, Electric Power Research Institute. p. 1-4.

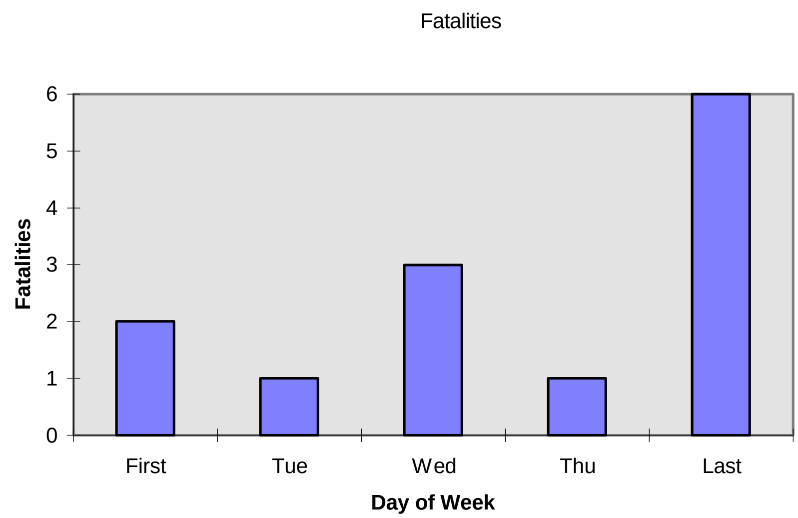

Figure 23 Substation Fatalities-Adjusted Data

The adjusted data is shown in Figure 23. Although it cannot be used as statistical justification from a purist's perspective, it provides a strong teaching point. The probability of an accident appears greatest on a person's last day of the workweek. The host utility's maintenance group record and Figure 23 suggest Mondays are also risky.

Conclusions

Possible reasons for more errors on the first and last days of the week are:

- people may be tired on returning to work.
- they may not be "in the swing of things" on their first day back.
- they might be preoccupied with what occurred over the weekend.
- they may have their mind on what they will be doing on their upcoming day off.
- they may be rushing to finish up before the weekend.
- there could be dependency problems.

A later discussion on errors vs. the time of day may shed additional light on this.

To take advantage of this probable relationship:

- operators and field personnel should be aware of the increased likelihood of errors and focus on the job.

- supervisors should schedule simpler jobs and lighter workloads on these days.
- operators could be scheduled in early on their first day back to give them time to review their upcoming jobs.
- operators should preferably return from their “weekends” in a non-switching position or on a lighter workload day.

One final note bears mention. A review of a year’s switching workload at the host utility showed that there were about 1/3 fewer jobs on Fridays vs. the other weekdays. If this is true for other utilities, the relative risk on the last day of the workweek would be even greater.

Shift schedule-Errors vs. Time of Day

Due to a lack of available data, there was no attempt made to test the relationship between errors and the time of the workday. Should utilities decide to formalize the collection of error data, the hour of the shift in which the error occurred would provide valuable information.

There was useful information from cognitive science and other fields. It is included here because of the close relationship to the previous discussion on errors vs. day of the week.

Cognitive Science

James Reason collected data on when slips occurred[50]. He had people maintain a diary on the type and time of mistakes as they happened. The people involved were associated with a university and therefore worked primarily 9-5, Monday through Friday. Figure 24 shows the number of slips by the hour they occurred.

The underlying curve will look very familiar to most system operators. It is similar to the shape of a graph of electrical demand through the day. As electrical usage is a measure of human activity, Figure 24 suggests that slips are proportional to the number of tasks performed.

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[50] Reason, J.T.,*Absent-minded? the psychology of mental lapses and everyday errors*,Prentice-Hall, Englewood Cliffs, NJ, 1982. p. 26.

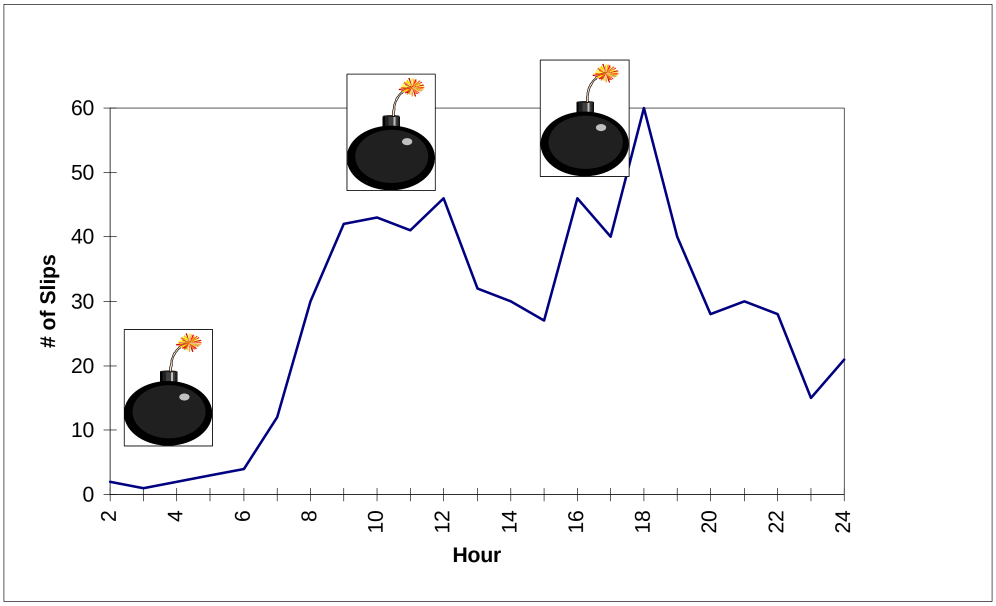

Figure 24 Slips vs. Time of Day

Two of the "bombs" on the graph are to highlight the trouble spikes that occur in the graph. The number of slips increase at a few specific times of the day. Recall in the earlier discussion on the human action model that slips occur when our attention is drawn elsewhere. Our attention is often elsewhere when we shift from one "mode" to another. In other words when we move from one set of tasks to something different. Examples would be:

- starting our workday (shifting from home related tasks to work related ones).
- going to lunch.
- ending our workday (shifting from work tasks to home related ones).
- getting ready for bed.

Referring back to the human action model, the mind has to prioritize our intentions, check the state of our world, set up a plan and act on it. This planning is important, but it either requires us to stop everything or else we have to work in "autopilot". Autopilot is where slips occur. Operators need to be careful at the beginning and end of their shift.

This autopilot idea might explain the apparent increase in mishaps on the first and last workday of the week. The same mechanism could be taking place.

The reader may have been confused by the "bomb" on the graph above during the wee hours of the morning. Not many slips occurred there. Remember that the people on which this study is based were day workers. If you're not awake, you won't make many slips.

There is a reason electrical demand follows a pattern similar to Figure 24. As human activity decreases, people use less electricity. Alertness and activity flows through a similar cycle called a circadian rhythm. The lowest activity is from the 3 a.m. to 5 a.m. This is where the body naturally tends to "shut down".

Everyone that works night shift experiences this shutdown. The reason for the "bomb" on the graph is to alert the operator that a second error mechanism (mishaps due to reduced alertness) likely exists during these hours. Operators should avoid work that requires significant attention during this time frame. Detail work (switching, writing and/or checking procedures) should be done outside this time.

☛ **Operating Pointer:** Avoid "detail" work between 3a.m. to 5 a.m. Do it earlier in the night shift.

☛ **Operating Pointer:** Slips appear most likely at the start and end of each workday and workweek. Be particularly careful during these times.

Other Study

The Bureau of Mines study mentioned earlier contradicts the idea that fatigue is a major factor in causing errors. The majority of reported accidents occurred in the first half of the work shift. Many people would assume that more would occur when people are more fatigued and therefore less alert. This points to the multidimensional nature of errors.

Survey Estimate on Slips (Operating the Wrong Device)

Operators responding to the survey reported slips as the second leading cause for their errors (15%). Their suggestions for preventing them can be found in Appendix 2.

Communications Problems

Communication problems were responsible for 18% of the errors that the surveyed operators experienced. This was the leading cause reported. Two companies in particular seemed to have this as a problem. The operators' recommendations are found in Appendix 2.

Automatic Devices Operating Unexpectedly (Traps)

This area caused 6% of the errors reported in the survey. See Appendix 2.

Procedure and Map Errors

This area caused 9% of all the errors in the survey.

The Switching Procedure was Written Incorrectly

Incorrect procedures caused 9% of the reported errors.

Unscheduled Jobs

Switching equipment out that had not been requested through normal procedures caused 8% of the errors operators reported. In these cases, the operator doing the switching is usually the one writing the procedure (assuming a procedure is written). An oversight, error in the procedure or the haste in getting the job done along with other responsibilities cause mistakes to happen. Companies that had problems with this also had trouble with workload and automatic devices. These all signal insufficient planning. Recommendations to prevent these problems are in Appendix 2.

Distractions

This area accounted for 14% of all errors. In a related study, Griffon-Fouco and Ghertman showed that nuclear operators had been distracted during the execution of the primary task in more than 15% of the incidents leading to a plant shut-down[51].

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[51] INPO. *An analysis of Root Causes in 1983 and 1984 Significant Event Reports*. INPO 85-027. Atlanta, Ga.: Institute of Nuclear Power Operations.

Other

Remaining reasons caused 8% of the operators' errors. Things that fell into this category were:

- Inexperience. (7 responses)
- Forgot an operating procedure. (1)
- Didn't prepare for the job well enough. (1)
- Outage paperwork was too congested. (1)
- Our present shift schedule might not be the best. (1)

Recommendations to prevent these problems in the future are in Appendix 2.

Links Between Error Categories

A correlation between error causes was done. This was to find out which causes tend to combine to produce errors. Although there were no strongly linked factors, the following were positively correlated:

- Unscheduled jobs and Automatic devices operating unexpectedly.
- Distractions and "I operated the wrong device" (slips).
- Unscheduled jobs and Communications problems.
- Distractions and Trying to do too many things.

Perhaps this can give dispatchers a clue in what to look out for when operating under one of the conditions.

Trouble Areas for New and Experienced Operators

A correlation was done on both new (< 4 years) and senior (>20 years) operators with the various causes. Each had a moderately positive link with a particular cause:

- new people "tried to do too many things".
- older operators "just operated the wrong device"(slips).

This should not be taken as a hard and fast rule. It should, however, alert the operators when they are getting into a troublesome situation.

EPRI Switching Safety Study

The recent EPRI study on switching safety has information that provides insight on operating errors[52]. It reviewed nearly 400 switching mishaps reported by utilities (the host utility for this study contributed to this). Part of the EPRI study is summarized in the following figures.

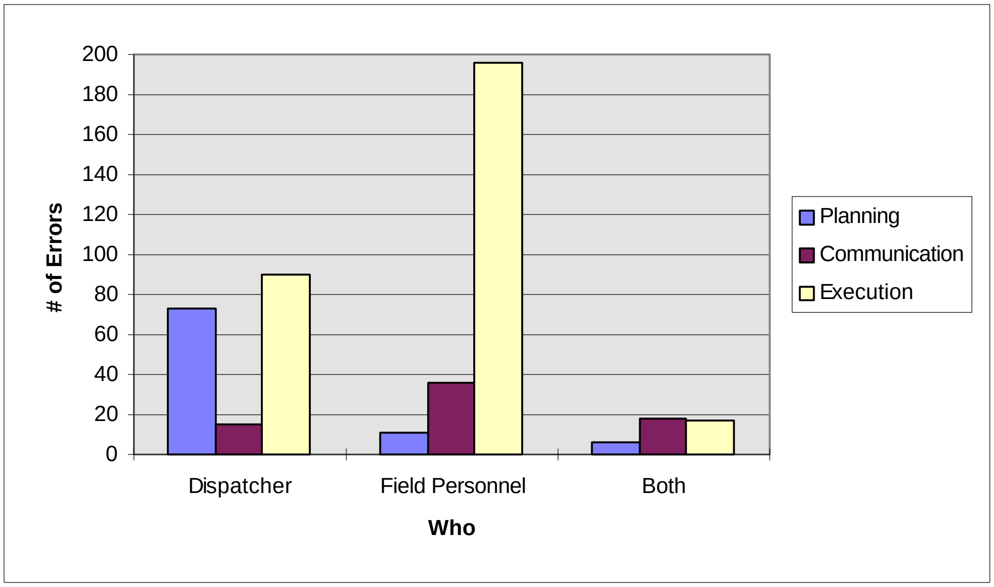

Figure 25 Errors by Type and Occupation

Figure 25 shows errors by type and where they were made. It turns out that dispatchers and field personnel committed almost the same number of errors, but are subject to different error mechanisms. Field operators are more susceptible to slips while control center operators are plagued by both slips and planning mistakes.

Table 5 Switching Error Contributors

	Dispatcher	Field Operator	Both	Maint. & Testing
# of Errors	163	175	29	34
Omission	33%	25%	34%	32%
Wrong Sequence	17%	6%	10%	0%
Wrong Action	18%	22%	14%	41%
Wrong Equipment	31%	47%	41%	12%
Fail to Check	53%	20%	71%	33%

[52] Beare, A., Taylor, J. *Field Operation Power Switching Safety*, WO2944-10, Electric Power Research Institute.

Table 5 is a summary of the reported errors and their causes from the switching safety study. The column percentages don't total 100 because some errors had multiple contributors.

Sharing Information

One of the most useful things that could come out of this study is the sharing of data and information among utilities. Companies with a problem in one area could learn a great deal from those who don't. The problem is that one of the prices of deregulation is reduced cooperation among utilities. Safety and reliability are two areas where they must still work together.

IMPROVING OPERATIONS

The goal of this section is to offer tools and tips a company can use to improve its operations. It starts with a method of analyzing and correcting error situations. It suggests management strategies to improve the dispatchers' performance. Finally, it offers tools that can be directly used to start an error reduction program.

Error Analysis

Introduction

This section describes a simple procedure to analyze errors after they occur. There are common problems with the way this is done by most organizations. The procedures used to review the incident (if a review is done) varies with each investigator. The conclusions reached often don't look deep enough, which results in inadequate recommendations.

A method is suggested that uses standard tools and forces the organization to take some remedial action. An actual event is used to better explain the process.

Problems with Accident Reports

Safety experts note that explanations of major industrial incidents are usually superficial analyses which result in cursory changes related to the particular event. In almost all cases the fixes are recommendations for better training along with stricter adherence to instructions[53].

Following a mishap, the spotlight naturally goes to the person nearest the problem when it occurred. This is usually the operator. In reality, there were likely latent problems in the process that could have been corrected beforehand. Because nothing is typically changed after the event, the same pathogens remain to trap another person in the future.

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[53] Cohen, H. , Cohen, D. "Myths about human mistakes", *Professional Safety*, October 1991.

The contributors to latent failures are the "sea of variables" that spawn common cause problems. By definition, management bears a primary responsibility to provide resources and direction to correct them.

Errors are only the tip of the iceberg as shown earlier in the accident pyramid. They are relatively rare. This means reviewing near misses using a similar process could prevent certain errors from ever occurring.

> *"Do not ignore accidents. They happened and will happen again, unless action is taken to prevent them from happening."* Trevor Kletz

Simplified Approach

Because accident analysis can be complicated, it is often avoided. A simplifying approach is to assume that an error occurs when three forces come together to cause it. There may be more, but in a practical sense, if the three major contributors can be identified and attacked, a similar situation shouldn't happen again. This is analogous to removing either fuel, oxygen or heat to prevent fires. Keeping the process simple allows the analysis to be done in-house.

Error at Racine Substation

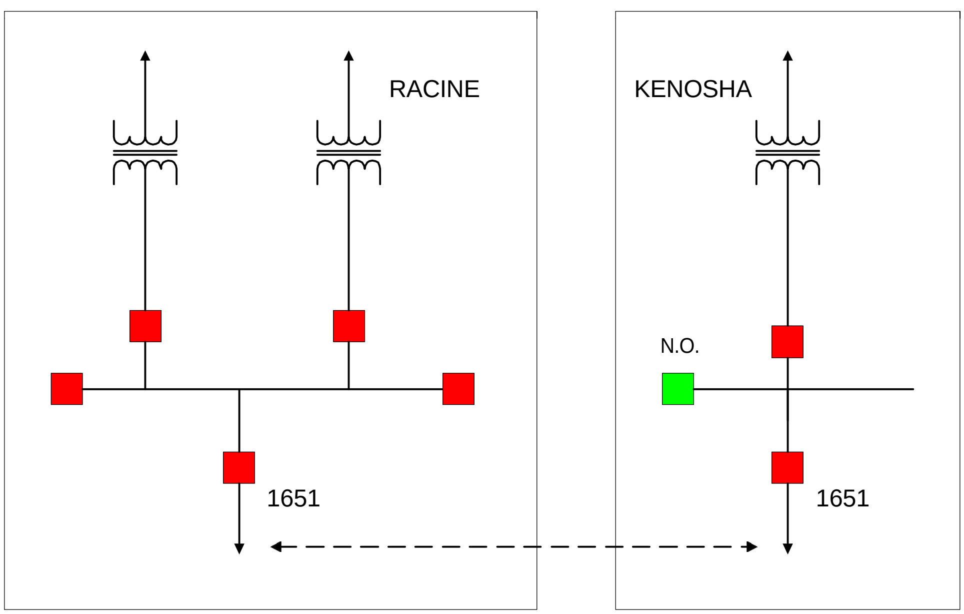

Figure 26 CRT Displays-Racine Substation Error

On the morning of April 27, a transmission operator was clearing a 138kv bus section at Racine substation (see Figure 26). He had successfully removed load from the Racine transformers. The operator opened the Racine line 1651 circuit breaker as a first step to deenergize the bus. Line 1651 feeds an isolated bus at the Kenosha substation and is therefore radial load. The load fed from the Kenosha transformer was lost. Power to Kenosha was restored in under 5 minutes.

Analysis of the Event

The first reaction of people reviewing the event is that the operator just slipped up. A closer review turned up the following facts:

- The switching procedure was written incorrectly, by a relatively new operator.
- The switching procedure was not checked by a second person before the operator received it.
- The night shift operator, who would normally review the procedures, spent most of his time taking care of the logistics for the next day's switching.
- The fact that line 1651 is "different", i.e. carries radial load, is not apparent on the Racine display.
- The operator was switching 7 jobs that day (some simultaneously).
- A heavy switching workload today means there was a heavy write-up workload two days ago (which contributed to the incorrect procedure).

The key information can be put on an Error Analysis Diagram to show the events graphically. This can lead to ideas that can stop the "flow" of individual contributors. The closer to the error a fix can be implemented, the more contributors that can be stopped. In addition, the "Operating Lessons Learned" form found in the *Tools* section of this paper can be used to collect error information.

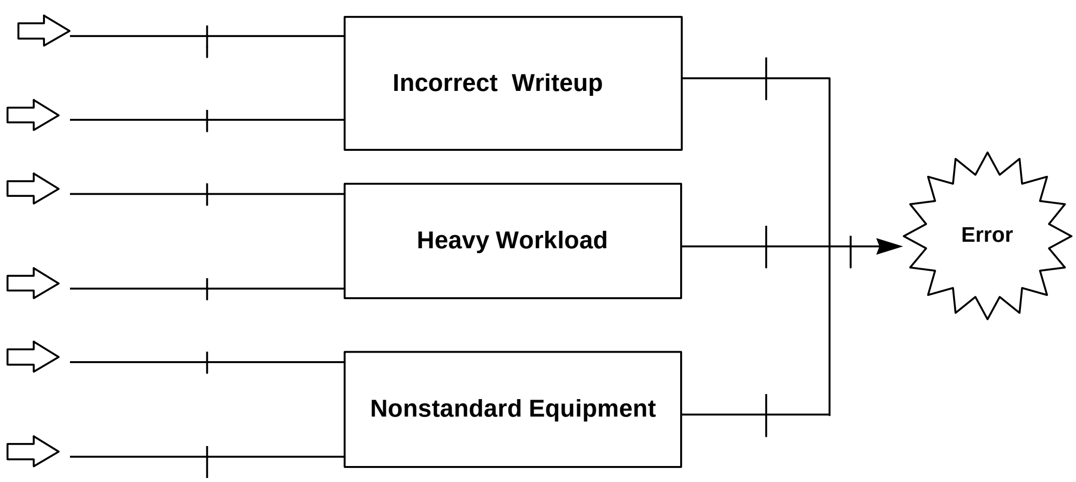

Figure 27 Error Analysis Diagram

Recommended Changes

Traditionally, a counseling session would be the primary step taken to prevent this or similar errors from happening again. To save the operator embarrassment, the information might not have been shared with others. Since that operator never committed the same error, it was assumed the counseling was effective (Note: The operator already learned what happens when you open line 1651 without taking care of the Kenosha load first. He didn't need the counseling).

A discussion with other operators identified these possible fixes:

1. Let everyone know their responsibilities to review jobs completely on night shift.
2. Remind everyone to review their work before switching.
3. Limit the number of jobs that a person should be switching.
4. Require a second review of switching procedures. The reviewer should initial the procedure to acknowledge ownership and to let people know it was checked.
5. Find some way to "flag" these traps.

Items 1, 2, 4 and 5 were ultimately implemented. Items 1 and 2 are considered "soft" changes that can't be verified and have limited impact. Most people know they are suppose to perform these steps. Recurring reinforcement is needed for them to be considered valid corrective measures. Item 5 was the largest change and bears discussion.

There are a number of ways traps can be flagged. Often times companies are tempted to put flashing messages by devices to bring the operators' attention to the problem. Since clutter and distractions can themselves lead to errors, a compromise was needed.

It was decided to identify and flag all traps on the system with a yellow diamond similar in shape and color to roadside caution signs. It tells the operator to look deeper. If the operator then refers to the Racine substation documentation page on the CRT, they see a similar diamond with an explanation of the trap. Figure 28 shows the change on the Racine substation diagram. It is not distracting, yet it stands out next to the device that can cause the trouble.

The goal of using the analysis diagram is to "cut off the flow" in the chain of events that lead to an error. This puts a barrier between the operator and the hazard. Making the change not only prevented a future problem at Racine substation, but other similar traps as well.

> *"When you build a new house, you should put a short wall around your roof. Then no one will fall from it and bring the guilt of blood upon your house".* Deuteronomy 22:8

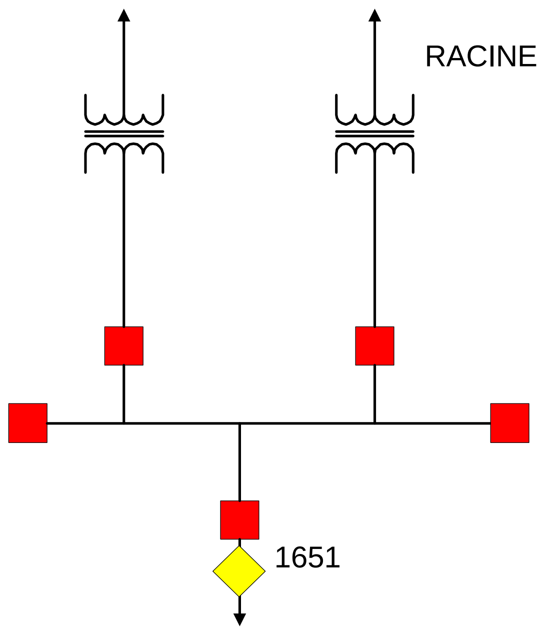

Figure 28 Operating Trap Flag

Impact of the Change

Over the previous few years, the transmission operators at this company had experienced 2-3 errors per year where a "trap" was present that wasn't apparent on the station diagram. Once all identified traps were flagged, there have been no errors due to similar events.

Flagging the traps had several supporting benefits. They were:

- It refreshed the memories of the experienced operators of the traps on the system.
- New operators learned the traps on the system more quickly.
- There are fewer procedure errors because the person writing the job will likely see the flag.
- If the procedure is wrong, the preceding shift and the operator doing the job will likely see the flag.

It should be noted that several of the more experienced operators were at first reluctant to implement the change. One felt everyone should know the system by heart. Others thought changing the diagram might be too distracting. Testing a few options came up with the compromise that has been effective in preventing errors.

One final comment should be made on the recommended fix of requiring a second review on switching procedures. It's been observed among several utilities that this requirement falls by the wayside if not enforced by management. In many operators' eyes, the task is of limited value and puts them at risk if the procedure they OK'd has a problem.

Consider the fact that 27**%** of the errors reported by the surveyed operators were due to incorrect procedures, unexpected operation of automatic devices and jobs that were unscheduled. An independent quality review would have probably resulted in a marked reduction in these.

Improve the Work Environment

This section touches on a variety of subjects related to improving performance in power supply offices. It was gleaned from operators' input and from published information. Much of it can indirectly support the goal of reducing operating errors.

Job Aids

A job aid is a device or written procedure to simplify a complex task. The goal is to have a tool that can be used when under time constraints or when performing infrequent jobs. A few examples are suggested in the following paragraphs.

Training Outlines

A "training outline" as found in the *Tools* section of this document is an example of a job aid. The information in the task covered (Restoring a tripped transmission line-cause unknown) is not all inclusive. It is designed to give an idea of a useful format and the type of information contained.

A template could be created to document the key steps performed in both common and infrequent operating tasks. A compilation of such documents would be useful in training new operators. If word processed, they could become "living" documents used for refresher training and also as a memory joggers when the actual situation arises. This is particularly true if the information could be quickly retrieved (kept in a binder or through the use of a 'key word" search program).

It might seem a large job to put together such a knowledge base. This is not necessarily the case. Given a task, an experienced dispatcher could pencil in the steps he or she normally takes in that situation. Someone could "paste" the information into a word processor template. Since many of these tasks have generic information common to most companies, utilities could share resources. Each company could modify and add to the tasks to fit their needs.

Operators are often reluctant to put good operating practices on paper. The reasons usually given are that no two situations are alike. The person must have the flexibility to take the needed actions to run the system. He or she should not be "hamstrung" by procedures. The result of this is that there can be divergent opinions on how situations should be handled. The operator's training, priorities, experience, and risk avoidance will determine their actions.

As long as the operator understands the intent of the guideline, it should not pose a problem. Different situations may render certain steps or the entire procedure not applicable. The intent is to document good general practices. Other constraints may void a procedure or at least prod the person to obtain guidance in resolving the conflict.

Improved Switching Procedures and Operating Instructions

Each company that participated in the study had different styles of switching procedures. Some were involved, noting each minor step. They were circulated for multiple reviews with hard copies sent to operators in the field. On the other end of the spectrum were short hand written procedures where no hard copy was disseminated. Switching orders in these cases were oral.

Written procedures are useful when performing tasks that are unfamiliar, contain a large number of steps, must be done under pressure or where the consequences of failure are great. There is no one best way to prepare switching procedures. This section, will however, list items to consider so that a company can improve what it now does.

Suggestions

- Instructions should be simple and easy to read.
- Procedures that don't undergo much change over time should be word processed. They have proven they work. They act as a store of knowledge.
- Since substations don't change often, permanent instructions in stations with copies in operating offices are useful.
- General information should be kept separate from performance steps.
- Key steps and isolation points should be highlighted.

Hazards[54]

The following bullets summarize the risks associated with following both oral and written instructions. They are useful for both training and the development of written instructions and procedures.

- The larger the number of steps, the greater the chance one will be overlooked.
- The more information in a given step, the more likely something will be missed.
- Steps that are not logically sequenced are likely to be omitted.
- If instructions are verbal with more than 5 simple steps, those in the middle are most likely missed.
- If instructions are written, isolated steps at the end have a reasonably high chance of being missed.
- During highly automated tasks, interruptions are likely to cause omissions, particularly when under time pressure.

Human Factors

Human factors is a branch of industrial engineering whose goal is to improve the "fit" between the job and the work at hand. Although there is no direct way to prove that streamlining a job will reduce errors, it is logical to assume that if an operator were more efficient at processing power system information, fewer mistakes would be made. An operator needs the correct tools to make the right decisions.

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[54] Reason,J.T. *Human Error*. Cambridge University Press. 1990. p. 239.

One way to improve operations would be to select an interested operator willing to become knowledgeable in human factors. This person could serve as coordinator to integrate these concepts. They should have some say in system development and improvement.

The Electric Power Research Institute looked at human factors at several dispatch centers[55]. Although this study did not directly address the topic of errors, it contains useful information. It is likely on the shelf in most utilities' corporate libraries.

Control Center Procedures

There are several procedural items suggested by the operators which would decrease the likelihood of mistakes.

Workload Control

Figures 18 and 19 showed there is a great deal of variability in the amount of switching that is done. The vast majority of switching takes place Monday-Friday. This is when the people in the field are working. An analysis at the host utility showed a nearly equal average amount of work Monday-Thursday. About 1/3 fewer jobs were done on Fridays.

Since there is evidence to support the relationship between workload and errors, it would be wise to control both the level and the variability of the work. Some of the ways suggested by operators to do this are discussed below.

Alternative work schedules for field personnel

Alternative work schedules are attracting interest among utilities. Most dispatchers surveyed work 12 hour shifts. Many power plants are either trying or investigating similar schedules. If the majority of the field personnel did not work 0800-1600 Monday to Friday, the switching activity could be spread out, reducing both the average and peak activity. Crews would also spend less time waiting for the dispatcher.

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[55] Koenig, D., Frank, C. *Human Factors Review of Electric Power Dispatch Control Centers*, EPRI EL-1960, Vol. 1-6.

Smarter Maintenance Programs

The field maintenance that takes place on the power system can be scheduled manually or with the aid of computers. There are advantages for automated systems, particularly when the operators have some interface with them. Some of the things a computer system could do to reduce switching risks are:

- a maintenance leveler (discussed earlier).
- identify and hold the jobs that don't have weather constraints. They could be done in slow months or rainy days (when other jobs are usually postponed).
- maintain a queue for low priority jobs. These can wait until the equipment is taken out of service for other reasons.
- notify and coordinate with other groups that need to work on the same piece of equipment. For instance, if one end of a long line is being taken out, the maintenance group(s) who have jurisdiction of the other end(s) should be notified. Likewise, those people responsible for line work should be told of a pending outage. They may have jobs to be done on the line itself.
- notify appropriate groups when an opportunity arises to work on a "hard to get out" item. An example would be when a particular power plant outage is needed to allow removing a nearby critical line from service.

Some of the other features an improved maintenance program could have would be:

- operator access to significant history about the particular piece of equipment or style of equipment.
- a history of what special considerations should be taken to take this device out (system load below a certain level, a particular generator configuration, Sunday-only situations, etc.). Maintenance personnel and operators both need this information.
- a way to leave notes for the maintenance people. Operators that spot problems with equipment or notice something unusual should have a way to route a message to the appropriate group. Since these problems are often found on back shifts and weekends, there should be a way to pass the information directly along to the workgroup and a way to respond to the operator once he or she returns to work. Quite often "small" problems are taken care of on the spot by the operator. If no data is recorded, the same thing may take place

several times on different shifts. Since small problems often become bigger ones, there should be a better way to keep track of them.

Operator Alertness

Operators are on duty 24 hours a day. The problem is that the human body was designed to rest at night. Each of us has a biological clock that tells us when to be awake and when to be asleep. The clock that controls our alertness cycles through the day, reaching a low point around 4 a.m. This is a danger period if "detail intensive" work is required. It has been suggested that human error due to this phenomenon contributed to Chernobyl, TMI and Challenger disasters[56].

There are certain steps operators and their supervisors can take to control themselves and the work environment to ensure they are alert and able to respond. Useful strategies to enhance alertness are outlined below[57].

- Rearrange the work. A stimulating task increases alertness. Ask questions, make comments, take notes, bring others into the discussion.
- Muscular activity stimulates the nervous system. Vigorous exercise can improve alertness significantly for an hour or more afterwards. The problem is that operating jobs are by nature sedentary. If exercise isn't possible, stretch in place, take breaks to walk around, even chew gum.
- Maintain your "sleep bank" balance. Alertness depends on how long it has been since we last slept. The need for sleep becomes more irresistible the longer we've been awake. Loss of even a couple hours of sleep will dampen alertness. The effect accumulates over several days. An operator must identify personal strategies that helps them get needed rest. They have a responsibility to be in a condition to work, particularly for 12 hour shifts.
- A nap of 30-40 minutes will leave you groggy. A short nap of 10-15 minutes provides more benefit.

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[56] Moore-Ede, Martin.,"Alertness is critical in today's twenty-four-hour society: Nine ways to keep you alert", *Nuclear News*, July 1993.
[57] Moore-Ede, Martin.,"Alertness is critical in today's twenty-four-hour society: Nine ways to keep you alert", *Nuclear News*, July 1993.

- Don’t substitute diet for sleep. Food, drink, and chemicals can stimulate, but it's a poor way to cope in the long run. A few cups of coffee are fine, but any more stays in your system, robbing you of future rest, which will hurt the next day.
- Control lighting at work and at home. Bright lights can have a dramatic effect on increasing alertness. The lighting should be about the level of natural light at dawn. Night shift operators should turn up lights before performing switching. Conversely, daylight streaming into a shiftworker’s bedroom can prevent them from getting a deep sleep. Cover your bedroom windows when working night shift.
- Control ambient temperature. Everyone knows a cold shower can wake us up. Control rooms should be kept at a comfortably cool temperature.
- Use background sound. Although some people think radios in operating offices are unprofessional, it has been found they help keep people alert in monotonous situations. They should be kept low, and turned off while switching or in emergencies.

Training

The most significant relationship identified in this study was the link between experience and error-free operation. Training seems a logical way to provide experience more quickly.

Most of us keep theory and “real life” in separate categories. It is important to relate the two. Concepts (theory) improve knowledge based operation, allowing the dispatcher to perform in uncharted waters. It also permits the understanding of the “why” behind a task or policy. It can then be used to judge when a situation doesn't apply.

Performance oriented or task training is the foundation of adult learning. It teaches the skills needed to do the day to day skill and rule based jobs.

With staff reductions in many utilities, job enlargement has been employed to carry out the same tasks with fewer people. Operators are not assigned specific tasks but are given a range of responsibilities. Tasks are done by whoever is available at the time. This concept does increase productivity in a competitive environment. It does also offer the possibility of increased satisfaction to some employees. Training, however, has to be done to ensure people are qualified to do this extra work.

Teach People the Right Way

In switching as in driving, people can be trained improperly or develop bad habits. Driving instructors use a checklist to evaluate a person's "behind the wheel" skills. Likewise, the *Switching Evaluation Form* found in the *Tools* section of this document could be used to evaluate a trainee and as an occasional refresher once he or she is qualified.

Include Switching Safety and Error Training in Operator Qualification

As part of the normal training program (whether formal or on-the-job), safety training should be part of their orientation. History is the best teacher. A PowerPoint® file with graphics and key information from this study is available from the author. It could be easily tailored to any utility.

Training Should be Performance Oriented

The typical operator training program consists of on-the-job training. He or she spends time with other more experienced people to learn the tricks of the trade. This may be supplemented with some type of classroom study and independent reading. Because of the informality of most programs, key information can be missed. A given topic might never come up. In addition, the trainee can become confused. Each operator has his or her strong points and knowledge base. Because of this, the trainee can observe 5 or 6 different ways to do the same task.

As a minimum, the new operator should have a list of tasks to learn. This will ensure that he or she has at least been exposed to key subjects. Ideally, each task should have a short supporting document such as the "training outline" described earlier.

Train on New Equipment, Systems and Methods

The operators' environment is constantly changing. New equipment is installed. Computer systems are updated. New design substations are put in service. Power contracts are expanded and negotiated with new sources. Because the typical dispatcher works rotating shifts, training is difficult. Quite often training consists of a memo and the operator is expected to work it out.

It is recommended that someone (usually an operator) be given the responsibility to condense the information on each new requirement down to a usable format. He or she should then develop a training outline and see that all others receive the "need to know" information. If the expertise lies outside the group (such as when a new piece of substation equipment is installed), the training information for operators should be part of the "startup package".

Include Drills and Simulations in the Training program

Much of the system operators' job is routine. There are, however, times when he or she must respond to emergencies. Some situations are so rare (system separations, localized voltage collapse, catastrophic failure of substation equipment), most operators have never experienced them. Once they happen is not the time to find out the dispatcher has never been trained on the topic or has forgotten what to do.

Drills and simulations provide a way to keep training fresh. They also suggest methods and systems that can be used to prepare for such events. Computer simulators can train operators on power system dynamics. "War gaming" can be used to test procedures and prepare for major storms or other severe events.

Integrate Training with Field Personnel

A common theme mentioned by operators is the need for a strong working relationship with field personnel. Each needs a feel for the other's job. Cooperative training with field personnel on new equipment and procedures can not only provide the needed knowledge, it can also result in improvements over what would be developed by one group alone.

Because it is difficult to get the majority of both groups together, people can attend as available. They should bring the information back and become trainers for their respective groups.

Most utilities have training departments whose job it is to put together technical instruction. These specialists can be used to coordinate this training and also make videos of special events for future use. Probably this group's greatest value would be in planning an integrated training package for operators.

Visit Other Companies

System operators have occasion to visit other operating sites. These stops are usually unstructured. A great deal could be learned if there were definite goals involved. Using switching as an example, the other company's procedures could be observed. Useful information and ideas could be brought home for consideration.

Cooperation among utilities has decreased under deregulation. Safety and reliability are two areas, however, where companies must continue to work together.

Utilities are undergoing a period of increased risk. In the world of deregulation, most effort is placed on new challenges, not fixing current problems. Even though safety is stated time and again to be the top priority of system operations, limited concrete steps are taken to improve safety. Putting out the fires of the day takes the majority of management's time. Meeting new requirements also takes the attention of support personnel.

Resources directed at improving productivity have relatively certain outcomes. Those enhancing safety do not. It is impossible to know exactly what errors would have occurred had no action been taken. Also, decision makers don't always interpret safety data accurately. Just because there have been no reported accidents in the last two months, doesn't necessarily mean that people have been doing a good job. It could be just chance.

Tools

The following pages contain several of the tools mentioned throughout this paper. Most of them would be of value to a company interested in implementing an error reduction program. Questions, comments and requests for additional information can be directed to the author.

Error Reduction Checklist

This section reviews steps a company can take to reduce errors. Since it covers material discussed throughout this paper, it is in summary form. It can be used as a checklist to guide the startup of an error reduction program. The general categories of the plan include:

- Philosophies
- Train
- Collect Information
- Implement Improvements
- Track and Publish Results

Philosophies

- Mistakes will always be made.
- The people doing a job know how to do it better than anyone else. The best solutions will come from them.
- Errors shouldn't be hidden. It is preferable to learn from others' mistakes than solely your own.
- People will share information in a professional, cooperative environment.
- There is a need for discipline in cases of negligence or intentional violation of procedures and safety rules, but discipline administered to "set an example" will cause people to hide information and mistakes.
- Promote professionalism and recognize good performance.
- Management should communicate and demonstrate their interest and involvement in this area.

Plan

Select coordinators from among field and control center operators. They should be motivated and trusted by coworkers.

Prepare materials for data collection and training.

Everyone involved is educated about the program.

Coordinators are trained in the error reduction material and the tools used to administer the program.

Collect Information

Collect error information using the error analysis forms found in the *Tools* section of this paper to get initial data.

Assemble error information.

> Condense error analysis forms into one Cause and Effect Diagram.
>
> Prepare Pareto charts of problem areas
>
> Assemble error analysis forms for distribution as a training resource.

Operators and management review collected information. Obtain other ideas sparked from their review.

Workers report errors and error likely situations.

Talk to and visit neighboring companies.

> Offer to share information.

Identify tools and processes they use.

What are their strategies to prevent the errors you experience?

Train

Train operators on switching safety and error reduction. Note: A PowerPoint™ file of graphics and summary information in this study is available from the author (training time 3-4 hours).

Keep/update a binder of errors as a training resource.

Don't forget to train new people after the program has started. They need it most.

Implement Improvements

Management evaluates recommendations and provides authority and resources for implementing them.

Implement high impact (from Pareto diagram) and easy to do improvements.

Suggestions from your operators.

Suggestions from operators in this study.

Remedial action on new errors and near misses after they occur.

Use the *Error Analysis Form* to study events and document corrective actions.

DO SOMETHING to prevent recurrence.

If training is used as a fix, the job isn't done until training is completed and documented.

Track and Publish Results

Track errors and near misses. Use a control chart or track mean time between errors (see Appendix).

Publish performance in a positive way.

Publish actions taken.

Publish success stories and special contributions.

Switching Evaluation

Operator: **Date:**

Before:

__ Reviewed the job prior to beginning.

__ Asked questions if something was not clear.

During:

__ Did not allow the job to be interrupted unnecessarily.

__ Kept the paperwork up to date:

__recording times.

__tagging devices.

__recording clearances.

__ Followed appropriate procedures and instructions.

__ Did not allow distractions in his/her vicinity.

__ Used standard procedures where available.

Communications with field personnel:

__ Discussed the scope of the job before issuing instructions.

__ Ensured the field operator understood their portion of the job.

__ Encouraged the field operator to ask questions.

__ Stopped miscellaneous conversation before issuing orders.

__ Notified the field operator that it was time to start recording.

__ Spoke slow enough for the field operator to record instructions.

__ Spoke loud enough for the field operator to hear him.

__ Avoided slang.

After:

__Double checked paperwork to ensure it was correct/complete.

__Took action to correct errors in maps, procedures, etc.

Comments:

Operating Lessons Learned

DATE: TIME:

1. DESCRIPTION OF EVENT

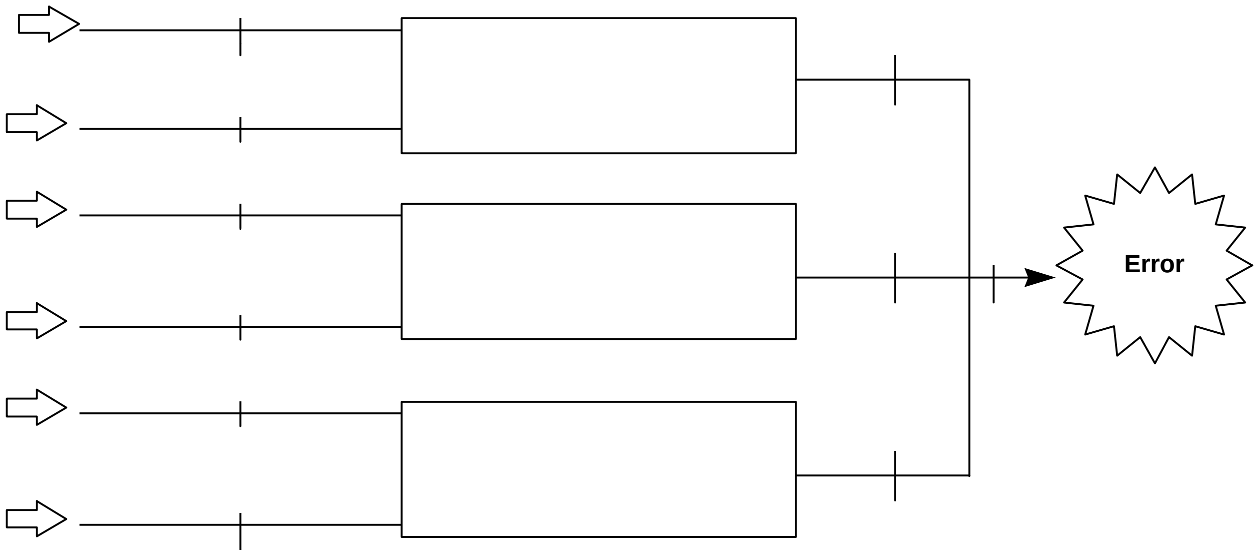
Attach continuation sheets, prints, etc.

2. CAUSE(S)

3. RESULTS

4. STEPS TAKEN TO PREVENT RECURRENCE (check when complete)

Error Analysis Diagram



Possible Fixes

Actions Taken

Training Outline

Title: Restore a tripped **transmission line** (cause unknown)

Date: March 22, 1995

Author: Herman Melville
==

ACTIONS

Note: It is important to get as much information as possible before restoring a line under mild weather conditions. There is no one correct answer for all situations. The operator should consider the following:

1. How critical is the line? (If nothing's in jeopardy, wait.)

2. Contact anyone working near the station or line (safety, information & assistance).

3. If the line is short, start a patrol.

4. If the fault was severe (many fault recorders, calls coming in asking about it), get more information.

5. Get immediately available data (SEL relays, targets at manned stations).

6. Is there history of problems with this line (ask others, look at comments page & line diagram)?

7. Don't overlook calls coming in related to the fault(customers can help pinpoint location)

8. If this is an interconnection, get information from other utility. Don't restore unless they concur.

9. If the line has underground segments, **Do not** try the line until target information is analyzed.

10. Check if there are any special procedures to follow when this line is out of service.

11. Wait as long as possible before trying the line (gives time to get clear).

If you decide to try the line: Make only one attempt (if it holds, proceed to the final steps, below).

If you decide to wait (or if reclose is unsuccessful):
Get people to the stations to get target data.
Start writing your outage procedure and recording pertinent information.
Notify other companies that are affected by this outage.
Start a line patrol once enough information is gathered to point them in the general location.

Final steps:
Obtain target information for system protection personnel.
Notify supervision of any significant events.
Record any significant history for future use.

OTHER REFERENCES:

G:\TRAIN\TRIP_UNK.DOC

Operating Pointers

This section is a recap of the points of value to operators. Most operators do many of these already. In some cases, they may have never thought why. They are good practices that will help prevent errors. Operators that have additional suggestions can forward them to the author.

☛ If there is no separate outage coordinator, the switching procedure should be reviewed by another person. This quality check would help prevent errors due to following an incorrect procedure.

☛ Word process switching procedures and save them. If this is not feasible, make copies of hand written procedures for future reference.

☛ The dispatcher should always slow down, take a deep breath to focus on the task at hand and take a second look before operating any device.

☛ If you operate capacitors and reactors off special CRT displays with only these devices, you will never accidentally open a line by mistake.

☛ Whenever someone calls to request an unscheduled outage, always break communication (tell them you will call them back), take the time to write the procedure and have someone review it. If there is any doubt about taking the equipment out of service, don't.

☛ Just before operating a piece of equipment, take a breath, reread the device label and verify it is the one you want.

☛ When returning to a job that has been interrupted, always back up a few steps and ensure each has been completed before proceeding.

☛ An important, yet overlooked responsibility of operators is to see that even small problems are fixed. Print errors, phone problems, loose switches, burned out bulbs, etc. , can and do lead to future operating mishaps through interruption, misinformation and miscommunication.

☛ Shift partners should pose questions to each other that develop troubleshooting skills and also offer potential action plans should the unexpected occur.

☛ Operators should be in the habit of questioning each other. This shouldn't be considered second-guessing, but an application of "two heads are better than one".

☛ A recent EPRI study on switching safety[58] found that 67% of reported field errors were due to slips. It recommended operators to follow a 6 step procedure to prevent these mishaps. The procedure is applicable to in control centers as well in the field. The procedure can be recalled by remembering "TOEPOT":

1. **Touch** the label of the device to be operated.
2. Check your **orders** to ensure you have the correct device.
3. Is the device in the **expected** position (if not, question the orders).
4. **Perform** the operation.
5. **Observe** the change of status of the equipment.
6. Record the **time** of the operation.

☛ The Federal Emergency Management Agency (FEMA) and individual states' emergency management divisions conduct drills to respond to natural and man-made disasters. They also provide tools and training that organizations can use to run internal drills and exercises. Utilities are welcome and should participate.

☛ Switching procedures should go through an independent review in addition to those done by the shifts that prepare for the outage. Companies that have experienced problems with incorrect procedures should have the reviewers sign or initial the procedure.

☛ A dispatcher should keep a note pad readily available at all times. A one-word note will later remind them to complete a task that can't be done immediately.

☛ Before operating a device, issuing orders, or repeating back actions completed, stop and take a deep breath to collect your thoughts and "drop out of autopilot".

☛ Before issuing switching orders, dispatchers should conduct a "tailgate session" to let field personnel know the goal of the orders. The field crews have valuable experience and can see things the dispatcher can't. Everyone knowing the goal increases the chance of getting there without a mishap.

☛ Avoid "detail" work between 3a.m. to 5 a.m. Do it earlier in the shift.

☛ Slips appear most likely at the start and end of each workday and workweek. Be particularly careful during these times.

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[58] Beare, A., Taylor, J. *Field Operation Power Switching Safety*, WO2944-10, Electric Power Research Institute.

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QUOTES

"Those who cannot remember the past are doomed to repeat it". George Santayana

"When you build a new house, you should put a short wall around your roof. Then no one will fall from it and bring the guilt of blood upon your house". Deuteronomy 22:8

"It is a profoundly erroneous truism...that we should cultivate the habit of thinking what we are doing. The precise opposite is the case. Civilization advances by extending the number of important operations which we can perform without thinking about them." A.N. Whitehead

"Don't try to change people's attitudes. Just help them with their problems." Trevor Kletz

"Don't take square-peg humans and try to hammer them into round holes.. Reshape the holes as squares." P. Foley

"It is much simpler to find a few good designers and inspectors than to staff, with assurance, potentially thousands of plants with skilled operators." C. W. Forsberg

"When safe behavior causes trouble, a change occurs in the unsafe direction." K. Hakkinen

"There is almost no human action or decision that cannot be made to look flawed and less sensible in the misleading light of hindsight." Report on the Clapham Junction railway accident

"Today, a worker injury is recognized to be a management failure." P.L. Thibaut Brian

"*No one who accomplished things could expect to avoid mistakes. Only those who did nothing made no mistakes.”* Harry S. Truman

“I prefer to profit by others’ mistakes and avoid the price of my own.” Otto von Bismarck

“There is a universal failure [in this command] to repeat oral orders back. This failure is certain to result in grave errors” GEN George S. Patton

“The central problem of leadership…is a failure to understand the information in variation. Leadership that takes aim at people that are below average in production, or above average in mistakes, is wrong, ineffective and costly to the company.” W. Edwards Demming

GLOSSARY

Accident: An unintended event with sad consequences.

Active error: A mishap with an immediate impact. They are usually committed by operating personnel.

Correlation: A statistical test that measures the relationship between two variables. The strength of the relationship is measured by the "coefficient of correlation" that varies from ± 1. The closer to 1, the stronger the relationship. A positive coefficient implies a direct link while a negative value suggests an inverse relationship.

Error: human action or omission not intended by the actor; not desired by a set of rules or an external observer, or that let the task or system outside its acceptable limits.

Expert System: A computer system that captures knowledge of experienced individuals in a user-friendly environment. This allows newer personnel to perform at higher skill levels.

Lapse: An omission from an original plan that causes undesirable results.

Latent error: An error with delayed consequences. They occur after something is done that sets a trap that waits for the right conditions to combine to cause a failure. Latent errors often are the most costly and are typically associated with disasters. Most of them are made by non-operators (designers, maintenance personnel, construction crews, managers, etc.).

Mistake: A planning failure where actions are taken as intended but the plan is flawed.

Operating Error: an action (or significant omission) by a dispatcher that results in equipment damage, a loss of customer load or improper protective zone for field work.

Protective Zone: A portion of the power system made "safe" for a particular job. This is normally done by deenergizing the appropriate devices, installing locks and protective tags to prevent reenergizing the work and also by the attachment of grounding devices at each point of possible energization.

Regression: A statistical process that "fits" data to the equation $Y = a + bx$, where Y is the value you are trying to predict, x is a factor that influences Y, a is the y intercept of the graph and b is the slope of the line.

R-Square (Coefficient of Determination): The square of the coefficient of correlation. It is the proportion of the total variation in one variable that is explained by the other variable. A value of 1 implies 100% correlation.

Sabotage: An intention act with the expressed purpose of causing damage.

SCADA: An acronym standing for System Control and Data Acquisition. It is the computer network that receives data from and monitors the power system. It allows both automatic and operator control of system devices.

Slip: An error of action, such as operating the wrong device.

Standard Deviation(s): A measure of the dispersion in a set of data. 68%, 95%, and 99.7% of a population will fall respectively within 1, 2 and 3 standard deviations of the average.

Testing: The job of maintaining and calibrating protective devices and instrumentation used on a power system.

Violation: An intentional act that deviates from accepted rules.

APPENDIX 1 - A METHOD TO TRACK OPERATING ERRORS

Introduction

While conducting this study, there were no cases found of utilities methodically tracking their operating errors. This may be partly due to the sensitive nature of the subject. Another possibility is that errors occur infrequently and at a random rate. For example, it is difficult to tell if the three mistakes that occurred this month are just a fluke or whether there is a trend taking place.

An answer to this problem comes from the field of quality control. A tracking method called the "p chart" can be used. P is the quality control term for fraction defective. It uses the binomial probability distribution to identify situations that are statistically unlikely which implies there has to be an assignable cause.

P-Chart Concepts

The idea behind the p chart is to use historical data to establish an average or "mean" error rate. Ideally this should be about 2 years of information. It can be started with less, but caution needs to be used in interpreting the results.

A measure of workload is needed for the calculation. The # of switching jobs, man-hours, days, etc., all give a measure of the amount of work being done. The easiest measure of workload is days.

A mean error rate is first calculated. To keep things simple, the rate should be computed in errors per day. This value P_{Bar}, called “p-bar”, is found by: P_{Bar}, = (total # of errors) ÷ (total # of days). The days are from the point where data collection was started. Since errors happen infrequently, a good way to keep track of them is by month. For simplicity, assume all months have 30 days.

Once the mean error rate is found, upper and lower bounds for each month are calculated. These are identified as the upper control limit (UCL) and lower control limit (LCL). These limits are at $\pm 3\ \sigma$ (standard deviations) from the mean. In simple terms, 99.7% of all months should have error rates within these limits. The calculations for the control limits are:

The formulas for calculating the control limits can be found in most quality control texts. The limits are calculated automatically by software programs that have Statistical Process Control Chart features. A PC based program supplied with this study will do this also.

Anything outside these limits is so rare that there has to be an assignable cause. If beyond the upper limit (UCL) the problem should be identified and corrected. If a month is at or below the LCL, the reason should be found and continued to reduce error rate.

One thing should be mentioned about the control limits. Although it is possible to mathematically derive a negative Lower Control Limit, zero is the lowest value that can be used. You cannot have less than zero errors in a month.

Using the P-Chart

The following is a summary of key points related to the use of p charts. Companies thinking about applying this concept should consult quality control references for more detailed information.

- If you go above the UCL, the cause should be identified and corrected. If at or below the LCL, the reason should be found and continued.
- Trend information also is flagged by the p chart. "Long" runs on one side of the mean are also rare events. They also help pinpoint assignable causes. For example, runs of 7 in a row or 10 of 11 on one side of the mean imply that something has changed. Again, if the run is above the mean, the problem should be found and corrected. Stretches below the average indicate operating improvement. The reasons should be continued to establish a new lower average error rate.
- The chart can be used to predict the range of possible errors that can occur in a future month.

Manufacturing companies often find an improvement just by implementing quality control charts. There are probably several reasons for this. First, it lets people know what management feels is important. This causes them to focus more attention to the particular task. Also, it gets people thinking about ways to improve their performance.

Steps in Starting a P-Chart Tracking System

1. Establish a definition of an operating error.
2. Use a population where you have control. For example, if you are concerned solely with operating errors, you should not include mistakes made by personnel doing maintenance, testing relays, construction, etc. This is because the data from the other areas will mask or skew the data from the group of interest. Also, the actions taken to reduce operating errors won't influence other areas.
3. Get error data. Calculations should ideally be on 2 years' history. It can be started with less, but use caution interpreting the results.
4. Enter the data in the program. If you decide to do the charts manually, refer to quality control references.
5. If there are any points outside the control limits, try to determine the cause. If it can be found, that month's data should be thrown out and step 4 repeated. This is because you want to establish an average that you know is representative of your operation.
6. Continue the chart over time.
7. If error reduction efforts are made or if there are changes are made to the operating process, document when they occurred. This can help explain future shifts in the chart.
8. Identify rare occurrences (at or beyond the control limits and the long runs stated earlier). Find their cause.
9. Continue making improvements to your operations and monitor the results.

Computer tracking program

The manual derivation of the p chart can be confusing to people without a quality control background. To simplify the process, a program has been developed by Dan Herrman, a Wisconsin Electric system operator. It produces a p chart and maintains a database on the errors.

The primary potential value of this program is that of a file manager. It will allow a company to develop a data base of their operating history. Errors are categorized along the same lines as this study. There is also room to keep remarks. Files can also be merged. This will allow tracking of separate groups (operating, maintenance, testing, etc.). They can also be combined to get a total company picture.

This program was written with the idea of building of a utility data base of recent operating history. Cooperating companies can share information and hopefully learn in the process. Those companies that are interested in sharing data should contact this paper's author.

P-Chart Alternative

The p-chart is a valuable tool for larger companies that experience multiple errors per month. It may not be appropriate for small companies or individual operating offices. The p-chart becomes ineffective to monitor progress when the defect rate is very low. This is because it can't discriminate when changes in the defect (error) rate are small. An alternative is to fix the number of defectives (errors) and measure the number of units (days, for example, in power system operations) required to produce them. This, in effect, becomes Mean Days between Errors.

APPENDIX 2- OPERATOR SUGGESTIONS

Introduction

The surveyed operators in this study offered improvement suggestions for each of the error categories in the survey. The number of people that offered a particular suggestion is shown in ( ). This number has some value, but single responses shouldn't be discounted. They may offer a unique perspective. This information offers ideas on error prevented.

Workload

1. Slow down, think the job through. Ask anytime there is a question. The job you are doing now deserves your total attention. (15)
2. Know your limit. Request help if you need it. (14)
3. Whenever possible, finish one job completely (including paperwork) before moving on to the next. Safety first, length of job second. Notify others that you are in the middle of a job and they'll have to wait or you'll get back to them. (13)
4. Control the number of jobs or assign more personnel. Take steps to reduce the variation in the day to day and hour to hour workload (day to day "leveler", crews working flexible hours, etc.). (11)
5. Have extra help for switching at key times. (11)
6. Work that is not real-time (to include writing future outage procedures) shouldn't be done by the dispatcher while there is a switching workload. (8)
7. Practice prioritization of work. Realize that sometimes not all tasks can be done. Supervisors need to support this. Be process oriented, not task oriented. (8)
8. Switching organized and completed according to the time actually needed. Crews should not pad the time in order to be sure to have the job ready when they show up. (3)
9. More staff during storms. (2)
10. Always follow your clearance procedure exactly. (2)
11. Double check all paperwork before making changes to clearances. (1)

12. Computer and other support system alarms routed to appropriate people (not the operator) on day shift. (1)
13. Look at methods to reduce the workload (automate time consuming tasks, eliminate busywork, don't duplicate things that are done by others within the company). (1)
14. Reduce the amount of manual logging. Rely on computers or use voice actuated tape recorders. (1)
15. Schedule work realistically. (1)
16. Some type of "time out" button that can route non essential calls to voice mail to allow the operator an opportunity to catch up. (1)

Slips (Operating the Wrong Device)

Operators responding to the survey reported slips as the second leading cause for their errors (15%). Their suggestions for preventing them follow.

1. Just before taking that last step, ask yourself "Is this the device I want to operate" then double check. (17)
2. Slow down and pay attention, don't do anything else while switching. (16)
3. SCADA enhancements such as reprogramming of a switching procedure which will alert the operator if the step (s)he is about to make deviates from what is planned. Add technology that could also "speak" short messages to the operator when they are performing SCADA operations. (4)
4. If you have a partner, take advantage of it and ask questions (two heads are better than one). (3)
5. If something goes wrong, don't compound a mistake by panicking and overreacting. (3)
6. Before operating any device, anticipate the effect on the system. (2)
7. More training and familiarity with the system. (2)
8. Reduce distractions. (2)
9. Standardization of substation design and operation. (2)
10. Employ human factors, improve the fit between the operators and the equipment they use. (1)
11. Make the map board and SCADA system similar. (1)
12. Stop and review the work ANYTIME there is a doubt. (1)
13. Avoid fatigue. (1)
14. Adequate lighting can help you stay alert. (1)

15. If a "confirmation" key is not provided on the SCADA system for supervisory operations, install one. (1)
16. Unique identifiers for field equipment, to include voltage, not just device numbers. (1)
17. Switch from substation displays rather than area displays. (1)
18. Consider a 3 step SCADA sequence (select, open, operate). (1)

Communications Problems

Communication problems were responsible for 18% of the errors that the surveyed operators experienced. This was the leading cause reported. Two companies in particular seem to have this as a problem. These are the operators' recommendations.

1. Talk the job through before issuing orders, ensure the person understands the work and what has to be done. This should include other work that might be conflicting. Stop if there is any doubt. Assume the lead in ensuring understanding, ask questions. (18)
2. Improve radios and phones. Take steps to eliminate interference and dead spots. People using the communications equipment should have input on its selection and improvement. Include training on the systems' capabilities. (11)
3. All parties always repeat instructions, both delivering and receiving. (5)
4. Take the extra time needed to think through what you plan to do and say. Don't rush. Concentrate. Learn to avoid assumptions. (5)
5. Ensure proper procedures are used by both dispatchers and field personnel. Give communications training and conduct routine audits. This also applies to written instructions. (4)
6. Increase and standardize information given at shift change. More time should be allowed. A list of system changes and tags should be kept in addition to the normal log. (4)
7. Dispatcher meetings should be scheduled monthly. Meeting time devoted to discussing operating "gotchas". Operators need to be included in plans that will affect them. (3)
8. Give direct access to people switching and doing work. Information needs to be provided in a timely manner. Use new technologies as they develop. (3)

9. Use standard operating instructions to simplify communications. Training should be conducted on these procedures. (3)
10. A dedicated phone line and radio channel used for switching and clearances. Special lines to critical locations. (3)
11. Telephone and radio traffic have greatly increased. Find a simple way to monitor the volume and find ways to reduce it. Too many people calling for information that is available elsewhere. (3)
12. If training is needed in proper communications (both for operators and field personnel), provide it. There should be training provided on effective listening. (3)
13. Don't use slang. (2)
14. There should be more communications between operators and supervisors and also between the operating group and other departments. (2)
15. More equipment should be controlled by SCADA to reduce the probability of mistakes caused by the additional communication link. (2)
16. More dispatcher discussion about work. Keep your partners informed, even if the information might seem unimportant. (2)
17. Develop standard abbreviations and terminology. (2)
18. Sound dampening material / noise control in the operating area. Remove distractions. (2)
19. Operators must be aware of their pace when giving instructions. The receiver should give regular queues that they are on track (such as saying "OK" when they have caught up). (2)
20. Be professional. (2)
21. Answering machines and voice mail being abused by support personnel. It is becoming more difficult to get answers or real-time problems fixed. Corrective measures are needed in these cases. (1)
22. If there is more than one operating area within a company. A means is needed to know "who is where" in the field. (1)
23. If both telephone and radio are available for a job, use the phone. (1)
24. Shift partners need to get along to ensure the needed information is exchanged. (1)
25. Field switchmen should call the operator before going on the road at the start of the day. (1)

26. Build rapport with field personnel. Solicit their input to ensure what the operator perceived to be going on in the field is actually what is happening. (1)
27. The shift doing the work should have final approval of the job. (1)
28. Take care of as many "loose ends" as possible before turning the shift over. (1)

Automatic Devices Operating Unexpectedly (Traps)

This area caused 6% of the errors reported in the survey.

1. Specific, objective training for new dispatchers with refresher training through your career. This should include relays and zones of protection along with "case histories" of events that happen infrequently. Other groups affected by these rare events should receive similar training. Training should also include new and changed equipment in the field. One recommendation was to have an "obscure device of the month" to train people on things they rarely encounter, yet have a major effect on their operations if overlooked. (20)
2. Review station description of operating devices. And other related information before starting the work. Think of what could happen beforehand. Talk with other operators. (12)
3. If an improper automatic operation occurs, be sure not only to correct this particular situation, but also check out similar devices for the same trap. (4)
4. Word processes instructions and other job aids to take advantage of others' knowledge. (4)
5. Special symbols or SCADA queues on devices that initiate an automatic action. (4)
6. Operator input on changes to remove traps. (2)
7. Involve relay engineers whenever there is a question. (2)
8. Standardize operating as much as possible-between positions and in the field. (1)
9. Identify and document problems before they occur. (1)
10. Positive indication of status needed for all devices operated via SCADA. (1)
11. When restoring equipment following a lockout or automatic operation, put station equipment on manual before proceeding. (1)
12. Stop, analyze and proceed. (1)

Procedure and Map Errors

This area also caused 9% of all the errors in the survey. The operator recommendations follow.

1. Correct instructions and maps on a timely basis. If there's a constant backlog, find out why (insufficient personnel, outdated methods, etc.) The people that correct the maps should be readily accessible to the operators. (18)
2. Quality control checks that maps and procedures are updated as changes occur. Have someone in charge of putting together a procedure and overseeing its implementation. (8)
3. Training in new equipment or system configuration changes prior to installation. Maps and procedures verified as part of the start-up package. These should be review/prepared by a task force made up of operating, maintenance and engineering personnel. (4)
4. Include a knowledge of procedures (a standardized comprehensive coverage) in the operators' training program. Review of these tools during quiet times can identify mistakes and problems. Training should be part of regular meetings. (3)
5. Procedures should not be changed to reduce overtime expenses or to accommodate a contractor or crew. If there is a problem with a job, the crew should bring it up. However, it shouldn't be changed just to make the job "easier". (2)
6. Less congested prints. (3)
7. Keep procedures simple. Look at ways to improve them. (2)
8. Involve the system protection engineer when there's a question in their area of expertise. (1)
9. Training to include inter-company procedures. (1)
10. Double check your SCADA information on deenergizing and restoring equipment. Verify the readings are as you would expect. (1)
11. Time and personnel allocated for field verification of prints. (1)
12. Flag unusual conditions on maps. Include purpose with instructions and procedures. (1)
13. The operator should have input on changes if a better way is found to do a job. (1)
14. Standardize terminology and labels on operating equipment. (1)

The Switching Procedure was Written Incorrectly

Incorrect procedures caused 9% of the reported errors. The operators suggest the following to prevent these problems.

1. Have all procedures checked by a third person who initials to show it was thoroughly checked it over. (29)
2. Double check the procedure. Ensure you understand and agree with each step. Don't assume it was written correctly. (16)
3. Practice prioritization of work. Realize that sometimes not all tasks can be done. Supervisors need to support this. Be process oriented, not task oriented. Informally track the number of corrections found. Implement people's suggestions and see if the trend is down. (8)
4. Double check all paperwork for completeness and clarity before turning your shift over. Take the necessary time on starting a shift to review all work in progress and scheduled. (4)
5. Written procedures should be word processed and saved for future use. Special information can then be saved, building a knowledge base. This would save write-up time needed for checking accuracy. They still need to be double checked. (4)
6. Written procedures should follow the correct switching sequence. Give field personnel prepared instructions to reduce workload (automate time consuming tasks, eliminate busywork, don't duplicate things that are done by others within the company). (2)
7. More than a day's lead time is needed to prepare for a job. (2)
8. Procedures should be written by someone that won't be interrupted while doing the task. Therefore it should not be the real time operator. (2)
9. Reduce the amount of manual logging. Rely on computers or consider voice actuated tape recorders. (1)
10. If a problem is found during switching, the job should come to a halt until it is corrected. (1)
11. Follow established procedures when making revisions to instructions. (1)
12. Review the job with field personnel beforehand (tailgate session). (1)

Unscheduled Jobs

Switching equipment out that had not been requested through normal procedures was contributed to 8% of the errors operators reported. In these cases, the operator doing the switching is usually the one writing the procedure (assuming a procedure is written). An oversight, error in the write-up or the haste in "getting the job done" along with other responsibilities cause mistakes to happen. Companies that had problems with this also had trouble with workload and automatic devices. These all signal insufficient planning. Recommendations to prevent these problems are noted below.

1. Once you've decided to do an unscheduled job, back off & look it over again before proceeding. Have someone else also review it. Slow down and ask questions. (27)
2. Getting into a habit of accommodating field personnel on short notice requests will lead to trouble. Find out who are the offenders that don't plan their work. Stick to a procedure requiring advance notice (24-48 hours depending on the company) if your judgment says it's best. Supervision should back this up. (27)
3. If someone calls with a legitimate request, physically break the communication (hang up and call them back when ready). This will give you the necessary time to prepare. (5)
4. Ensure you have complete information from those requesting the work. Use all your resources (maps, instructions, SCADA, station notes, field personnel, etc.) before proceeding. (4)
5. If extra operators are available, have them work on the unscheduled job. (3)
6. Educate field personnel in the risks surrounding this, especially when they pressure the operator by being impatient. Taking time ensures their safety. Even if the job is unscheduled, you should be given enough lead time to properly prepare for it. (3)
7. Training is what will keep you out of trouble in an emergency where there is limited time to prepare to take equipment out of service. (3)
8. Except in emergencies, unscheduled work should always take a lower priority to pre-planned work. (3)
9. A "mental alarm" should sound anytime unscheduled work is requested, alerting you to stop & take the time necessary to prepare for the job. (2)
10. Create an "Unscheduled Job" form that reminds the operator of the risks involved and a checklist of the steps to take to limit the risk. It should be used to document why this situation occurred. It should be kept on file to see if there are abusers of the system. (2)

11. If an emergency arises that requires immediate action, only do the switching required to render the situation "safe". Then back off and take the needed time for completing the job. (1)
12. Supervisors should avoid pressuring to rush jobs. (1)
13. Staying current with system conditions should minimize the impact of doing an unscheduled job. (1)

Distractions

This area accounted for 14% of all errors. Dispatchers recommend the following preventive measures.

1. Too many people in the operating area. Coworkers, support personnel (and supervisors) need to remember to stay away while the dispatcher is switching. Security in the area should be enforced. (51)
2. Restrict traffic flow in the operating area. Post "quiet zone" signs. (9)
3. Reduce the number of phone calls. Inform people of the proper place to call in the future. Supervisors should use voice mail rather than automatically forwarding their calls to the operator. (7)
4. Don't jump in to help the operator unless he or she asks or unless you're sure help is needed. This causes confusion. If you do help, make sure both of you know what each other is doing. (4)
5. Eliminate duties that are not real-time while there's a switching workload. If clerical help is needed to do these tasks, get it. (4)
6. Eliminate nuisance alarms. Prevent low priority momentary alarms from coming in unless they are up for more than one scan. (4)
7. Lower the noise (decibel) level of all equipment (phones, alarms, printers, etc.). (4)
8. It is not always apparent that a dispatcher is switching. Devise a "busy light" that comes on whenever the operator is interactive with the SCADA system or when he or she is on a "dedicated" communication channel (phone or radio). (2)
9. Relief dispatchers should be located where they can handle "walk-in" problems and non real-time duties. (1)
10. Faster, more reliable computer system. (1)
11. Consider restricted zone lines or reconfigure operating console to control access. (1)
12. Decrease tension in the work area. Fix problems, not blame. (1)

13. Focus on the task at hand, particularly when on the phone or radio Stop and think about what you are doing. Block out unrelated activities. If distractions arise, stop and take action to stop them. (7)
14. Give the "busy-work" responsibilities to the operator and shift that does the least switching. (1)
15. Supervisors should listen to their people's concerns. They are his/her distractions. (1)
16. If your shift change occurs during periods of high activity, consider changing it. (1)
17. Dispatchers should not be taking customer calls during times when they are switching. (1)
18. If the job is interrupted, back up a few steps to be sure you haven't skipped something. (1)

Other

Remaining reasons caused 8% of the operators' errors. Recommendations to prevent these problems in the future:

1. An ongoing training program should be developed and used. This should include simulations, substation equipment training, and documented hands-on tasks for the job. (5)
2. Improve station instructions. Ensure they note anything nonstandard (relaying, jurisdiction, etc.). (2)
3. If operating performance indicators are tracked and posted in the operating area, the information should be displayed in a positive light. (2)
4. EMS logic to alert the operator when a procedure is about to be violated. (1)
5. Install a programmable SCADA "alarm clock" that can queue the operator that it is time to accomplish a particular task. (1)
6. Thoroughly review the work beforehand. Ask questions when in doubt. (1)
7. Plan ahead. (1)
8. Allow the field operators to think. Let them know you appreciate their questions. Reinforce the concept that they are your eyes and ears in the field. (1)
9. Incentives and job enlargement (during quiet periods) could improve motivation and improve the operations of the workgroup. (1)
10. Don't put an operator in a switching position on their first day back from a several day absence. (1)

11. If there was a major change in the work schedule (8 hours to 12 hours, 7 days in a row to something less, a change in rotation, etc.) an evaluation should be made after a trial period to see if things have improved. (1)
12. Have more flexibility in scheduling (more people during heavier work periods). (1)
13. Reapportion the workload between operating desks if the work is unbalanced. (1)
14. Simplify access to contingency information. (1)
15. Scheduled switchmen should be on time. People requesting outages should not "pad" the time to be sure equipment is out when they show up. (1)
16. If you're ill or fatigued, you should not be switching. (1)
17. Generator disconnect status should be monitored on the SCADA system. (1)
18. Review hiring procedures. Be sure you are getting people with the proper background. (1)
19. A more participative work environment. (1)
20. Be sure to put all pertinent information (special procedures, cautions, etc.) on switching procedures. (1)