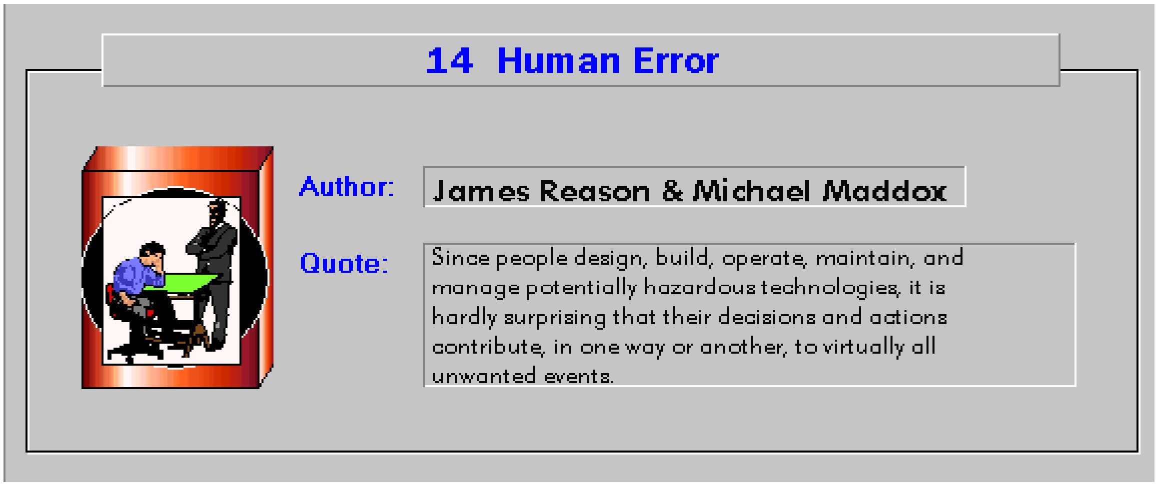
Chapter 14
HUMAN ERROR



14 Human Error

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Quote: Since people design, build, operate, maintain, and manage potentially hazardous technologies, it is hardly surprising that their decisions and actions contribute, in one way or another, to virtually all unwanted events.

INTRODUCTION

Human error figures prominently in most of the well-known calamities in the world, such as Bhopal, the Exxon Valdez, and Chernobyl.[1] In common with most other complex technical activities, human error is implicated in the majority of aviation-maintenance-related quality lapses, incidents, and accidents.[2] General estimates of this human error contribution have increased over the years, from a low of around 20% in the 1960s to values in excess of 80% in the 1990s.[3] **Figure 14-1** shows this general trend.[4]

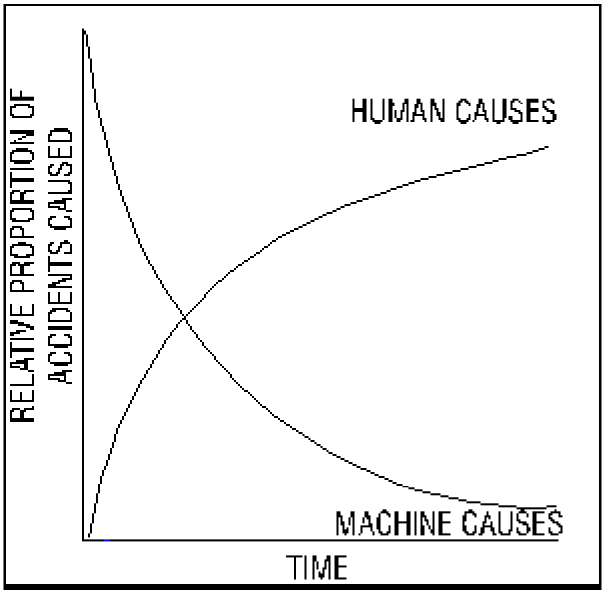


Figure 14-1. *Trends in accident causation*

Does this mean that people have become more careless, forgetful, inattentive and reckless over this period? Not really, but it does reflect two important and widespread trends.

1. Aircraft components, along with most other items of equipment, have become both more sophisticated and more reliable over the past three decades.
2. There is a growing appreciation that designers, manufacturers, corporate decision makers, and maintenance managers can make mistakes which, in turn, create the conditions promoting errors on the hangar floor.

The combination of these two trends has resulted in fewer and fewer component-related failures along with more reports of human errors.

We have become aware, therefore, that those at the sharp end are more often the inheritors rather than the sole instigators of faulty maintenance practices. Since people design, build, operate, maintain, and manage potentially hazardous technologies, it is hardly surprising that their decisions and actions contribute, in one way or another, to virtually all unwanted events.

This chapter outlines the varieties of human error and some of the ways in which they can be managed. Although it is customary to lump these different failings under the catch-all heading of "human error," the distinctions between them are important because different error types have different underlying mechanisms, occur in different parts of the aircraft maintenance system, and require different methods of management. The key to all error management is to target limited resources on those things most amenable to correction and improvement. In short, it means managing the manageable.[5]

BACKGROUND

It has been evident for most of recorded history that people are prone to commit errors ("To err is human..."). Various researchers and our own common experience indicate that we all commit many errors each day.[6] Most of the errors we commit are minor and have few, if any, consequences. Given this wealth of experience with errors, it might seem obvious that we know a lot about which types of errors we commit and why we commit them. However, it has been only within the past 50 years or so that we have come to study, classify, and understand the mechanisms underlying various types of errors.

Human errors were recognized as a major hazard to safe flight operations at least as early as World War II.[7] Most of the efforts of the aviation research community have focused on operational errors committed by flight crews and air traffic controllers.[8] This is entirely appropriate, since the majority of serious aviation accidents are the result of operational errors. However, as anyone working in aviation maintenance knows, there have been a number of serious, even fatal, accidents over the years that were caused primarily by maintenance errors. Public and regulatory sensitivity to the role of maintenance errors increased dramatically after the Aloha Airlines B-737 accident in 1988.[9]

General Model of Human Error

To understand how errors are committed, we first need to look at a fundamental model of human performance. While there are many such models, a simplified view of human information processing will serve our needs.[10] **Figure 14-2** is a block diagram showing the three general processes an **AMT** (or anyone else) goes through to perform an action. In general, these processes are sensing and perceiving information, processing that information and making a decision about which action(s) to take, and then taking some action.

Errors can originate in any of the three processes depicted in **Figure 14-2**. The underlying causes of errors and methods for effectively reducing errors differs, depending on where they occur in the information processing model. For example, errors in sensing and perceiving information might be caused by inadequate design of workspace lighting, too much noise, poor-quality printed materials, etc. Errors in decision making might be due to such factors as fatigue, lack of training, and time stress. Errors in completing an action could be caused by poor tool or equipment design, lack of adequate procedures, distractions, and cold or hot workplace temperatures.

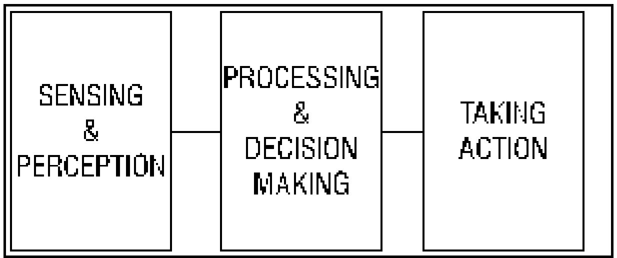


Figure 14-2. *General Human Performance Model*

Types of Errors

Errors have been categorized in many ways. Human error researchers meeting in the early 1980's recognized at least 3 ways that errors might be generally categorized.[11] The first categorization scheme (or taxonomy) is phenomenological, that is, describing at least superficially what happened. An example of this type of classification is to group together all errors in which **AMT**s missed a component during reassembly. The second scheme lumps together errors according to the underlying cognitive mechanism that caused it. For instance, we could list all perception errors together. A third taxonomy classifies errors according to human biases or tendencies. An example here might be to associate all errors caused by the human tendency to exclude evidence that doesn't support an early hypothesis.

Traditionally, quality lapses, unsafe acts and less than adequate (LTA) maintenance performance are sorted according to their adverse impact upon the aircraft. These error types fall into two general classes:

- The introduction of an aircraft discrepancy that was not there before the maintenance activity began.
- The failure to detect damage or incorrect components during maintenance inspections.

Such errors may be further broken down into specific categories, as was done, for example, in a Pratt and Whitney study of the causes of 120 inflight engine shut downs (IFSDs) on Boeing 747s in 1991.[12] These discrepancies were then ranked according to their frequency of occurrence, as shown below.

- Missing parts
- Incorrect parts
- Incorrect installation of parts
- Use of worn or deteriorated parts
- Careless installation of O-rings
- B-nuts not safety wired
- Nuts tightened but not torqued
- B-nuts over-torqued
- Seals over-torqued
- Not loosening both ends of connecting tube during replacement
- Replacing tube assembly without first breaking connections between matching parts
- Loose or missing oil-tank caps
- Dirty or loose cannon plugs
- Foreign objects dropped into engines

- Water in fuel
- Skydrol in oil system

Analysis of 122 quality lapses detected by a major airline over a period of three years revealed very similar discrepancy types.[13]

- Omissions (56%)
- Incorrect installations (30%)
- Wrong parts (8%)
- Other (6%)

When omissions, the largest single category, were examined further the following categories of error were identified.

- Fastenings left undone or incomplete (22%)
- Items left locked or pins not removed (13%)
- Filter/breather caps loose or missing (11%)
- Items left loose or disconnected (10%)
- Spaces, washers, etc., missing (10%)
- Tools, spare fastening, etc., not removed (10%)
- Lack of lubrication (7%)
- Panels left off (3%)
- Miscellaneous (11%)

Although these consequential analyses tell us little about why the individuals made these particular errors, they reveal a great deal about the relative error-proneness of the different phases of the aircraft maintenance task. In particular, they show that **LTA** performance is much more likely to occur during reassembly than during disassembly. The reasons for this will be discussed later in the chapter.

Locus of Errors

Three distinctions have proved useful in identifying the various origins of **LTA** performance. As we noted earlier, such distinctions are important because different types of human failure have different psychological origins, occur in different parts of the system, and require different methods of remediation.

If it is accepted that error may be defined as *the failure of planned actions to achieve their desired goal*, then there are two ways in which this failure can occur.[14]

Slips

First, the plan of action may be perfectly adequate, but the actions do not go as planned. That is, we planned to do the right thing, but something happened that prevented us from doing it properly. Some necessary act(s) may be omitted or an unwanted act(s) may intrude. Alternatively, the right actions can be carried out, but in the wrong order, or in relation to the wrong objects, or poorly timed, or clumsily executed. These are execution failures and are commonly termed **slips, lapses, trips,** or **fumbles**.

The problem may occur at one or more of the three processes in the general model shown in **Figure 14-2**. Slips and lapses occur during the execution of routine, well-practiced tasks in familiar surroundings in which the individual actions are controlled in a largely automatic fashion. In other words, these execution failures typically occur at the skill- or rule-based level of performance.

Skill-based slips. The skill-based (SB) level of performance is related to actions that have been done many times, typically on a daily basis over a period of many years. Skill-based performance is usually related to manual manipulation. Typing is a good example of skill-based behavior. A common skill-based mistake is to type an incorrect letter. This is called "fat-fingering" in the computer community.

Rule-based slips. The rule-based (RB) level of performance is characterized by tasks for which training, experience or procedures have provided ready-made solutions or "rules." Rule-based slips are typically the result of failing to properly follow the rules that have been established. To qualify as a slip, the **AMT** must have chosen the correct rule, but simply failed to follow it -- by omitting a step, for example.

Mistakes

The second potential locus of error is in the planning itself. The actions may go entirely as planned, but the plan itself is not adequate to achieve its intended outcome. These are higher-level failures, termed **mistakes**, associated with the formulation of the plan. Mistakes can be further sub-divided into two classes, according to the level of performance at which they occur.

Rule-based mistakes. RB mistakes involve failures in the selection or application of these problem-solving rules. Such rule-related errors can involve either the application of a bad rule, or the misapplication of a normally good rule that local circumstances have rendered inappropriate. That is, the **AMT** is properly following a rule, but the rule itself is either incorrect or wrong for the task.

Knowledge-based mistakes. The knowledge-based (KB) level of performance is characterized by the need to solve novel problems for which the individual possesses no pre-packaged "rules," and is thus required to work out a solution from first principles. Such on-line reasoning is highly error-prone. Indeed, trial-and-error learning is one of the principle ways of dealing with such situations. KB mistakes can occur in many different ways.

Violations

We have noted previously that errors are, by definition, unintentional. However, another class of events that can result in similar consequences is violations. Violations are deviations from safe operating procedures, recommended practices, rules or standards. Although they can be committed unintentionally (e.g., driving in excess of the speed limit without being aware either of the current speed or the local restriction), most violations are deliberate. People generally intend the non-compliant acts, but not the bad consequences that occasionally ensue. Only saboteurs intend both the act and its adverse consequences.

While it is not possible to make hard and fast distinctions between errors and violations (since some violations can be mistakes), the important differences between these two kinds of potentially unsafe act are summarized in **Table 14-1**. Three main kinds of violations have been identified.[15]

Table 14-1. Summarizing the main differences between errors and violations.

Error	Violations
• Unintended.	• Usually deliberate.
• Arise mainly from informational problems; incorrect or incomplete knowledge, either in the head or in the workplace.	• Arise mainly from motivational factors and are shaped by beliefs, attitudes, social norms and organizational culture.
• The likelihood of errors can be reduced by improving the relevant information.	• Violations can only be reduced by changing beliefs, attitudes, social norms and organizations cultures that tacitly condone (or even encourage) violations in order to get the job done.
• Over the normal span of working life, error proneness is largely independent of demographic factors such as age and gender.	• The tendency to violate is clearly related to age and gender. Young men violate, old women generally do not.

Routine violations

These usually involve cutting corners in order to take the path of least effort between two task-related points. They occur mainly at the skill-based level of performance and, eventually, can become part of a person's repertoire of largely automatic actions. Routine violations are promoted by a relatively indifferent environment. That is, one that rarely rewards compliance or sanctions non-compliance. An example of a routine violation is pushing all work card sign-offs to the end of the task even though regulations require sign-off after each activity.

Human actions serve a variety of personal goals and not all of them are strictly task-related. For example, a driver's functional goal may be to get from A to B, but in the process he or she can (either knowingly or unwittingly) optimize the "joy of speed" or indulge aggressive instincts. Similarly, long-haul pilots and nuclear power plant operators sometimes deviate from procedures in order to alleviate tedium. The tendency to violate "for kicks" can become part of a person's performance style. It is also characteristic of certain demographic groups, particularly young males.

Necessary (or situational) violations

Safe operating procedures are continuously being amended to prohibit specific actions that were implicated in some accident, incident or near miss. The result is that the scope of allowable action shrinks as the system or technology matures. But the range of actions necessary to get the job done under less than ideal circumstances need not diminish. This creates the conditions necessary for situational violations. That is, non-compliance that is committed simply in order to get a particular job done.

Here the problem lies mainly with inadequacies of the workplace, tools, equipment, or with the inappropriateness of the procedures for those particular working conditions. Situational violations occur primarily at the rule-based level of performance.

Intentions to violate

Recent research[16] has shown that intentions to violate safe operating procedures are shaped by three inter-related factors.

1. **Attitudes to behavior ("I can do it")**.

These are the beliefs a person has regarding the consequences of some behavior. How do the perceived advantages of violating balance out against the possible risks and penalties?

2. **Subjective norms ("They would do it")**.

These are the views that some important reference group (relatives, friends, etc.) might hold about your behavior. Will they approve or disapprove, and how much does the person want to be admired or respected by these "close others?"

3. **Perceived behavioral control ("I can't help it")**.

How much control does the person feel that he or she exercises over the violating behavior? This factor is likely to be of considerable importance in fatalistic cultures, particularly in regard to judgments about the consequences of violations. It will also come into play when the individual observes that although local management may pay lip service to the regulations, they actually condone violation, particularly when noncompliance means getting an urgent job done on time.

Failures

We call the serious consequences of human errors "failures." Some human errors have serious consequences, but most do not. In a typical conversation with another person, we might misspeak several times. The only real consequence of these errors is to cause us to repeat or clarify our speech. A small percentage of human errors can cause or contribute to safety lapses or, in severe cases, accidents that destroy property or injure people.

Latent vs. Active Failures

We typically distinguish between "active" and "latent" failures. The difference here concerns the length of time that passes before human errors have an adverse impact upon the safety of the aviation system. In the case of active failures, the negative outcome is almost immediate. But, for latent failures, the consequences of human actions or decisions can take a long time to reveal themselves, sometimes many years.

The distinction between active and latent failures can be summarized as follows:

- *Active failures* are the result of unsafe acts (errors and violations) committed by those at the "sharp end" of the system (pilots, air traffic controllers, **AMT**s, etc.). They are the people at the human-system interface whose actions can, and sometime do, have immediate adverse consequences.
- Latent failures are created as the result of decisions, taken at the higher echelons of the organization. Their damaging consequences may lie dormant for a long time, only becoming evident when they combine with local triggering factors (e.g., errors, violations and local conditions) to breach the system's defenses.

Local vs. Organizational Factors

Latent failures can be attributed to local factors, which are present in the immediate workplace, and organizational factors that lie "upstream" from the workplace. Organizational factors create the local error and violation-producing conditions.

In a study carried out within the engineering facilities of a major world airline, [17] 12 local factors and 8 organizational factors were identified as having an adverse effect upon the working practices of those on the hangar floor. The 12 local factors listed here were associated with maintenance activities in a line management hangar.

1. **Knowledge, skills and experience**. Being unfamiliar with a defect or aircraft type, lack of specific training or skills, inappropriate experience for a job, changes in aircraft type clashing with past routines or expectations, etc. (see **Chapter 7**)

2. **Morale**. Personality clashes, frustration, being unhappy with the work situation, inadequate

incentives, insufficient consultation with the workforce, etc. (see **Chapter 12**)

3. **Tools, equipment and parts**. Problems with availability, quality, location, delivery and/or collection, identification, handling heavy or awkward items, etc. (see **Chapter 6**)

4. **Support**. Problems with support from other areas, people unavailable in other areas, under-manning, avionics or other trade cover, third party companies and their local representatives, etc. (see **Chapter 16**)

5. **Fatigue**. Problems with tiredness, unusually slow working, disturbed sleep patterns, particularly at the beginning of a shift, the balance between work and rest, noticeable increases in slips, lapses and fumbles, etc. (see **Chapter 4**)

6. **Pressure**. Problems with high workload, the workforce being spread too thinly over the jobs, many interruptions, hassle from management or customers, too little time to do the job to the highest standards, etc. (see **Chapters 1** and **6**)

7. **Time of day**. Problems with shift patterns, time of day or night, closeness to the deadline, etc. (see **Chapter 4**)

8. **Environment**. Problems with rain, snow or fog, temperature (either too hot or too cold), high noise levels, inadequate lighting, insufficient environmental protection, etc. (see **Chapter 5**)

9. **Computers**. Being unfamiliar with the computer type or mode of operation, unfriendly interfaces and software, the introduction of a new system, insufficient terminals, some people being "computer shy," etc. (see **Chapters 9** and **15**)

10. **Paperwork, manuals and procedures**. This includes unclear Technical Log entries, unavailability of relevant manuals or procedures, failures to complete paperwork correctly, inconvenience or difficulty of locating relevant material, etc. (see **Chapter 15**)

11. **Inconvenience**. This relates to ease of access (or lack of it) to the job, pace of work going on around, congestion around the aircraft, airside traffic conditions, etc. (see **Chapters 5** and **6**)

12. **Safety features**. Problems with hazard warnings, quality of safety equipment, safety training and awareness of hazards, personal protective equipment, etc. (see **Chapters 3** and **15**)

Whereas these local factors varied from one workplace to another (e.g., from a hangar to a workshop), the upstream organizational factors remained the same throughout the system as a whole. The following eight organizational factors were selected as being the most influential adverse latent influences in the first instance:

1. **Organizational structure**. This concerns worries about restructuring and downsizing, ill-defined duties and responsibilities, too many layers of management, necessary tasks not covered by the existing structure, etc.

2. **People management**. Lack of top-level awareness of problems at the sharp end, ill-defined career pathways, the wrong balance between incentives and disciplinary measures, workforce insufficiently consulted, etc. (see **Chapter 16**)

3. **Provision and quality of tools and equipment**. Lack of proper equipment and resources in the workplace, existing equipment is inadequate to cope with new aircraft types, cost-cutting is

put before the needs of the job, workplace facilities are out of date, etc. (see **Chapters 5** and **6**)

4. Training and selection. Trade skills out of step with current needs, inadequate balance between avionics and mechanical trades, insufficient licensing incentives, recruitment and selection not netting the right kind of apprentices, etc. (see **Chapter 7**)

5. Commercial and operational pressures. Conflicts between quality standards and commercial and operational pressures, conflicts between safety standards and commercial and operational- pressures, etc. (see **Chapter 3**)

6. Planning and scheduling. Poor quality of planning and scheduling, remoteness of planners from the reality of the job, conflicts between long-term strategic plans and the immediate needs of the present jobs, plans and schedules being unclear or unworkable, etc. (see **Chapter 4**)

7. Maintenance of buildings and equipment. Inadequate building maintenance, inadequate equipment maintenance, necessary improvements deferred on cost grounds, requests for maintenance and improvements not acted upon, etc.

8. Communication. Workforce being isolated from managerial decision makers, bottom-up communications ignored, unclear or ambiguous communications, communications that promote a "them and us" attitude, etc. (see **Chapter 13** and **16**)

These eight factors do not represent a definitive list of all the possible organizational problems affecting safe and reliable work. They are offered as examples of the kind of latent factors that can have adverse effects upon workplace conditions, and hence upon human performance. Different organizations are likely to have different kinds of organizational problems, but these eight factors are likely to be fairly typical of most aircraft maintenance facilities.

Latent failures-and organizational accidents

The technological advances of the last 20 years, particularly in regard to engineered safety features, have made many hazardous systems largely immune to single failures, either human or mechanical. In order to breach the "defenses-in-depth," it now requires the unlikely combination of several contributing factors, each necessary but none sufficient to cause the accident by itself.

Unfortunately, the increased automation afforded by cheap computing power also provides greater opportunities for the insidious accumulation of latent failures. Contemporary aircraft systems have become more opaque to the people who control and maintain them and are thus especially prone to the rare but often catastrophic "organizational accident." Tackling these organizational failures has been called "the last great frontier" in air transportation.[18]

The anatomy of an "organizational accident" is shown in **Figure 14-3**. The direction of causality is from left to right.

- The accident sequence begins with the negative consequences of organizational processes (i.e., decisions concerned with planning, scheduling, forecasting, designing, specifying, communicating, regulating, maintaining, etc.)

- The latent failures are transmitted along various organizational and departmental pathways to the workplace (the maintenance hangar, the workshop, the ramp, etc.) where they create the local conditions that promote the commission of errors and violations.
- Many unsafe acts are likely to be committed, but very few of them will penetrate the defenses to produce damaging outcomes. The fact that engineered safety features, standards, controls, procedures and the like can be deficient due to latent as well as active failures is shown by the arrow connecting organizational processes directly to defenses.

The model presents the people at the sharp end, the **AMT**s, as the inheritors rather than as the instigators of an accident sequence. This may seem as if the "blame" for accidents has been shifted to the system managers. However, this is *not* the case for at least two reasons.

First, attributing blame, though often emotionally satisfying, hardly ever translates to effective counter-measures. Blame implies delinquency, which is normally dealt with by exhortations and sanctions. But these are wholly inappropriate if the individuals concerned did not choose to err in the first place.

Second, high-level decisions are shaped by economic, political and operational constraints. Like designs, such decisions are always a compromise. It is thus taken as axiomatic that strategic decisions will carry certain negative safety consequences for some part of the system. This is not to say that all such decisions are flawed, though some of them will be.

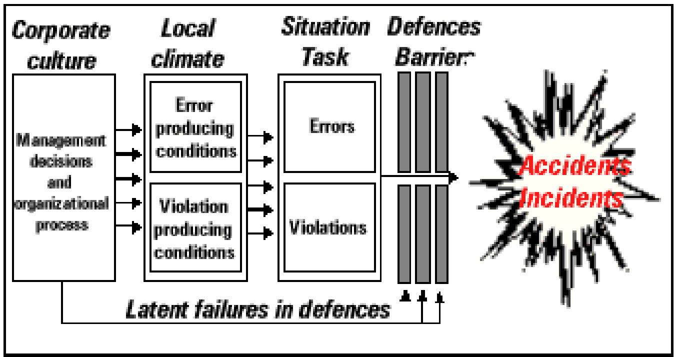


Figure 14-3. *Stages in the development of an organizational accident*

Even those decisions judged at the time as being good ones will carry a potential downside. Resources, for example, are rarely allocated evenly. There are nearly always losers. In judging uncertain futures, it is inevitable that some of the shots will be called incorrectly. The crux of the matter is this: We cannot avoid creating latent failures; we can only strive to make their adverse consequences visible before they combine with local triggers to breach the system's defenses.

These organizational root causes are further complicated by the fact that the aviation system as a whole involves many interdependent organizations: manufacturers, maintainers, airlines, air traffic controllers, regulators, accident investigators, and so on. The model shown in **Figure 14-3** is simplistic. Reality is considerably more complex, with the behavior of other organizations impinging on the sequence at many different points.

Error Management

Error management (EM) is a very broad term covering a wide variety of measures. These can be classified under two headings:

- **Error reduction**: Measures designed to limit the occurrences of errors.
- **Error containmen**t: Measures designed to limit the adverse consequences of those errors that still occur.

At this general level, **EM** is indistinguishable from quality management or, indeed, from good management of any kind.

People do not intend to commit errors. As a result, it is very difficult for others to manage what individuals cannot easily manage for themselves - that is, occasional deviations of action from intention, or absent-minded slips and lapses.

Nor are errors intrinsically bad. They are the debit side of what are useful and essential mental processes. Trial and error play a key role in learning novel tasks. Similarly, absent-minded slips and lapses are the infrequent penalties we pay for being able to run our routine actions on "automatic pilot" with only small and intermittent demands being made on our limited attention capacity. But sometimes the whole of this attention resource gets captured by something other than the task in hand, and then actions can run along unintended pathways, usually habitual ones.

Error management, in its general sense, is as old as organizations with potentially hazardous operations. Today, all such organizations employ a wide range of error-reducing and error-containing techniques. In aircraft maintenance, these include:

- Personnel selection
- Human resource management
- Training and retraining
- Licensing and airworthiness certification
- Checking and signoffs
- Quality monitoring and auditing
- Incident reporting systems
- Procedures, rules and regulations
- Implementation of ISO 9000+
- Total Quality Management (TQM)

Among the world's major airlines, these measures have created a high level of maintenance reliability. Yet maintenance continues to account for a small but conspicuous number of accidents. At least one study of major (hull loss) aviation accidents, predicts that maintenance errors will account for 10-20% of such accidents into the foreseeable future.[19]

We know how to reduce certain types of errors associated with aviation maintenance. In particular, a number of studies have shown that simulation-oriented training can reduce serious errors that occur during troubleshooting tasks.[20] We also know from previous studies done in the aviation, space, and nuclear industries that proceduralization can reduce certain types of errors.[21]

Existing **EM** techniques have evolved over 70 years of commercial aviation. They have been driven in large part by the desire to prevent the recurrence of the last incident or accident. Though of proven value, these existing forms of EM have a number of limitations, particularly narrowness of focus. Some of these problems are listed below.

- They focus upon active failures rather than latent or system failures.
- They focus upon the personal rather than the situational and organizational contributions to accidents.
- They tend to "fire fight" the last incident or quality lapse rather than anticipating and preventing the next one.
- They still rely heavily on exhortations and disciplinary sanctions, i.e., blame and train.
- They still employ blameladen terms like "carelessness," and "bad attitude," and "irresponsibility"
- They do not distinguish adequately between random and systematic error-causing factors.
- They are generally not informed by current human factors knowledge regarding errors and accident causation.

In brief, they tend to be piecemeal rather than planned, reactive rather than proactive, fashion-driven rather than theory-driven. They also ignore the substantial developments that have occurred in the behavioral sciences over the past 20 years in understanding the nature, varieties, and causes of human error.

Task Dependence

Boiled down to its essence, the task of an **AMT** is to take off and then replace some of the three to four million removable parts on a modern commercial airliner. Much goes on in between, of course, but these basic steps of disassembly and reassembly remain constant features of the work.

The error data clearly show that reassembly is far more error-liable than disassembly. Well over half of the errors recorded involve the omission of necessary steps or parts during reassembly. This is not unique to aircraft maintenance. The largest single human factors problem in nuclear power plants are omissions during inspection, testing and maintenance.[14]

Unlike many other error forms, it is possible to predict the likelihood of an omission with a fair degree of confidence. Certainly, it is possible to identify the omission-prone steps of a proceduralized task. Knowing in advance where an omission is likely to happen is at least halfway towards effective error management. The other half is finding effective ways of drawing people's attention to the possibility of an omission so that they might avoid it.

Consider the bolt with marked nuts on it shown in **Figure 14-4**. If the task was to remove the nuts and then reassemble them in a predetermined order, then there is really only one way in which the items can be disassembled, but there are over 40,000 ways in which they could be put back in the wrong order (i.e., 8 factorial).

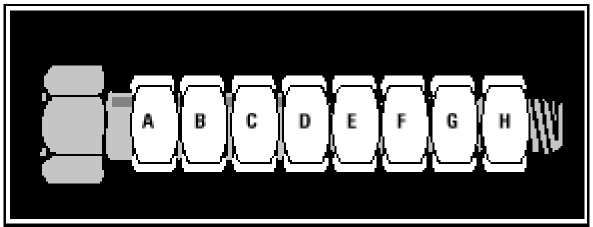


Figure 14-4. *The Bolts and Nuts example*

The point of the example is this: There is only one way of taking such an assembly of items apart. Each nut has to be removed sequentially. The task of disassembly (usually) constrains human actions to one particular sequence, with each succeeding step being prompted by the last. All the necessary knowledge is provided by the natural physical structuring of the task. In other words, all the necessary guidance is located in the world: psychologists call this *knowledge-in-the-world* or KIW.

By contrast, reassembly needs a good deal of *knowledge-in-the-head* (KIH), either in memory or in some written form. Since most people doing a hands-on job are reluctant to consult written instructions - the two activities do not go well together - this usually means a greatly increased memory load. This is probably adequate when the task has been practiced continuously on a daily basis - but most maintenance tasks are not like this, and we all know how easily we can forget the details of a task even after a short interval. Thus the probability of omitting a step or mis-ordering the reassembly is high.

To make matters worse, a wrongly assembled item is not always obvious on later inspection. The absence of bushings, washers, fixings, caps, oil, and the like can be concealed within the assembly. Thus, reassembly has the potential for double jeopardy: a strong chance of omitting something due to forgetting, and a low probability of detecting the error once the job is apparently completed.

Recent Techniques

Airline maintenance organizations and airframers are presently experimenting with many techniques for error management.[22] Three representative efforts, **MEDA**, **MESH**, and self-report analysis are described below.

Several airlines, in cooperation with Boeing, are participating in efforts that use a *post hoc* error analysis technique known as the Maintenance Error Decision Aid (MEDA).[23] Like other *post hoc* techniques, MEDA is used to investigate errors that have already been committed. Unlike most other techniques used in the aviation maintenance domain, MEDA thoroughly evaluates all of the factors that contributed to the error and recommends changes to mitigate those factors. Because of its emphasis on finding all of the underlying factors associated with an error (or group of errors), MEDA can identify systemic elements that contribute to a broad range of errors.

British Airways has pioneered a proactive technique aimed at identifying conditions that favor committing errors. This technique, called Managing Engineering Safety Health (MESH), solicits anonymous ratings from maintenance workers regarding the shortcomings of various local factors known to contribute to errors.[17] Organizational factors are measured in much the same way, but using management grade people instead of line workers. The idea behind MESH is to monitor those factors that are known to contribute to errors and correct them before they stray outside of acceptable ranges.

Finally, at least one airline is using self-reporting and team investigation techniques in the spirit of *kaizen*.[24] Self-reporting occurs when the maintenance organization becomes aware of an error and reports it to the **FAA** before the FAA finds the error. The Aviation Safety Reporting System (ASRS) is an example of a self-reporting system used in the aviation operation environment.[25] Once a self-report is filed, a team is convened to determine what happened and to identify the contributing factors. Once these factors are identified, corrective actions are proposed and carried out. The person who committed the error is part of the investigative team. This type of investigation is much more oriented toward fixing the problem(s) rather than the blame.

ISSUES AND PROBLEMS

It is our goal to minimize the effects of human error in aviation maintenance. We suffer economic loss if maintenance errors lead to reduced productivity, equipment damage, or re-doing certain tasks. There is also the possibility of incurring human pain, suffering, and even death, if certain maintenance errors are allowed to go unchecked or unidentified. Reducing the effects of error, however, is not really the issue -- rather, it is a consequence of appropriately addressing other factors. We will address the topic of error management directly in the **GUIDELINES** section.

Design

The best way to prevent errors is to eliminate them during the design process. While this is every designer's goal, we are seldom able to achieve it in a practical and cost-effective manner. Even if we couldn't prevent errors through design, it would be nice if all designs were error-neutral. That is, if design can't prevent errors, at least it should not promote errors.

Unfortunately, poor design constitutes an unknown, but large, proportion of causation for human errors. Instruments that are difficult to read, workspaces in which it is difficult to work, noisy and poorly-lit work environments, ambiguous and confusing information on user-equipment interfaces, etc., constitute traps for **AMT**s and inspectors.

In the aftermath of the Three Mile Island accident in the late 1970's, the Nuclear Regulatory

Commission (NRC) impaneled a group of human factors experts to examine the NRC's long-term human factors research plan. One element of this plan was a heavily-funded effort to perform human reliability assessment for control room design. The conclusion of the panel was that the money would be better spent simply designing things as well as possible, thus minimizing any inherent risk.[26] The point is that we can over-analyze error-prone systems when we could more easily re-design them.

Error Identification

Identifying errors would seem to be a simple process. Wait for something to go wrong and then investigate until we find out who or what didn't do the correct thing. However, most errors don't have any serious consequences. Either the error is minor, its effects are trivial, it is caught and corrected before it can a more serious failure, or other elements in the system prevent the error from having a major effect. Since most errors don't cause problems, most errors go unreported and unidentified to all but those most closely involved with it.

Ideally, we want to know about small errors before they turn into big failures with serious consequences. One of the issues we will address later in the chapter is how to identify errors before their effects can accumulate and become big errors.

Public Safety

At the heart of any discussion concerning aviation maintenance errors is concern for the safety of the flying public. Theoretically, almost any error, regardless of how trivial it might be in isolation, can combine with other errors or events to cause an aircraft to be less than airworthy. In our discussion and guidelines related to managing errors, the approach will be to expend our resources in the most efficient way. That is, we will address the most frequent errors and error-causing conditions first. By definition, decreasing the frequency and the consequences of errors increases the safety of the public.

Training

The traditional approach to investigating errors and preventing their recurrence is sometimes called "blame and train." That is we look for somebody to blame for the error and essentially tell them not to commit that error again. We point out in this chapter that training works well for changing certain behaviors that are under the positive control of technicians and inspectors.

Unfortunately, errors are, by definition, unintentional acts. When a person does not intend to do something, then training can simply reinforce their resolve not to do it. Training is an issue in human error, therefore, simply because of our over-reliance on it as an error management technique.

Worker Safety

The safety of the public is our paramount concern. However, in practice many more **AMT**s are injured in a given year than are members of the flying public. Most worker injuries are the result of errors either they or some other member of the work force commit. We stated above that reducing errors and error-producing situations will theoretically improve public safety. The effects of error reductions on worker safety can be much more direct and dramatic. In fact, a major incentive for reducing worker errors (and thereby reducing injuries) is to reduce Workers Compensation insurance rates.

REGULATORY REQUIREMENTS

Parts 121 and 135 of the Federal Aviation Regulations (FARs) contain general requirements related to maintaining aircraft that come under their scope of applicability. However, there are no specific requirements in these parts of the FARs that relate directly to human error. In fact, the FARs do not define human (nor any other type of) error. Instead of errors, the FARs rely on identifying regulatory violations, for which various types of proceedings and potential penalties are prescribed in Part 13.

The major differences in how violations are treated lie in the type of investigative process that is undertaken. The **FAA** has some discretion as far as this decision, but the main distinction seems to lie in the use of an informal investigation or administrative action versus aformal investigation. Formal investigations are predicated on the FAA's initial evaluation of the response to an "order of investigation." Formal fact-finding investigations are described in Subpart F. Formal hearings are defined in Subpart D and can include witnesses, depositions, lawyers, etc.

The self-reporting technique reported in the **METHODS** section involves what is essentially an informal hearing or an administrative action, which are considerably less complex and punitive in nature than a more formal investigative hearing. The only reason this is possible is because the airline identifies and reports the violation instead of an **FAA** Inspector. Most maintenance errors do not result in violations of the **FAR**s. Therefore, it is not appropriate to use the terms "error" and "violation" synonymously.

CONCEPTS

Since human error has been the subject of so much research, many error-related concepts have been identified and defined. There is some disagreement among researchers regarding the precise definition of some of these concepts. In this section, we describe the concepts that are fundamental to the discussion of human error.

Accident

There are many formal definitions of accidents. We all have an intuitive understanding of what constitutes an accident. One of the simplest definitions in the literature is that accidents are "...unwanted exchanges of energy."[11] This definition emphasizes that accidents produce physical damage. Accidents can be caused by errors, but many are not. Likewise, very few errors actually result in accidents.

Active Failure

An active failure is the result of an error that has immediate consequences. An example of an active failure is a mechanic driving a truck in the airport and not braking in time to avoid running into a parked aircraft (a classic ground damage accident).

Cause

The common notion of causation is that every error can be traced to a fundamental set of actions and conditions that precipitated the error. This turns out to be a simplistic view of the world. Most errors have multiple causes. In searching for the cause of an error, we can typically move backwards in a chain. For example, I missed the turn because I didn't get in the turn lane in time. I didn't get in the turn lane in time because I didn't see the sign telling me this was the proper exit. I didn't see the sign because I was preoccupied trying to call the office on my car phone. The most appropriate "cause" of an error often depends on our purpose for trying to find it.

Common Mode Failure

In reliability terms, a common mode failure is one that affects redundant parts of a system. Twin-engine aircraft have redundant power sources. If one engine fails, then the other can supply sufficient power to safely operate the aircraft. However, tainted fuel can cause both engines to fail. Thus all of the redundancy is removed. Humans are the single largest common mode failure sources in most systems. An example of a human-induced common mode failure is the infamous case of leaving O-rings off the chip detectors on all three engines on an L-1011.

Defense in Depth

Objective analysis and our own experience tells us that accidents are rare events. Of all the opportunities that exist for accidents to occur, only a minute fraction actually result in any type of "failure." That is because complex systems are typically designed so that more than one failure is required to precipitate an accident. In fact, a series of events must occur to allow an accident. Experts call this the "chain of causation." (see **Design for Error**)

Design for Error

We know that humans are prone to commit errors. We also know which types of errors are most likely to be committed. When we design systems that include human operators, it is imperative that we account for the likelihood of various errors. The result of a foreseeable human error should not be property damage, injury, or death. Systems that can handle human errors in a benign manner are said to be designed for error.

Error

We noted in the **BACKGROUND** section that error can generally be defined as the failure of planned actions to achieve their desired goal. Other authors have defined human error as any action that is out of acceptable limits, where "acceptable limits" are defined by the system.[27] There are a number of factors that can be added to these definition, such as the intentions of the person who commits the error, whether the action led the system to move outside its acceptable limits, and so on.

Fault

Unlike the concepts of "error" and "failure," which are generally viewed objectively, fault is often synonymous with blame. Certain mechanical and electrical failures are called faults. However, in terms of human error, there is no commonly accepted definition of the concept of fault, except the obviously pejorative assignment of blame.

Fundamental Attribution Error

When we hear of a person committing an error, we tend to attribute any negative element associated with the error, such as stupidity, laziness, carelessness, etc., to that person. We often ask ourselves how someone could be so dumb as to commit a particular error. Such attribution is an error in itself, since people do not intentionally commit errors. Instead, the circumstances surrounding an error, the background and training of the person involved, and other factors usually provide ample reasoning for performing in a manner that resulted in the error.

Human Reliability Assessment (HRA)

The domains of risk assessment and system reliability include various techniques for statistically assessing the probability that a system will fail in particular circumstances. These techniques generally take into account the probability that any given component of the system will fail in particular ways. Human Reliability Assessment, or HRA, extends these techniques to include the human operator component.[28] In an HRA analysis, the probability that a human operator might misread a display (for example), is included among other mechanical and failure modes that might cause a process plant to move outside its operational envelope.

Kaizen

Kaizen is a Japanese word meaning "continuous improvement involving the entire system and everyone in it." It is a process of "deliberate, patient, continual refinements."[29] It does not involve looking for dramatic one-off solutions, rather it entails a constant struggle to find better and more reliable ways of doing the job. In terms of human error, *kaizen* is associated with the philosophy of "fixing the problem instead of the blame."

Knowledge-Based Performance

Human performance is not homogeneous. That is, the things we do demand different levels of attention, training, manual skill, etc. Rasmussen (1981)[29] has categorized the types of things people generally do at work into three categories: skill-based, rule-based, and knowledge-based. Knowledge-based performance is associated with the most complex tasks, i.e., those for which we have no pre-learned responses or rules. In terms of human error, knowledge-based performance is the most error-prone, since we are often in a trial-and-error mode when dealing with novel situations.

Knowledge in the Head (KIH)

The probability of human error is directly related to what we have to know to perform a task. If a task requires a complex series of actions that must be done in a particular order, then we must somehow remember or be given this information at the proper time. Any information that we must retain in memory is called "knowledge in the head," or KIH. Tasks that require a significant amounts of KIH are highly error-prone.

Knowledge in the World (KIW)

The corollary to knowledge in the head is knowledge that somehow resides in the task components. In essence, the elements of the task have all the information we need to perform the task correctly. In the body of the chapter, we used the example of an assembly consisting of a bolt with several nuts and washers attached. There is one, and only one, sequence in which these components can be disassembled. Thus, all disassembly sequence knowledge is contained in the task elements. This is an example of "knowledge in the world," or KIW.

Latent Failure

The corollary to an **active failure** is a latent failure. Latent failures are consequences of errors, but they do not show up immediately. Latent failures can be actual physical conditions, such as leaving the lock wire out when re-installing a fastener, or organizational factors that set the stage for later failures. Latent failures are insidious because they are often hidden.

Mistake

In this chapter, we have identified two categories of errors -- slips and mistakes. Mistakes are errors that occur in the decision-making or selection processes. Mistakes commonly occur in the troubleshooting process. We decide to replace a component and do so without error. Unfortunately, the component we replace is not broken.

Performance Shaping Factor (PSF)

We know from experience that various factors can increase or decrease the likelihood of committing errors. In a more general sense, such factors can affect our overall level of performance. For example, we can work longer without fatigue when the ambient temperature is 75 degrees F than when it is 100 degrees F. Any element that affects human performance is called a "performance shaping factor," or PSF. Performance shaping factors can be environmental, such as temperature, psychological, organizational, or related to the design of tools, procedures, workspaces, schedules, etc.

Redundancy

In systems that have two independent components that perform (or are capable of performing) the same function, the multiple components are said to be redundant. Redundancy makes systems less likely to fail. Redundant systems are also more tolerant of human errors. If an error causes one redundant component to fail, then the other component still allows the system to operate (see **Single Failure Criterion**).

Rule-Based Performance

Certain work-related tasks are governed by rules, either explicitly learned through formal training or acquired through practice. Such rule-based performance suffices for familiar, well-practiced tasks. However, as we know from common experience, rules can vary in their specificity. Some rules are explicit and must be followed to the letter. Other rules are more general, such as rules of thumb, which are called heuristics. Rule-based performance is typically not error-prone unless the rules are applied in novel or inappropriate circumstances.

Single Failure Criterion

A common design goal is that systems should be single-failure tolerant. That is, we do not want the failure of a single component to cause an accident. This criterion is met by assessing the contribution of each component to the overall functioning of the system. Any component that can cause the overall system to fail is usually made redundant. This is the reason that modern airliners have multiple engines and electrical and hydraulic power sources.

Skill-Based Performance

Skill-based performance is associated with tasks that typically require some degree of manual manipulation and are practiced on a routine basis over a period of years. Cutting and bending sheet metal is a skill, as is soldering electrical wires, typing, etc. Skill-based actions are subject to errors, but these errors are usually obvious and recoverable. There are exceptions of course. Errors in measuring internal bearing clearances during an engine overhaul can result in a latent failure.

Slip

Slips are errors that occur when we're trying to perform a correct action. In a variation of the troubleshooting example we used in describing mistakes (see above), let's say that we properly diagnose a failed component and decide to **R&R** it. We might forget to attach an electrical connector when re-installing the new component. In thiscase, we have properly diagnosed the failed component and chosen the correct course of action. However, we made a slip (failing to attach the connector) when executing a proper action (reinstalling the component).

Violation

Violations are deviations from safe operating procedures, recommended practices, rules or standards. Although they can be committed in error (e.g., driving in excess of the speed limit without being aware either of the current speed or the local restriction), most violations are deliberate. People generally intend the non-compliant acts, but not the bad consequences that occasionally ensue.

METHODS

There are a number of methods available for identifying, investigating, and managing human errors and their consequences. In this section, we describe a sample of these methods.

Anonymous Reporting

Before errors can be managed, they must be identified. This sounds like a fairly easy process, after all one need only look for the failed components or procedures. However, most errors do not result in failures. In fact, most errors are caught before they cause any problems. Experience in the flight operation domain has shown that people are willing to report failures if they can be assured that they will remain anonymous and will not suffer regulatory sanctions. The Aviation Safety Reporting System (ASRS) is an example of a system that allows failures to be reported without fear of sanctions.[25]

The fundamental problem with most reporting systems, anonymous or not, is that they are *post hoc,* or after the fact. A failure must occur before it can be reported. A method that can address this shortcoming is the **Critical Incident Technique**.

Critical Incident Technique

A common human factors method for assessing the likelihood of failures in a particular work environment is the Critical Incident Technique. The idea behind this method is that failures don't usually occur spontaneously. Rather, for each failure that is committed there are many "critical incidents" that set the stage for failures. A critical incident is any situation in which errors almost cause a failure or in which a failure is in progress, but something or somebody prevents it from going to conclusion.

The Critical Incident Technique is one of many anonymous reporting methods. It typically relies on some form of anonymous survey to solicit information from workers. Also, the method works best when it is a continuing program, rather than a one-time solicitation. As with the **ASRS** program, people who submit information in a critical incident program are encouraged (but not required) to provide enough identification to allow investigators to contact them for additional details. Their identity is stripped from the report so they can never be identified by fellow workers.

Error Environment Assessment

Earlier in the chapter, we described a number of factors that contribute to human errors. These include both local and organizational elements that can establish an environment in which errors are more or less likely. Ideally, we want to prevent errors before they occur. A good way to do this is to assess the factors that lead to an environment that minimizes the chances of error. The **MESH** technique was developed for British Airways to do this type of assessment (see the **BACKGROUND** section). It solicits ratings from maintenance workers and managers regarding the state of various local and organizational factors.

MESH has not been objectively validated. That is, we have no independent, scientific evidence that it actually reduces errors, failures, or accidents. However, since MESH is an *a priori* assessment method, it can theoretically alert managers to factors that are trending toward error-producing levels before errors are actually committed. Managers and workers can then take steps to bring these factors back into acceptable ranges.

Fault Tree Analysis

Fault tree is the name given to a family of analysis and investigation methods. All fault tree methods are diagrammatic. They require the system, task, procedure, or component in question to be logically decomposed into functional elements. Once the relationships among these elements are identified, a diagram is developed that depicts the elements and their relationships.

A typical fault tree consists of an outcome (either successful operation or a particular failure) shown at the top, or most general level, of the tree. Elements that contribute to the outcome are listed below it in the diagram with connections (branches) showing the logical relationship between the element and the outcome. In some techniques, such as Probabilistic Risk Assessment (PRA), a statistical probability is attached to each connection.

The distinguishing feature of fault trees is that they support top-down analysis. That is, the outcome is postulated first. Once an outcome is defined, then contributing factors are identified and placed into the diagram. The appearance of a fault tree is that many elements combine, in pyramid fashion, to produce a single outcome. The trick is to identify all of the underlying elements (and combinations of elements) that might combine to produce a particular outcome.

Diagrammatic techniques such as fault-trees and Failure Modes and Effects Analysis are not trivial. Using them effectively requires specialized knowledge and training. Readers who want to use these techniques should obtain expert assistance.

Failure Modes and Effects Analysis (FMEA)

Another diagrammatic method for evaluating risk or hazards is Failure Modes and Effects Analysis (FMEA). As with fault trees, FMEA requires that system elements and their interrelationships be identified. However, instead of first postulating an outcome, FMEA postulates certain types of failures in particular system components, including human components. The component failure is then traced through the system to see what effects it might have on system operation or safety. FMEA is essentially a "what if" type of analysis. During the analysis, we ask a series of questions such as "What will happen if this component fails in this manner?"

The advantage of **FMEA** over fault tree techniques is that it is bottom-up. We don't have to think of every possible way a particular outcome could occur. Rather, we first hypothesize a detailed failure and then see what happens in the system. Once individual components are analyzed, combinations of failures are linked together to see what effect they might have. The most effective analyses combine FMEA and other fault tree techniques.

Pareto Analysis

In the **BACKGROUND** section, we described various classification schemes for errors. One of these was termed "phenomenological," or describing what actually occurred that we called an error. In real work environments, we are more interested in events that happen more than once. That is, we want to know what errors occurred and how often they happened.

Pareto analysis is a technique borrowed from Total Quality Management (TQM). It is nothing more than a frequency analysis technique designed to identify events that occur most often. The lists of errors we included in the **BACKGROUND** section were sorted by frequency of occurrence (shown as a percentage of overall errors).

While pareto analysis is a *post hoc* technique and can only work after errors have been committed, it is useful for identifying where the biggest error reduction payoff will be. Assuming equal levels of consequence, it makes much more sense to direct our resources at reducing errors that occur 100 times per year rather than trying to eliminate errors that occur only 5 times a year.

Proceduralization

A common response to rule-based errors is to put the rule into formal procedures. Research and practical experience has shown that procedures can improve certain types of performance, such as troubleshooting complex systems (see **Chapter 8**). In the flight operations domain, procedures and checklists are used to ensure that mission-critical steps are performed and that they are executed in the proper order. Examples include takeoff and landing checklists. Work cards are, in essence, abbreviated procedures that deal with routine maintenance tasks.

To be effective, of course, procedures have to be usable and used. The design of work cards is addressed in **Chapter 15**. Even if they are well-designed and routinely used, however, procedures can only deal with well-known tasks. For errors related to knowledge-based behavior, procedures are of little use, since these incidents involve novel situations for which no rules exist.

Worker Teams

Error management and continuous quality improvement initiatives often involve forming teams of technicians, inspectors, and managers. When properly constituted and directed, worker teams can identify practical and effective approaches to reducing errors and the conditions that support them. Recent efforts in the maintenance resource management (MRM) area indicate that substantial improvements in maintenance quality can be achieved when teams of workers are sensitive to quality issues and communicate well with each other. (see **Chapter 16**)

READER TASKS

One of the major goals of any aviation maintenance manager is to reduce the number of errors that occur in his or her part of the organization. It is important to recognize that the causes of certain errors are beyond the control of individual managers. We have described a category of latent errors that are often linked to organizational policies or conditions. Realistically, managers will not be able to control all of the conditions that set the stage for such latent errors. However, it is perfectly reasonable to expect to be able to identify various types of errors, identify their root causes, and to manage their causes and reduce their effects.

In this section, we describe three reader tasks that are well within the ability of maintenance managers, **AMT**s, and inspectors. As with other tasks we describe in the *Guide*, the difficulty of these tasks can be viewed on a continuum. Readers of the *Guide* will be able to perform error-related tasks without expert assistance up to some level of difficulty. Beyond that level, which should be fairly obvious in practice, we recommend that readers seek expert help.

For example, finding the root cause of an error such as leaving a component out of an **APU** when it is rebuilt is probably not going to require a complex analysis using expert consultants (assuming this error shows up before the APU flies). However, investigating a major ground accident involving multiple pieces of equipment, property damage, and personal injuries probably calls for outside help.

Identifying Errors

It is perhaps stating the obvious to say that errors cannot be investigated or managed until they are identified. An important distinction to be made, however, is how we identify errors. At the reactive end of the scale, we could simply sit back and wait for the **FAA** or some other regulatory agency to write a Letter of Investigation (LOI) informing us that somebody in our organization has made a serious error and we need to do something about it. This is not an acceptable approach for a number of reasons, the most important of which is that this method is unlikely to identify most of the errors that are committed in the workplace.

The goal regarding error identification is to identify and manage errors while they are manageable. That is, we want to identify small errors and correct them before they lead to large errors with significant consequences. The **GUIDELINES** section offers a number of ways to catch errors before they reach the level of significance that would prompt regulatory consequences.

Identifying Root Causes

Once an error is identified, we try to eliminate it and to prevent its recurrence. To do this, we first have to determine why the error occurred. As we pointed out earlier in the chapter, the first (and incorrect) tendency is to blame the person(s) who committed the error. It is almost universally true, however, that an error will have more than one cause. We must identify as many of the root causes as practical before we can develop an effective approach to error management.

The **GUIDELINES** section provides some practical recommendations that will help readers identify all of the root causes of an error. We describe two techniques that have been developed for this purpose. One, called Management Oversight and Risk Tree (MORT), was developed by the Department of Energy. The other, Maintenance Error Decision Aid (MEDA) was developed by Boeing, in cooperation with various airlines and other vendors.

Managing Errors

Fortunately, we know a lot about the things that cause errors and how to design systems to minimize the likelihood of certain types of errors. We also know that human errors are ubiquitous and that the conditions that promote and allow human error are always present. Managing errors requires that we do all we can to prevent them from occurring and to minimize their consequences when they do occur.

To prevent human error, we must monitor the conditions that support them. To paraphrase an American revolutionary hero, the price of preventing errors is constant vigilance. A technique developed in the airline maintenance domain, Managing Engineering Safety Health (MESH), is a good example of methods that proactively examine the work environment to catch error-producing trends before they result in serious errors. The **GUIDELINES** section briefly describes the MESH technique.

Regardless of the precautions we take, we know errors will occur. If we depend on error-free human performance, then our system will eventually fail. For those errors we cannot avoid, we must design system elements to minimize their effects. In the **GUIDELINES** section, we will provide a series of recommendations for minimizing the effects of inevitable human errors.

GUIDELINES

In this section, we recommend a number of techniques to accomplish the tasks described above. By its nature, human error is subtle and often complex. Readers should not expect to find here all of the information they need to identify errors and their causes, as well as to manage errors and their effects. However, using these recommendations and the resources listed in the **WHERE TO FIND HELP** section, readers should be able to put together an effective error identification and management program.

Identifying Errors

Too often, we identify errors by their effects. That is, errors tend to be invisible until they cause an aircraft to miss its ramp time or, worse, cause property damage or injuries. Techniques that identify errors after the fact are called *post hoc* methods. All accident investigation techniques are *post hoc*. Something has already happened and we're trying to find out why. These techniques are adequately covered in the succeeding section of the *Guide*.

Of more interest here, are methods that we can use to do either of the following:

- Identify error trends and relationships from past incidents.
- Identify small errors before they have serious consequences.

We will examine relatively simple methods for doing both of these tasks.

Error Trends

Most aviation organizations record information on every aspect of operation and maintenance. The overwhelming emphasis on aircraft safety, regulatory requirements, and aviation culture demands that written paperwork or some sort of computer database entry accompany every task related to maintenance or operation. What we have in most organizations are more data than we need for error analysis rather than less. The challenge is to identify useful bits of information among the vast stores of non-relevant facts.

A straightforward method for categorizing errors and identifying trends is Pareto analysis. We briefly described this technique in the **METHODS** section. Pareto analysis comes from the domain of quality control and total quality management (TQM). The idea is to look at a number of cases in which something went wrong and list the top two or three contributing factors in each case.

Over a number of failures, certain factors will emerge as occurring more frequently than others. Pareto analysis will give us a good idea as to where we should expend our resources. Why spend a lot of time trying to eliminate a source of error that occurs only twice in 100 incidents? Wouldn't our time and money be better spent looking at an error that occurred in 80 of 100 incidents?

Pareto analysis is conducted most effectively by a team of people. The analysis team should include people from a variety of job classifications. As a minimum, a Pareto analysis team should include managers, technicians, inspectors, and at least one support person, such as a parts clerk or scheduler.

A team is required because there will be some interpretation required to decide which elements to include in the analysis. For example, should we include the top 3 causal elements or the top 5? Maybe we should include all the elements we can identify for each incident. Which incidents should we include? Is this really a communication problem or a procedural problem? Using a team eliminates the problem of using only one person's interpretation of facts or terminology.

The critical factor in effectively using Pareto analysis is in finding the proper level of information related to the incidents we include in the analysis. Many investigative techniques lump all performance-related causal elements as "human error." This does not tell us anything useful, except perhaps to narrow the list of incidents we should examine. That is, look at all incidents for which "human error" is listed as one of the causes. A more useful breakdown of causal factors is contained in **Table 14-2**. This is not an exhaustive list, but should provide an idea of the types of factors we are interested in analyzing. A more detailed maintenance error taxonomy can be found in the **Guide to the *Guide***, at the beginning of this document.

Once the incidents are selected for analysis, the analysis team should identify the contributing causal elements and decide how many to record for each incident. Lacking a better strategy, rank order the causal elements in terms of their strength of association with the incident and its effects. After ranking, include the top 5 elements for each incident in the frequency calculation.

Table 14-2. Selection factors for Pareto analysis.

Select maintenance-related incidents with any of the following contributing factors:

- Automation
- Clothing
- Confined spaces
- Crew coordination
- Environmental elements (e.g., temperature)
- Equipment design
- Emotional stress
- Fatigue
- Human error
- Inspection
- Job aids
- Physical factors (e.g., strength, size)
- Procedures
- Protective equipment
- Scheduling
- Shift work (including turnover)
- Substance abuse
- Time pressure
- Tools
- Training
- Work platforms

In addition to causal elements, a number of other factors should be recorded for each incident. These factors, some of which are shown in **Table 14-3**, will help us determine whether incidents have a particular locus within the organization, in time, etc. Note that the one thing we do not want to capture during the analysis is the identity of anyone involved in the incidents. Ideally, the analysis team should not see any information that will let them identify the people involved in the incidents they analyze. This might require having a clerk go through each incident report to "sanitize" it before the analysis team examines it.

Once the analysis team has gathered and collated this information, the next question is what to do with it. There are two main uses for these data. First, the pareto output, which is essentially a set of frequency histograms, should be used to prioritize resources for decreasing errors and their effects. Spend your resources where they are likely to have the greatest reduction in errors, i.e., try to reduce those errors that occur most frequently, those that occur in the same locations, under the same weather conditions, etc.

The second use of these analytical data is to correlate the pareto output to the elements contained in **Table 14-3**. This requires a bit of data mining. For example, do most errors that involve communication problems occur among AMTs with very little experience? Do most errors involving poorly-designed tools occur outdoors at night? A professional statistician, or at least a statistical analysis package, might help with this type of analysis.

Table 14-3. Information to be noted during Pareto analysis.

The following information should be recorded for each incident:

- Aircraft type
- Aircraft tail number
- Time of day
- Shift name (if applicable)
- Elapsed time from beginning of shift
- Day of week
- Month
- Location of the incident
- Ambient temperature (if available)
- Weather conditions (if applicable)
- Procedure(s) being used
- Tool(s) being used
- Job title(s) of people involved
- Experience level of people involved

Small Error Analysis

Pareto analysis involves the examination of fairly large numbers of past errors. Another approach to identifying errors is to actively solicit reports of small errors that, for one reason or another, do not result in delays, damage, or injuries. In the **METHODS** section, we described the Critical Incident Technique.

Traditionally, the Critical Incident Technique is used to solicit reports of situations in which errors or accidents almost occurred, but didn't. For our purpose, this technique can be extended to solicit reports of small errors. All of the critical elements of traditional critical incident solicitation, such as guaranteed anonymity, absence of punitive actions, etc., also apply to this variant of the technique.

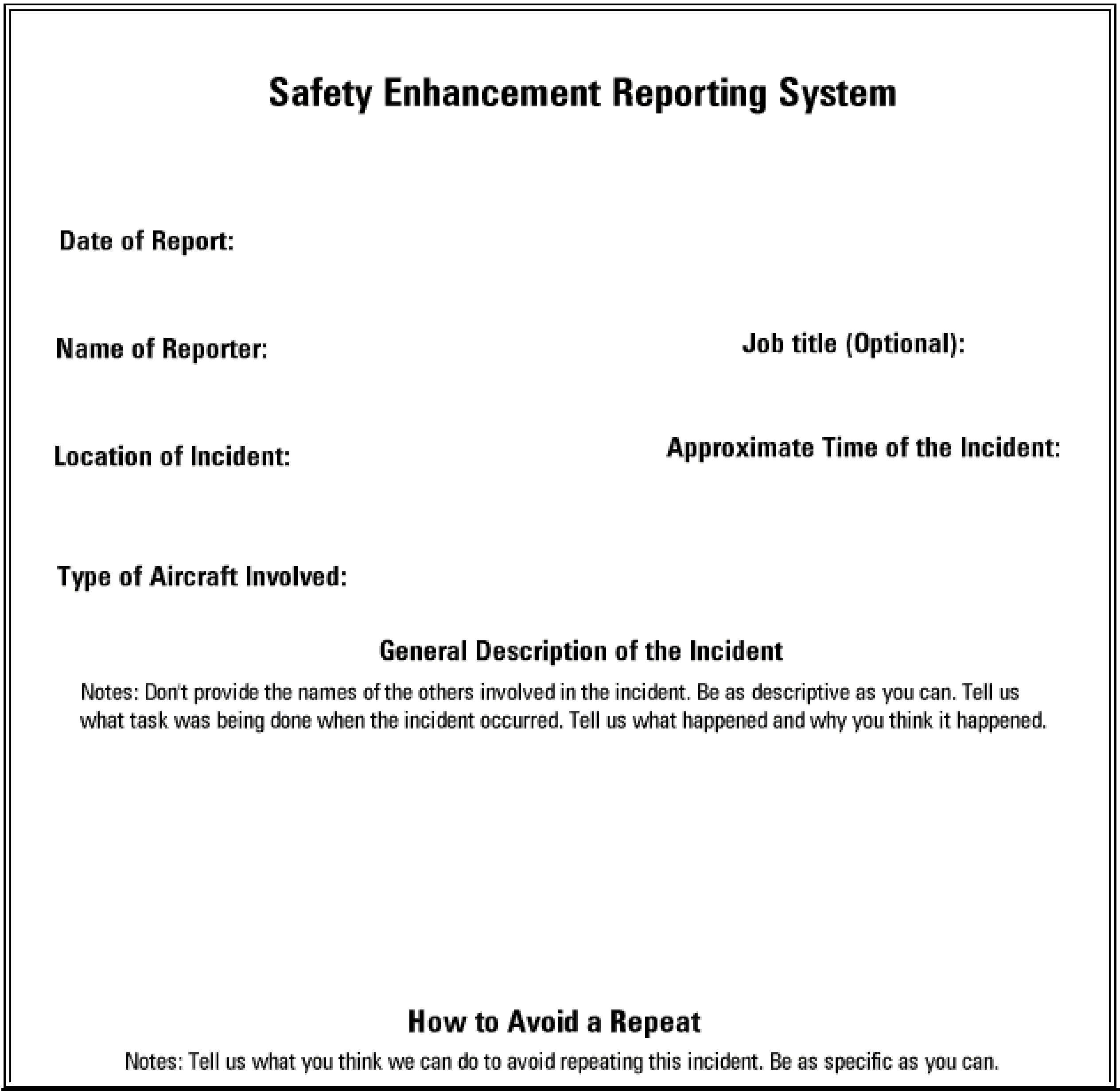
Implementing a critical incident reporting system is straightforward. Using e-mail, an internal Web site, or written reports, workers should be encouraged to report small errors, or situations that contain conditions supporting eminent errors. The reporting form should contain fields that will help analysts identify the major causal factors of the error or the significant conditions of the error-causing situation. An example of a small error reporting form is shown in Figure 14-5. Note that we have changed the name of the form to reflect a more positive image of what reporters will be doing.

Reporters should be encouraged to identify themselves, but allowed to be completely anonymous. Conversely, reporters should be told to never identify other people involved in the error, except by job title, age, experience level, and other factors that can be plugged into a pareto or correlation analysis. The only reason for encouraging reporters to identify themselves is to get more explanatory data on particular errors. In any case, information that can be used to identify reporters should be stripped from the report before analysts consider it.

If a reporter provides his or her name on the report form, then their report should be acknowledged as soon as it is received, along with an approximate date by which the report will be analyzed. After the analysis team evaluates the report, the reporter should be given a summary of actions recommended as a result of their report.

Identifying Root Causes

There are a number of investigative techniques that can be used to identify the root causes of errors, incidents, and accidents. The two methods that appear to be most applicable to the aviation maintenance domain are commercially available. Maintenance Error Decision Aid (MEDA) has been developed by the Boeing Customer Services Division, in cooperation with the **FAA**, various airlines, and Galaxy Scientific



Safety Enhancement Reporting System

Date of Report:

Name of Reporter:

Job title (Optional):

Location of Incident:

Approximate Time of the Incident:

Type of Aircraft Involved:

General Description of the Incident

Notes: Don't provide the names of the others involved in the incident. Be as descriptive as you can. Tell us what task was being done when the incident occurred. Tell us what happened and why you think it happened.

How to Avoid a Repeat

Notes: Tell us what you think we can do to avoid repeating this incident. Be as specific as you can.

Figure 14-5. *Example of a Small Error Reporting Form*

Corporation, Atlanta. MEDA has been tested in actual maintenance organizations. Because of its origins, MEDA appears to be directly applicable in the aviation maintenance environment.

Galaxy Scientific Corporation, Atlanta, has developed a commercially-available training product (TEAM) that is tied directly to the **MEDA** technique.

MEDA is a paper-based investigation technique that leads investigators through a series of five steps to identify the root causes of failures. It also includes computer-based tools that can be used to identify organizational trends toward certain error-producing situations. The MEDA steps are as follows:

1. First-cut analysis

2. Data collection
3. Error scenario development
4. Contributing factors analysis
5. Intervention strategies analysis

These steps take the investigation from the quickest and most superficial level through a detailed analysis of local and organizational factors that contributed to the incident being evaluated.

Management Oversight and Risk Tree (MORT) was developed by EG&G for the Department of Energy. MORT is a diagrammatic technique that forms the basis for a number of computer-based tools designed for quality assurance, accident/incident investigation, hazard analysis, and root-cause analysis. MORT has been around for many years and has been used in a wide range of application domains. Well-developed training programs exist to teach MORT techniques.

Because **MORT** is a commercial product, the *Guide* cannot endorse or recommend it. **MEDA** is offered free of charge by the Boeing Commercial Airplane Group. Both MEDA and MORT appear to be applicable to the aviation maintenance domain. Certainly MEDA can be used to find root causes of aviation maintenance errors, since it was developed in this domain. Likewise, MORT has been used in so many different domains that it is likely to be directly applicable to aviation maintenance.

Readers interested in either of these techniques should contact their respective vendors, listed in the **WHERE TO FIND HELP** section of the *Guide*.

Managing Errors

Human factors problems arise from two basic sources: human fallibility and error-provoking work situations. Workplace problems, in turn, have their origins in upstream organizational factors. As indicated earlier, the situational and organizational factors are more easily managed than the purely psychological factors.

Unsafe acts and quality lapses are like mosquitoes. You can swat them, spray them and use insect repellent; but they still keep biting. The only really effective way to deal with a mosquito is to drain the swaps in which they breed. Unsafe acts breed in the "swamps" of bad equipment, poor working conditions, commercial and operational pressures and the like.

When we read reports of necessary items being left off aircraft, of the wrong parts being fitted, of tools not being removed when the job is done, or of the incorrect installation of components, a common reaction is to wonder how anyone carrying out such safety-critical work could have been so stupid, careless or reckless. Our natural tendency is to locate the origins of (and hence the blame for) such lapses squarely within the minds and behavior of those directly involved with the work. As a consequence, we have (at least in the past) directed most of our remedial efforts at the people in question. We sanction them, we exhort them, we retrain them and we write additional procedures.

Unfortunately, such measures have very limited value. One reason for this is that they run counter to an important principle of error management, namely that errors are consequences not causes. Identifying errors is merely the beginning of the search for accident causes, not the end.

Managing the Manageable

The mental states directly associated with an error (i.e., preoccupation, distraction, forgetfulness, etc.) are the last and least manageable parts of what is usually a much longer sequence of contributing factors. This chain of events includes the nature of the task, the quality of tools and equipment, the conditions within the workplace and the way the system is organized and managed. All of these are far more easily managed than are the inevitable, unpredictable and transitory mental states associated with making an error. We cannot change the human condition.

We are all prone to momentary failures of attention and memory. We cannot stop people having domestic worries that preoccupy them, nor can we prevent them from being interrupted or distracted. There are no "magic bullet" solutions that will ensure perpetual vigilance or timely recall.

The Blame Cycle

Why are we so inclined to blame people rather than situations? The answer comes in two related parts. The first is what psychologists call the *fundamental attribution error*.

When we see or hear of someone performing less than adequately, we are inclined to attribute the cause to some negative characteristic of the person: laziness, carelessness, incompetence, and the like. But if one were to ask the person why he did it, he would almost certainly tell you how the circumstances or the system forced him to act in that way. The reality, of course, lies somewhere between these two extremes.

The second part of the answer concerns the *illusion of free will*. People place great value in the belief that they are free agents, the controllers of their own fate. Indeed, so important is this belief that people can become mentally ill when deprived of this sense of personal freedom through old age or institutionalization.

Given our own feelings of being in control of our destinies, we assume that other people are the same. We view others as being able to choose between right and wrong, and between correct and erroneous courses of action. But this freedom is illusory. All human actions are constrained to some degree by local circumstances beyond a person's control.

It is this belief that drives the Blame Cycle. Errors on the part of other people are seen as being the result of a choice; people are perceived as having deliberately elected to take an error-prone course of action. Since errors are judged as having a voluntary component, they attract blame, and blameworthy actions are treated by warnings, sanctions and exhortations to "be more careful."

But errors are unintended, so these measures have little or no effect on the commission of subsequent errors. These later errors are then seen as even more blameworthy, since they seem willfully to ignore the warnings and to defy the sanctions. And so the futile cycle goes on.

A careless or stupid act does not make a careless or stupid person. Everyone is capable of a wide range of actions. Another basic principle of error management is that the best people can sometimes make the worst mistakes. Being trained for the job, being skilled and experienced reduces the absolute rate of errors, but it does not eliminate them entirely.

Breaking out of the Blame Cycle

A prerequisite of effective error management is to break free of the Blame Cycle. To do this requires recognizing that:

- Human actions are invariably constrained by factors beyond an individual's immediate control.
- People cannot easily avoid actions that they did not intend to commit in the first place.
- Errors are consequences rather than causes. They are the product of many interacting factors: personal, task-related, situational and systemic.
- Within a skilled, experienced and well-motivated workforce, jobs, situations, and organizations are easier to change than people.
- Unsafe acts, quality lapses, incidents and accidents are more often the result of error-provoking situations and error-liable tasks than they are of error prone people.

The good news for error management is that we can analyze the steps in a maintenance procedure and estimate its probability of being omitted. The likelihood that a given step be omitted is determined by a number of inter-related principles. These are listed below.

- The larger the number of steps in a sequence, the greater the likelihood that one or more of them will be omitted.
- The greater the memory loading of a particular procedural step (i.e., the amount of necessary knowledge-in-the-head), the more likely it is that items within that step will be omitted.
- Procedural steps that are not obviously cued by preceding actions (as in the case of disassembling the bolt and nuts in **Figure 14-4** or that do not follow in a direct linear sequence from them are likely to be omitted.
- When instructions are given in a written form, isolated steps at the end of a sequence (e.g., replacing caps or bushes, removing tools, etc.) have a reasonably high probability of being omitted.
- In a well-practiced, highly automatic task, unexpected interruptions are frequently associated with omission errors, either because some unrelated action is unconsciously "counted in" as part of the task sequence, or because the interruption causes one to "lose one's place" on resuming the task. This 'resumption' effect causes an **AMT** to believe he or she had completed more steps before a task was interrupted than had actually been completed
- Such routine tasks are also especially prone to premature exits - moving on to the next activity before the previous one is completed, thus leaving out the final steps. This is particularly likely to happen when the person is working under time pressure, or when the

next job is physically near at hand.

As with many human factors problems, the most practicable solutions are technical rather than psychological ones. The steps for dealing with error-prone tasks are set out below.

- Identify an omission-prone aspect of the reassembly task (e.g., lock wires, wheel spacers, removing tools, etc.). This can be done reactively from examining the quality lapse data, or proactively using the principles summarized above.
- Try various ways of reminding the AMT to carry out the necessary steps by placing appropriate knowledge-in-the-world (i.e., a clearly visible reminder) close to the vulnerable phase of the task. Ideally, of course, the error-liable components should be redesigned to afford only one correct way of reassembly, but in practice this is rarely possible.
- Do not expect total success from any one method of reminding. Think *kaizen*. *Kaizen* is a Japanese word meaning "continuous improvement involving the entire system and everyone in it." It is a process of "deliberate, patient, continual refinements."[28] It does not involve looking for dramatic one-off solutions, rather it entails a constant struggle to find better and more reliable ways of doing the job. In this context, it means continuously striving to find better ways to reminding and of extending the scope of existing reminders

Recently, Boeing[31] became concerned about recurrent failures to replace lock wires, particularly in leading edge flap assemblies. They tackled the problem by setting up a small project group to devise ways of minimizing these lapses. The group came up with various possible solutions, but the one most favored involved small linen bags with both a draw string and a picture on the outside that clearly emphasized the need to insert lock wires.

The idea was that, on disassembly, the mechanic would remove the relevant fastenings and place them into the linen bag. The bag would then be hung on a nearby board until reassembly. At that time, the mechanic would retrieve the bag and, in so doing, be reminded about the need to insert a lock wire.

Clearly, this is not a perfect solution, but -in the spirit of *kaizen* - it would shave away some of the opportunities for an omission error. The important point, however, is that the remedial method was essentially an engineering one, involving a technical knowledge of the practicalities of the task rather than a deep understanding of human nature.

Managing Engineering Safety Health (MESH)

MESH (Managing Engineering Safety Health) was created for British Airways Engineering. It is a set of diagnostic instruments for making visible, within a particular aircraft engineering location, the situational and organizational factors most likely to contribute to human factors problems (and, indirectly, human error). Collectively, these measures are designed to give an indication of the system's state of safety and quality.

MESH is proactive. It seeks to identify local and organizational problems before they combine to cause an accident or incident. Quality and safety, like health and happiness, have two aspects: a negative one revealed by quality lapse reports, incidents, and accidents, and a positive one having to do with the system's intrinsic resistance to human factors problems. Whereas the former convert easily into numbers, trends, and targets, the latter is much harder to pin down and measure.

Reactive reporting procedures are a crucial part of any safety or quality information system. But, by themselves, they are insufficient to support effective quality and safety management. The information they provide is both too little and too late for longer-term purposes. In order to promote proactive accident prevention, rather than reactive "local repairs," it is necessary to monitor an organization's "vital signs" on a regular basis. This is what **MESH** is designed to do. It supplements, rather than supplants existing *post hoc* reporting systems.

The basic assumptions underpinning **MESH** are listed below.

- High standards of safety, quality, and productivity are all direct functions of organizational 'health' - that is, the system's intrinsic resistance to accident producing factors.
- Organizational health emerges from the interplay of several factors at both the local workplace level and the organizational level.
- A system's state of health can only be assessed and controlled through the regular measurement of a limited number of local and organizational factors.
- **MESH** is designed to provide the measurements necessary to sustain a long-term organizational fitness program.

Accident-producing factors in the workplace fall into three basic groups: human fallibility, technical and procedural shortcomings, and local hazards. We can think of them as three buckets, see **Figure 14-6**.

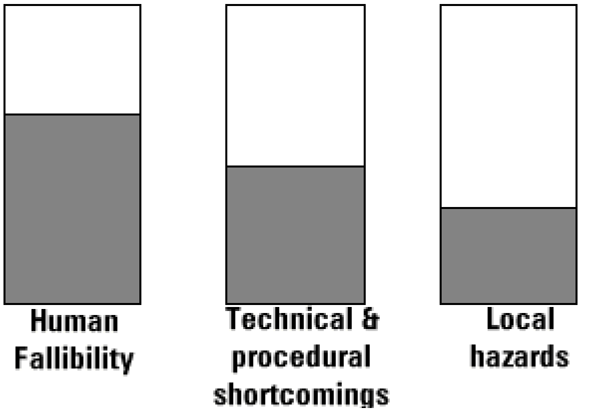


Figure 14-6. *Local accident-producing factors*

The contents of each of these buckets can vary from time to time, but they will never be completely empty. Imagine that each bucket gives off particles. The fuller the bucket, the more it gives off. Let us also assume that accidents and incidents arise when these various particles combine by chance in the presence of some weak or absent defense. **MESH** is designed to give an up-to-date indication of the fullness of the buckets. It does this by sampling selected ingredients in each bucket.

MESH, in its present form, is implemented as a software application. Instead of trying to provide complete guidelines for building the MESH application from scratch, it will be much simpler for interested readers to contact the MESH developers directly. We have provided a contact point in the **WHERE TO FIND HELP** section, which immediately follows.

WHERE TO GET HELP

Human error is pervasive. There are many commercial products that aim to identify, classify, and reduce errors. In the *Guide*, we have generally not listed commercially-available products in this section of the chapters. Instead, we prefer to provide unbiased sources of help that are generally recognized within the aviation maintenance industry.

For this chapter, however, we list two commercial products that support accident/incident investigation and reliability analysis. One of these, **MEDA**, has been recently developed within the aviation industry. The other, **MORT**, was developed for the Department of Energy and has been used over a number of years in many different domains. We don't necessarily endorse these products, but urge interested readers to contact the vendors and evaluate the usefulness of the products for their purposes.

A general source of information for all human-factors-related issues, including human error is the Human Factors and Ergonomics Society (HFES), located in California. The HFES is the only national organization representing the human factors profession. The Society structure includes approximately twenty Technical Interest Groups for members interested in particular topics. The HFES also publishes a Consultant Directory that can be used to find help for specific projects or problems. Contact the HFES at the following address:

Human Factors and Ergonomics Society

PO Box 1369

Santa Monica, CA 90406

Phone: (310) 394-1811

Fax: (310) 394-2410

Web site: http://hfes.org

Email: hfes@compuserve.com

For help with specific human factors problems, including human errors, a good source of information is the Office of Aviation Medicine (AAM) in the **FAA**. The AAM sponsored the development of this *Guide*. It also sponsors a good deal of human factors research and development each year. Since part of the charter of the FAA is to help the commercial airline industry address human factors problems, the AAM is a good starting point for inquiries related to such problems. Contact the AAM at the following address:

Ms. Jean Watson

Federal Aviation Administration

Office of Aviation Medicine
800 Independence Ave., SW
Washington, DC 20591
Phone: (202) 267-8393

The investigative tool **MEDA** was developed by Boeing, in cooperation with the **FAA**, various international airlines, and Galaxy Scientific Corporation. MEDA is available free to airlines. MEDA was developed within the aviation industry and has been tested in a number of airline maintenance organizations. If you are interested in learning more about MEDA, contact Boeing at the following address:

Maintenance and Ground Operations Systems
Customer Services Division
Boeing Commercial Airplane Group
PO Box 3707, M/S 2J-54
Seattle, WA 98124
Phone: (206) 544-0745
Fax: (206) 544-8502

The error-environment monitoring tool, **MESH**, was developed by British Airways Engineering and Jim Reason. It has been used in a real-world environment by **BA**, but has not been scientifically validated. MESH is not a commercial product. British Airways has reported on their use of MESH at the annual Human Factors in Aviation Maintenance meetings sponsored by the **FAA** Office of Aviation Medicine. While it is not a commercial product, it is a real software application that is being used every day. Interested readers should contact BA Engineering at the following address:

Mr. Edward Rogan
Human Factors Engineering Manager
Quality & Training Services
British Airways
Technical Block A (S352)
PO Box 10 - Heathrow Airport
Hounslow - Middlesex TW6 2JA
England

The Department of Energy, through its contractor EG&G, developed the investigative, hazard analysis, and quality assurance tool MORT (Management Oversight and Risk Tree) in the 1970's. It is the underlying diagrammatic base underlying a number of investigative processes, including root cause analysis. Various commercial products based on MORT have been developed. Most of them are computer-based. As with other commercial products, we do not endorse MORT-based applications. However, MORT has been around a long time and has been used in a wide range of domains. Interested readers should contact the following vendor:

Conger & Elsea

9870 Highway 92

Suite 300

Woodstock, GA 30188

Phone: (770) 926-1131 or (800) 875-8709

Fax: (770) 926-8305

E-mail: congerd@aol.com

Web: www.conger-elsea.com

FURTHER READING

The documents listed below contain information pertaining to human error. They may or may not have been referred to in the chapter.

Drury, C. G., & Rangel, J. (1996). Reducing automation-related errors in maintenance and inspection. In *Human Factors in Aviation Maintenance-Phase VI: Progress Report Vol. II* (pp. 281-306). Washington, DC: Federal Aviation Administration/Office of Aviation Medicine.

Hawkins, F.H. (1987). *Human factors in flight*. Chapter 2 - Human Error. Brookfield, VT: Gower Technical Press.

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Senders, J.W., and Moray, N.P. (Eds.) (1991). *Human error: Cause, prediction, and reduction*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Wenner, C. L., & Drury, C. G. (1996). A unified incident reporting system for maintenance facilities. In *Human Factors in Aviation Maintenance-Phase VI: Progress Report Vol. II* (pp. 191-242). Washington, DC: Federal Aviation Administration/Office of Aviation Medicine.

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EXAMPLE SCENARIOS

The scenarios presented below represent some of the typical kinds of human-error-related situations that one can expect to encounter in the workplace. The purpose of including these scenarios in the *Guide* is to demonstrate how the authors foresee the document being used. For each scenario, we describe how the issues raised in the scenario can be resolved. There is usually more than one way to approach these issues, so the responses given below represent only one path that users of the *Guide* might take.

As a general rule, always start to look for information by using the Index at the end of the *Guide*. There will be instances in which you already know where the required information is located. However, unless you frequently use specific sections of the *Guide*, you might miss information pertaining to the same issue that is located in more than one chapter.

Scenario 1 - Can't anybody do this right?

Over the past year, you've had what you believe to be a large number of ramp delays. It seems to be something different each time and you can't seem to get a handle on the real cause of these delays. As the Maintenance Manager, you're starting to get some real heat from the operations people.

Issues

1. Are there any techniques that might let you identify the cause of these ramp delays?
2. Someone suggested sending everybody back through refresher training. Is this likely to have an effect on the ramp delay problem?
3. You're thinking of offering an incentive for fewer delays -- maybe an extra half-day of vacation. What effect is this plan likely to have on ramp delays?

Responses

1. There appear to be a number of these ramp delays and they've occurred over a period of time. If we were looking at just one incident and trying to find its root causes, then we might try one of the investigative techniques, such as **MEDA**. However, in this case, we're still trying to figure out just what types of errors are responsible for the ramp delays. We address identifying errors in the **GUIDELINES** section. Since we have so much data available, in the form of operational reports, this is a good candidate for **pareto analysis**.

2. We point out in several places in the chapter that errors are unintentional acts. The discussion of training points out that training is useful for initiating or changing intentional behavior. For unintentional acts, however, training isn't likely to be very effective. We can't say for sure that training wouldn't work in this instance, since we don't know what is causing the ramp delays. In general, however, training isn't likely to reduce errors.

3. We don't address the use of incentives in the chapter. However, incentives are like training in one respect. That is, incentives work to modify intentional behavior. It is unlikely that incentives will reduce errors. It is possible that incentives will reduce ramp delays, since people have a tendency to do whatever is necessary to be rewarded. Unfortunately, this might have unintended (negative) effects on aircraft safety. If we don't reduce errors, but experience fewer ramp delays, then something has to give (like error reporting).

Scenario 2 - Not much of a pit crew!

One of your aircraft had a potentially serious situation recently. On its takeoff roll, a wheel fell off of the left main gear. Luckily, the gear had two wheels and the pilot was able to abort the takeoff without incident. You've been interviewing all of the technicians and inspectors who worked on the gear, but you haven't really been able to pinpoint the problem. The **FAA** has sent your airline a Letter of Investigation and you'd really like to get to the bottom of this so you can "fix" whatever is wrong.

Issues

1. Are individual interviews likely to get to the root cause of this incident? Why or why not?
2. Are there more efficient or effective methods you can use to find the cause(s) of the incident?
3. Why not just wait for the **FAA** to conduct its own investigation and then take action?

Responses

1. This is somewhat of a trick question. The fact of the matter is that accidents rarely have only a single root cause. However, ignoring the use of the singular in the question, the issue is still valid. We don't address this particular question in the chapter. While we describe two methods designed to identify root causes, we don't say anything about other methods, such as interviewing. We do, however, talk about finding fault and attributing blame to individuals. It shouldn't be too surprising that people are reluctant to admit responsibility for an error or to place blame on a co-worker.

2. In the **GUIDELINES** section, we describe two structured methods for identifying root causes - **MEDA** and **MORT** (pages 14-29 through 14-31). Either of these methods is more efficient and effective than using the "Perry Mason" approach, i.e., expecting someone to admit his guilt.

3. The **FAA** investigation and hearing processes are potentially punitive in nature. In the **REGULATORY REQUIREMENTS** section, we indicate that the FAA has some discretion regarding how they handle violations. If the airline conscientiously reports, investigates, and corrects errors, then the FAA process can be much less intrusive and time-consuming. The best situation is to prevent errors from occurring. However, errors will occur even with the best efforts of maintainers. The next best situation is to identify and report errors before the FAA Inspector does.

Scenario 3- A poor craftsman blames his tools.

You've pretty much had it with the power plant folks. For the fourth time in as many months, they've failed to spot worn seals during routine borescope inspections of engines on a particular type of aircraft. This has resulted in two in-flight shutdowns and two extended ramp delays. The technicians say the borescope doesn't provide sufficient illumination at the seal and that they have trouble getting into a good position to view that particular area of the engine.

Issues

1. Someone told you that a pareto analysis would help you get to the bottom of this problem. Is that likely?
2. This same borescope is used to inspect lots of different engines and components. If the tool were at fault, wouldn't this problem show up with other aircraft?
3. What sorts of factors should you be looking at to eliminate these oversights?

Responses

1. **Pareto analysis** is described in the **METHODS** and the **GUIDELINES** sections. Pareto analysis is useful when we have a lot of incidents to investigate. Since it is essentially a frequency analysis tool, we need more than a few incidents to generate enough data to be useful. Since we have only four incidents, one of the root cause identification techniques would probably be more useful.

2. Not necessarily. All of these errors occurred on a particular type of aircraft. Perhaps there is something unique to this aircraft that causes or allows these errors to occur. We noted in the chapter that there is rarely only one cause for an error or incident. It might be the case here, that this aircraft has a unique combination of features that causes this particular error.

3. There are a number of factors that might have some part in these errors. The list of factors would provide a good start when investigating these errors. Note that this list includes tools, such as the borescope in question.

Scenario 4-Don't ask, don't tell

The company has instituted a new team maintenance concept with the idea that ramp delays, re-installation errors, and **FAA** violations will decrease. To help them be proactive, they've instituted an error reporting system in which technicians and inspectors can report errors and violations. This is an e-mail based system. Analysts who pull the reports from the system, simply attach the reporter's e-mail address and then use it to get more details.

Issues

1. Is this system likely to produce any results in its present form? Why or why not?
2. Does the idea of a proactive reporting system have merit? Why or why not?
3. What would you do to this system to increase its chances of success?

Responses

1. In the **METHODS** section, we talk about **anonymous reporting** processes and about the **critical incident technique**. The concept described in this scenario has only one major flaw, but it's fatal. The reports are not anonymous. By tagging the incoming reports with the reporter's e-mail address, the process has automatically captured the identity of the person reporting the error or violation. Such systems must allow anonymous reporting.

2. Yes. Not just proactive reporting of near misses as with the **critical incident technique**, but proactive assessment of the conditions that support the commission of errors, as with **MESH**.

3. The single best thing you could do with this system is to strip the e-mail address of the reporter from the report.

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