THERE ARE TWO approaches to studying human performance in high-technology hazardous systems: one involves the “fly-on-the-wall” observation of normal activities; the other is triggered by the occurrence of an adverse event. An “event” is something untoward that disrupts the flow of normal or intended activities and which may, and often does, have harmful consequences.

In human factors research at least, there can be little doubt that the dominant tradition is the event-dependent one. Such analyses focus upon the errors and violations that either constitute or contribute to an event. The worse the event, the more intensive is the investigation of the preceding decisions and actions. As a result, we have learned a good deal about the varieties of unsafe acts and, to a lesser degree, we know something of the circumstances that can provoke and shape them.

Unfortunately, this has established a very biased view of the human factor—as something that is causally implicated in the large majority of bad events. To compound the problem further, stating that people make errors is probably one of the least interesting observations about the human condition—on a par with declaring that we breathe oxygen and will some day die. Such information is undoubtedly important, but hardly newsworthy. Nonetheless, errors are sufficiently uppermost in the minds of the managers of hazardous technologies that they often regard the main goal of safety management as the elimination of human fallibility rather than the avoidance of its damaging consequences.

So if human fallibility is a mere truism, what is there that is really interesting about human performance? The answer I believe, lies on the reverse side of the coin. As operators of complex systems, people have an unmatched capacity to adapt and adjust to the surprises thrown up by a dynamic and uncertain world. This includes the often remarkable ability to compensate for their own errors.

Making errors is a fact of life, but recovering from them—particularly when these recoveries involve heroic improvisations—is quite another matter.

Gimli glider: On 23 July 1983, a Boeing 767 aircraft enroute to Edmonton from Ottawa ran out of fuel over Red Lake, Ontario, about halfway to its destination. The reasons for this were a combination of inoperative fuel gauges, fuel leading errors and mistaken assumptions on the part of the flight crew. These errors and system failures were dealt with at length in the 104-page report of the Board of Inquiry.

Only three paragraphs were devoted to the most extraordinary feature of this event: the forced landing at Gimli, a disused military airstrip, from which all 61 passengers and eight flight crew walked away unhurt from an aircraft that was fit for service after relatively minor repairs.

When the second engine stopped, the aircraft was at 35,000 feet and 65nm from Winnipeg. All the electronic gauges in the cockpit had ceased to function, leaving only stand-by instruments operative. The first officer, an ex-military pilot, recalled that he had flown training aircraft in and out of Gimli, some 45 miles away. When it became evident that they would not make it to Winnipeg, the captain, in consultation with air traffic control, redirected the aircraft to Gimli, now 12 miles away on the shores of Lake Winnipeg. The report continues as follows:

“Fortunately for all concerned, one of Captain Pearson’s skills is gliding. He proved his skill as a glider pilot by using gliding techniques to fly the large aircraft to a safe landing. Without power, the aircraft had no flaps or slats to control the rate and speed of descent. There was only one chance of landing. By the time the aircraft reached the beginning of the runway, it had to be flying low enough and slowly enough to land within the length of the 7,200ft (2,200m) runway.

“As they approached Gimli, Captain Pearson and First Officer Quintal discussed the possibility of executing a side-slip to lose height and speed close to the beginning of the runway. This the captain did on the final approach and touched down within 800ft (244m) of the threshold.”

The last laconic sentence is a masterpiece of understatement. “It is unlikely that either Boeing or Captain Pearson’s employers had ever imagined the side-slip manoeuvre being applied to a … jet airliner.”

This was heroic improvisation at its most inspired. Theoretical framework: The literature provides relatively little in the way of theoretical guidance when it comes to understanding and facilitating these remarkable adaptations. Most safety-related studies have focused upon identifying those factors that create moments of vulnera-

bility rather than elucidating the nature of resilience. The two notable exceptions are, firstly, the observation-based analyses of high-reliability organisations; and, secondly, the more person-oriented work on mental readiness in the achievement of sporting and surgical excellence. Although these two research areas derive from different disciplinary backgrounds, they reveal similar processes operating at both the organisational and individual levels.

There would appear to be at least two vital components underpinning both high-reliability organisations and individual excellence:

• a mindset that expects unpleasant surprises.
• the flexibility to deploy different modes of adaptation in different circumstances.

In short, there is a mental element and an action element. Of these, the former is at least as important as the latter. Effective contingency planning at both the organisational and the personal levels depends on the ability to anticipate a wide variety of crises. Both components are resource-limited. Any person or organisation can only foresee and prepare for a finite number of possible circumstances and crisis scenarios. Crises consume available coping resources.
All [operators] make errors, but the best ... have the ability to compensate for [them]. This ability depends on the ... and recovery of their errors.
A closer inspection: What really happens in the cockpit

ACHIEVING SAFETY requires accurate data about the way an organisation functions in normal operations and how it responds to threat and error.

However, airlines have historically relied on data from performance in training and on formal proficiency checks conducted in simulators. These data provide accurate information on a pilot’s technical competence and ability to respond to particular challenges. In the case of line oriented evaluation (LOE) the data show ability to respond to normal and abnormal situations. Data are also obtained from line checks in which an evaluator grades performance during normal flight operations.

The limitation of this kind of data is that they do not tell you how crews behave when they are not under formal surveillance. Are the behaviours during formal evaluation routinely followed by crews not under scrutiny?

Another source of safety data comes from monitoring digital flight data recorders (flight operations quality assurance or FOQA). FOQA data provide a precise record of flight parameters and crew actions and have been hailed as a major contribution to safety. However, the limitation of FOQA data is that no information is recorded about why particular actions were taken.

Finally, formal analyses of data on accidents and incidents provide insights, but are limited because they are rare events that may not be representative.

To get a full picture of crew behaviour and system performance and to check on the impact of safety initiatives such as crew resource management (CRM), our research group at the University of Texas at Austin placed specially trained, expert observers in the cockpit of normal line flights. We call this a line operation safety audit, or LOSA.

The critical difference between a LOSA flight and a line check is LOSA’s guarantee of anonymity for the crew. Data are entered into a de-identified database and no crew actions are reported to management or the regulatory agency.

From the information we have collected, we are confident that trust has been achieved, and that we are indeed observing normal operations.

One of the important aspects of LOSA is the fact that it captures exemplary as well as deficient performance: it is important for organisations to know areas in which they excel as well as those in need of improvement.

Observers generate a narrative of the flight classified by phase. Coding begins with crew behaviour in the pre-flight phase and includes ratings of the behavioural markers of CRM practices developed by the University of Texas group (see Helmreich and Foushee, 1995 for history).

Up to 1997 we observed more than 3,000 flight segments in five airlines using ratings based on CRM behaviours. Since 1997 the research group has focussed explicitly on threat and error, and has observed more than 1,000 flight segments. This involves coding external threats to safety and errors committed by external agents such as air traffic control. The behavioural markers employed to manage threat are also coded.

Error is classified in LOSA as deviation from organisational or crew expectations or intentions. Errors committed by the flight crew are described and coded along with actions (if any) taken to deal with the consequences of the error.

Varieties of error. Drawing from the observations of error, we have been able to classify all of the errors seen into five broad categories: procedural errors, communications errors, decision errors, proficiency errors and violations.

Procedural errors. These are what most people think of as errors: crews intending to follow a procedure, but doing it incorrectly. Procedural errors include the usual classification of slips, lapses and mistakes. This type of error can only be committed when actions are covered by formal procedures.

Communications errors. These involve failures in the transfer of information, including misstatements, misunderstandings and omissions. The identification of communications errors in accident investigations provided impetus for the development of CRM training.

Decision errors. When crews choose to follow a course of action that unnecessarily increases risk to the flight in a situation not governed by formal procedures, this action is classified as a decision error. For example, crews may choose not to deviate around weather on their flight path, resulting in an encounter with turbulence.

Proficiency errors. This classification is applied to situations where a crew member lacks the knowledge or stick-and-rudder skill necessary to perform a task. A number of observed proficiency errors involve lack of knowledge of flight deck automation.

Intentional non-compliance. When crews obviously and intentionally violate company or regulatory requirements, these are classified as intentional non-compliance errors. Failing to abort an unstable approach as required by company procedures would fit into this classification.

The outcomes of threats and errors can be inconsequential or consequential. In our methodology, consequential errors are those that result in an undesired aircraft state or lead to additional crew error. Undesired aircraft states include deviations from desired navigational path or altitude, unstable approaches, long or hard landings, being on the wrong runway or taxiway and arriving at the wrong airport or wrong country. Most undesired states put flights at increased risk.

When an error (or threat) becomes consequential, the crew is no longer managing threat.
and error, their task becomes management of the undesired state.

Since 1997, we have conducted six formal LOSAs involving US and foreign air carriers using the threat and error management methodology. The data show that 72 per cent of flights observed encountered one or more threats, with an average of two per flight and a range of 0 to 17. The most frequently encountered threats were adverse weather (34 per cent), ATC actions or errors (34 per cent) and aircraft malfunctions (15 per cent).

Errors were observed on 68 per cent of flights, again with an average of two per segment and a range of 0 to 14. The most frequent source of error was data entry into the mode control panel or flight management computer. The second most frequent error involved the use and completion of checklists. The figure below shows the percentage of each error type as well as the percentage of each type classified as consequential.

The most frequent type of error – more than half of those observed – was non-compliance or violation. In contrast, proficiency errors were the least frequent (five per cent) – a tribute to the qualification standards of the airlines.

Violations matter: With only two per cent of violations leading to undesired aircraft states, it is tempting to say that most intentional non-compliance is of little import, a bit like driving just over the speed limit. However, analysis suggests that this is not the case: violations matter since those who violate place a flight at greater risk.

We reached this conclusion by splitting the database into two groups, those flights with one or more violations and those with none. We then looked at the incidence and consequences of other types of errors by each group. We found that crews with a violation were almost twice as likely to commit one of the other four types of error and that the errors were nearly twice as likely to be consequential.

Examination of the outcomes of error reveals that 85 per cent of all errors are inconsequential – evidence of the error tolerance of the aviation system. Of those errors that were consequential, 12 per cent resulted in undesired aircraft states and three per cent resulted in additional error, creating an error chain. When the error resulted in an undesired aircraft state, 79 per cent of these were mitigated by crew action. In two per cent of the cases crew action exacerbated the situation while in 12 per cent no attempt to alleviate the situation was observed.

There was also substantial variability in the occurrence of threat and error across phases of flight (see table below). Consistent with the global accident rate, it is not surprising to find that the highest percentage of both threats and errors were encountered in the approach and landing phase. What is surprising is the fact that more than 20 per cent of threats and errors were found during the pre-departure/takeoff phase, emphasising the importance of pre-flight and departure activities.

We note that the most significant differences between national cultures found in our survey of pilots in more than twenty nations related to the importance of adhering to rules. The US scored as the least accepting of the importance of following rules. As a result of these cultural differences, we would not expect to find a comparable percentage of intentional non-compliance errors in cultures higher on the rules and order dimension.

A high degree of variability was found between airlines in the number of threats encountered, the number of errors committed and the percentage leading to undesired aircraft states. This is hardly surprising as the airlines sampled differed in many ways. The implications of this are that the methodology can be used to sample any type of operation and can show norms and also variability in a highly complex system.

Value-assured: Organisations that have participated in LOSA have been enthusiastic about its value. The data provide management with information that helps them to prioritise safety initiatives, and training departments can use the information to develop targeted training.

The various types of error suggest different remedial strategies. For example, a high incidence of violations can point to poor procedures, weak leadership, and/or a culture of non-compliance.

Procedural errors may suggest poor workload management or may be a reflection of inadequate procedures. Communications errors may reflect a need for more focus on CRM, especially interpersonal communications issues.

Similarly, decision errors may suggest a need for further CRM concentration on expert decision making and risk assessment. Finally, proficiency errors suggest a need to tighten standards for qualification and evaluation.

Requests from airlines in the US and abroad far outstrip the capabilities of the University of Texas research group. The current LOSA procedures are better suited to research than to operational assessment. The research team aims to develop a more user-friendly set of procedures that can be applied by organisations for self-assessment. As it grows, the database can be used to answer very specific questions, for example is crew performance better with the captain or the first officer flying? Based on data from 3,800 flights, the answer is that it makes no difference if the environment is benign, but effectiveness is significantly higher in complex, challenging environments with the first officer flying (Hines, 1997).

One of the strengths of the LOSA project is the fact that a database is being developed that allows organisations to compare their results with those of other airlines. Such comparisons help in interpretation of the significance of, for example, the number of procedural and decision errors observed and the effectiveness of threat and error counter-measures.

Using the data from LOSA, we have developed a model of threat and error management. The model fits well with Reason’s renowned “Swiss cheese” model (1990). It recognises both overt and latent threats and how they fit into the management of error and undesired states. The error component of the model is shown in the diagram below.

The model is proving useful as a guide to the analysis and understanding of incidents and accidents and is being employed by the safety department of one major airline.

**THE THREAT AND ERROR**

<table>
<thead>
<tr>
<th>Phase of Flight</th>
<th>Threat %</th>
<th>Error %</th>
</tr>
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<tbody>
<tr>
<td>Pre Departure / Taxi</td>
<td>22%</td>
<td>23%</td>
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<td>Take-off / Climb</td>
<td>28%</td>
<td>24%</td>
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<td>Cruise</td>
<td>10%</td>
<td>13%</td>
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<tr>
<td>Descent / Approach / Land</td>
<td>39%</td>
<td>40%</td>
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<tr>
<td>Taxi / Park</td>
<td>1%</td>
<td>2%</td>
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**Chapter 3: Human Factors**

**ERROR MANAGEMENT**

Using the model as a template can aid in the identification and remediation of latent threats before they have adverse consequences.

Non-judgemental assessment of crew behaviour provides a valid picture of normal flight operations. The fact that a majority of the errors observed involved violations of procedures or regulations indicates that crews trust the system and do not perceive the observations as threatening their status.

Bob Helmreich is head of the University of Texas Human Factors Research Project.

The error management component of the University of Texas threat and error management model.
A nalysis of the behaviour of operational personnel in accidents and incidents has traditionally been the method used to assess the impact of human performance on safety.

The behaviour preceding a negative outcome is analysed, searching for human error, with usually only limited consideration of the processes that could have led to the “bad” outcome. An investigator will already know that the behaviours displayed by operational personnel were “bad” because the negative outcomes are a matter of record, a benefit the operational personnel obviously did not have at the time. In this sense, investigators examining human performance in safety occurrences enjoy the benefit of hindsight.

Conventional wisdom holds that, in aviation, safety is first. Consequently, human behaviours and decision-making are considered to be totally safety oriented. However, all production systems – and aviation is no exception – generate a migration of behaviours under the imperative of economics and efficiency, people tend to operate at the edges of the system's safety space.

A more realistic approach is to consider operational behaviours and decision-making as a compromise between production and safety.

Operational errors do not reside in the person, as conventional safety knowledge would have us believe. They reside within task and situational factors, emerging as the consequence of mismanaging compromises between safety and production. These compromises are a complex and delicate balance, and humans are generally very effective in applying the right mechanisms to achieve success, hence the extraordinary safety record of aviation.

Humans do sometimes fail to balance the compromise, so contributing to safety breakdowns. However, since successful compromises far outnumber failures, in order to understand human performance in context the industry needs to systematically analyse the mechanisms underlying successful compromises, rather than those that failed.

**Incident and accident investigation.**

The most widely used tool to document operational human performance and define remedial strategies is the investigation of accidents. However, there are limits to the lessons available through this process.

For example, it might be possible to identify the type and frequency of errors, or discover specific training deficiencies related to identified errors, but this is only the tip of the iceberg.

Nevertheless, accident investigation has a clear role within the safety process. It remains the appropriate tool to uncover unanticipated failures in technology or rare, bizarre events. If only normal operations were monitored, defining assumptions about safe/unsafe behaviours would prove to be a task without a frame of reference.

Therefore, a properly focussed and contemporary accident investigation can reveal how specific behaviours, including errors and error management, can generate an unstable or catastrophic state of affairs. Should accident investigation restrict itself to mere retroactive analyses, its only contribution in terms of human error would be increased industry databases, the usefulness of which remains dubious.

Incidents are more telling markers than accidents – at least of system safety – because they signal weaknesses within the overall system before it breaks down. There are, nevertheless, limits to the value of this information.

First, incidents are reported in the language of aviation and therefore capture only the external manifestations of errors. Second, incidents are self-reported, so the processes and mechanisms underlying an error may not reflect reality. Third – and most importantly – accident reporting systems are vulnerable to what has been described as “normalisation of deviance!”

**Normalised deviance.**

Over time, operational personnel develop informal and spontaneous group practices that circumvent poor equipment design, clumsy procedures, or policies incompatible with operational realities, all of which complicate operational tasks. Precisely because they are normal, neither these practices nor their downsides will be noted by incident reporting systems.

This problem is compounded by the fact that the most willing reporters may not fully appreciate what events should be reported. If you are continuously exposed to substandard managerial practices, poor working conditions, or flawed equipment, you might have difficulty working out what problems are reportable.

While these factors would arguably be reported if they generated incidents, there remains the difficult task of evaluating how they create less than safe situations.

Incident reporting systems are better than accident investigations for understanding system and operational human performance. Their value lies in pinpointing areas of concern, however, incident information does not necessarily capture the concerns themselves.

**W... operational personnel develop informal and spontaneous group practices that circumvent poor equipment design, clumsy procedures, or policies incompatible with operational realities, all of which complicate operational tasks.**
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HUMAN FACTORS SPECIAL

The majority of errors have no damaging consequences because operational personnel employ successful coping strategies, and system defences act as a containment net.

The observation of training behaviours, such as flight crew simulator training, is another tool which can help us to understand operational human performance. However, training behaviours are heavily biased towards safety—things are done “by the book”, providing only an approximation of behaviour during line operations.

Digital Flight Data Recorder (DFDR) and Quick Access Recorder (QAR) information from normal flights are valuable diagnostic tools. While DFDR/QAR read-outs provide information on the frequency operational limits are exceeded and their locations, these cannot yield information on the human behaviours leading to an event. Pilot reports are still necessary to provide the context in which to diagnose the problems.

Although probably under utilised because of cultural and legal factors, DFDR/QAR data can help to identify the operational contexts within which movement of behaviours towards the edge of the system’s safety limits take place.

In order to uncover the mechanisms underlying the human contribution to failures and successes in aviation safety we need to focus on the monitoring of normal line operations. Any typical line flight involves inevitable—mostly inconsequential—errors. Examples include selecting wrong frequencies, dialling wrong altitudes, acknowledging incorrect readbacks and mishandling switches and levers. Some errors are due to flaws in human performance, others are fostered by shortcomings in the system, most are a combination of both. The majority of errors have no damaging consequences because operational personnel employ successful coping strategies, and system defences act as a containment net. It is by understanding these successful strategies and defences that we can best learn to shape remedial strategies, rather than by continuing to focus solely on failures.

Looking only at data after the fact seems a bit like trying to design a good celebration by focussing on “sweeping up after the parade.” It is essential to move beyond the visible manifestations of error when designing remedial strategies.

A new approach: Progressing to normal operations monitoring requires adjusting the prevailing view of human error. In the past, safety analyses in aviation have viewed human error as an undesirable and wrongful manifestation of human behaviour. In recent years, a considerable body of practically oriented research has substantiated a fundamental concept of human cognition: error is a normal component of human behaviour. Regardless of the quantity and quality of regulation, new technology, or new training, error will continue to be a factor in operational environments because it is simply the down side of human logic.

Error is a conservation mechanism afforded by human cognition to allow us to operate flexibly under demanding conditions for prolonged periods without draining our mental batteries. In other words, error is the price we pay for being able to think on our feet.

In operational contexts, errors that are caught in time and do not produce damaging consequences are, for practical purposes, inconsequential. Counter-measures to error should not just look at avoiding errors, but rather to making them visible and trapping them before they produce damaging consequences. This is the essence of error management.

Under a Line Operation Safety Audit (LOSA), flaws in human performance and the prevalence of error are taken for granted, and the objective becomes improving the context within which humans perform. LOSA aims ultimately to introduce a buffer zone or time delay between an error and the point its consequences become a threat to safety. This better the quality of the buffer or the longer the time delay, the stronger the tolerance of the operational context to the negative consequences of human error.

The challenge for the large-scale implementation of analysis of normal operations is to overcome the obstacles presented by a blame-oriented industry.

Captain Daniel E. Maurino is head of the human factors program for the International Civil Aviation Organization.

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FLIGHT SAFETY AUSTRALIA, JANUARY/FEBRUARY 2001 • 39
Score your safety culture

CHECKLIST FOR ASSESSING INSTITUTIONAL RESILIENCE

<table>
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<tr>
<th>Scored: YES = This is definitely the case in my organisation (scores 1); ? = “Don’t know”, “maybe” or “could be partially true” (scores 0.5); NO = This is definitely not the case in my organisation (scores zero).</th>
<th>YES</th>
<th>?</th>
<th>NO</th>
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<tr>
<td>Mindful of danger: Top managers are ever mindful of the human and organisational factors that can endanger their operations.</td>
<td>☐</td>
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<tr>
<td>Accept setbacks: Top management accepts occasional setbacks and nasty surprises as inevitable. They anticipate that staff will make errors and train them to detect and recover from them.</td>
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<td>Committed: Top managers are genuinely committed to aviation safety and provide adequate resources to serve this end.</td>
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<td>Regular meetings: Safety-related issues are considered at high-level meetings on a regular basis, not just after some bad event.</td>
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<td>Events reviewed: Past events are thoroughly reviewed at top-level meetings and the lessons learned are implemented as global reforms rather than local repairs.</td>
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<td>Improved defence: After some mishap, the primary aim of top management is to identify the failed system defences and improve them, rather than to seek to divert responsibility to particular individuals.</td>
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<td>Health checks: Top management adopts a proactive stance towards safety. That is, it does some or all of the following: takes steps to identify recurrent error traps and remove them; strives to eliminate the workforce and organisational factors likely to provoke errors; “brainstorms” new scenarios of failure; and conducts regular “health checks” on the organisational processes known to contribute to mishaps.</td>
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<td>Institutional factors recognised: Top management recognises that error-provoking institutional factors (like understaffing, inadequate equipment, inequality, outdated training, bad human-machine interfaces, etc.) are easier to manage and correct than fleeting psychological states such as distraction, inattention and forgetfulness.</td>
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<td>Data: It is understood that the effective management of safety, just like any other management process, depends critically on the collection, analysis and dissemination of relevant information.</td>
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<td>Vital signs: Management recognises the necessity of combining reactive outcome data (e.g., near misses and incident reporting systems) with active process information. The latter entails far more than occasional audits. It involves the regular sampling of a variety of institutional parameters (scheduling, budgeting, forecasting, procedures, defences, training, and the like), identifying which of these “vital signs” are most in need of attention, and then carrying out remedial actions.</td>
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<tr>
<td>Staff attend safety meetings: Meetings relating to safety are attended by staff from a wide variety of departments and levels.</td>
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<tr>
<td>Career boost: Assignment to a safety-related function (quality or risk management) is seen as a fast-track appointment, not a dead end. Such functions are accorded appropriate status and salary.</td>
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**INTERPRETING YOUR SCORE**

- 1-5 You are very vulnerable.
- 6-10 Not all that bad but there’s still a long way to go.
- 11-15 You’re in good shape, but don’t forget to be uneasy.
- 16-20 So healthy as to be barely credible.

**HEALTH WARNING**

High scores on this checklist provide no guarantee of immunity from accidents or incidents. Even the “healthiest” institutions can still have bad events. But a moderate to good score (8-15) suggests that you are striving hard to achieve a high degree of robustness while still meeting your other organisational objectives. The price of safety is chronic unease: compliance is the worst enemy. There are no final victories in the struggle for safety.

Checklist written by Professor James Reason and presented at the 2000 Manx Conference.