THE GLOBAL AVIATION INFORMATION NETWORK (GAIN)

Using Information to Make the Aviation System Less Error Prone and More Error Tolerant

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Abstract: The worldwide commercial aviation system is a complex system involving hardware, software, and liveware (humans). All of these components must work together efficiently and effectively in a variety of environments in order for the system to function successfully. One of the least predictable aspects of how the system operates is what the humans will do. In the aviation system, much of this lack of predictability results from inadvertent error and/or operators of the system trying to optimize the functioning of the system in unanticipated situations. When undesirable consequences result from the inadvertent error and/or well-intentioned efforts to make the system work better, the human action is usually classified as "human error." As the aviation system becomes more complex, safety professionals are concluding that responding successfully to "human error" necessitates increased focus on the system. Focusing primarily upon the individual who committed the "error" (a) assumes, sometimes incorrectly, that the most effective remedy is getting the individual to behave differently, and (b) fails to consider the role of the system in leading to the undesired behavior. An essential element for enhanced system focus is better information. Rapid advances in information technologies are creating unprecedented opportunities for safety professionals to collect better information about how the operators of the system make it work. That information helps safety professionals improve the system by making it (a) less likely to result in human error, i.e., less error prone; and (b) more capable of withstanding human error without catastrophic result, i.e., more error tolerant. The Global Aviation Information Network (GAIN) is promoting and facilitating the voluntary collection, analysis, and sharing of information in the international aviation community to improve safety. GAIN was proposed by the U.S. Federal Aviation Administration (FAA), but it has evolved into an international coalition of aviation community members – airlines, manufacturers, unions, and governments. GAIN is helping to create legal and cultural environments that encourage and facilitate the collection of large quantities of data. GAIN is also creating tools and processes to help aviation safety professionals convert that data into useful information to (a) identify potential safety issues, (b) prioritize them, (c) develop solutions, and (d) evaluate whether the solutions are working. Two aspects of GAIN that have been discovered from experience are significantly enhancing its development. First, the tools and processes can be used not only in other transportation modes, but also in other industries, including chemical manufacturing, nuclear power, public utilities, health care and national security. Second, experience is demonstrating that the systematic collection and sharing of safety information can not only facilitate the correction of troublesome trends, but can also result in significant immediate cost savings in operations and maintenance. In theory, other industries applying these tools and processes should also be able to reap significant immediate economic benefits. Extensive information about GAIN is on the Internet at www.gainweb.org

Key words: Aviation safety, mishap prevention, proactive information programs, human error, error prone, error tolerant, data collection, data analysis, data sharing

1. ROOT CAUSES OF HUMAN ERROR IN COMPLEX SYSTEMS

Most of the worldwide commercial aviation community workforce is highly trained, competent, experienced, and proud of making the system work well. Despite these efforts to make the system work, however (along with numerous other activities to improve safety), mishaps occur – albeit at a commendably low rate. Inasmuch as the workforce is proud, competent, and trying to make the system work, why do they nonetheless make errors that can be harmful, even (in the case of pilots) to themselves?

The commercial aviation system consists of a complex array of ever-changing, interdependent, tightly coupled components, all of which must work together efficiently and effectively in order for the system to function successfully. The complexity of the system has been increasing over the years, and most experts expect even more complexity in the future. The increasing complexity of the system engenders human error in three ways.[2]

First, more complexity increases the difficulty of designing human error out of a system, even when it is operated by a competent, highly trained, experienced workforce. Designing a component of a system to be "error

[2] These three are in addition to other factors that can exacerbate human error, irrespective of whether complexity is increasing, e.g., pressures to accomplish more with less.

proof" is challenging enough, but making it error proof in a dynamic, tightly coupled, interdependent environment is considerably more challenging.

Second, more complexity increases the likelihood that the operator will face situations that the operator, and possibly even the designer, did not anticipate. In a complex, tightly coupled, dynamic system, it is very difficult for component designers to foresee all of the circumstances or environments in which the components will be operated.

Third, more complexity increases the likelihood that the operator will encounter situations in which responding "according to the book" would not, in the perception of the operator, make the system work best. Consequently, competent, highly trained, experienced operators who are trying to make the system work better may not respond "according to the book."

Sometimes the actions of the operators in these three categories – inadvertent error, unanticipated situations, and non-optimal operating instructions – lead to desirable results, and sometimes they do not. If the results are undesirable, the actions are generally classified as "human error."

The "human error" categorization is literally accurate because the "error" was performed by a human. In the case of unanticipated situations and non-optimal operating instructions, however, and sometimes even in the case of inadvertent error, the description is unduly pejorative in suggesting that the person did something "wrong." If other people similarly situated would have taken the same action under the circumstances, as is often the case, query how accurate or helpful it is to label the action as "error."

For example, if people trip over a step "x" times out of a thousand, how big must "x" be before we stop blaming the person and start focusing more attention on the step, e.g., should it be painted, lighted, or ramped, or should a warning sign be posted? Blaming the problem on "human error," even if literally accurate, (a) fails to prevent recurrences of the problem, and (b) exacerbates the problem because the negative implication of "error" discourages people from reporting the problem to those who can fix it.

2. THE NEED FOR INCREASED SYSTEM FOCUS

When people are trying to make an increasingly complex system work well but still make errors, including errors that can hurt themselves, our historic primary focus on the individual is no longer sufficient. Instead of focusing primarily upon the operator, e.g., with regulation, punishment, or training, we must probe further to find out why the operator did or did not take a certain action. Determining "why" requires focusing more attention on the system in which the operators are operating. Because human error cannot be eliminated, the challenge of this increased system focus is how to make the system (a) less likely to create conditions that could result in human error, i.e., less error prone; and (b) more capable of withstanding such errors without catastrophic result, i.e., more error tolerant.[3]

Responding to human error by making the system less error prone and more error tolerant does not mean *reducing* the safety accountability of the system's operators. To the contrary, it means *increasing* the safety accountability of the people who design, build, and maintain the system.

An example of the need to expand to more of a system focus is a 1974 accident on an approach to Dulles International Airport (Washington, D.C.) (Aircraft Accident Report 1975). The pilots were following the published instructions for navigating to the runway (known as the "approach chart"), but they were confused by the chart and the air traffic controller instructions, and they descended too soon and hit a ridge. The accident hearing revealed that other pilots had experienced the same confusion but did not crash because, unlike on the day of the crash, the ridge was not obscured by the clouds.

In this accident, the pilots made the final error, but effectively preventing recurrences necessitates going far beyond merely warning pilots to be more careful. Among other things, the remedies include correcting the confusing approach chart, revising pilot/controller communications protocols, installing more sophisticated navigation equipment at airports, installing terrain alerting software in air traffic control radar systems, and installing terrain alerting equipment in airplanes.

One of the most tragic aspects of this accident is that pilots from one airline reported the approach chart confusion to their management – which was unusual in those days – and management distributed warnings to their pilots; but the crash involved a different airline. Thus, this accident is cited here, despite its age, because is an example of a problem that exists to this day – inadequate collection and sharing of information in the worldwide aviation community about potential safety problems in the system.

In health care, the U.S. Institute of Medicine (IOM) issued a report about the need to expand beyond operator-focused remedies to system-focused remedies (U.S. Institute of Medicine 2001). Noting a concern that 44,000 -

[3] Improvements that increase error tolerance may facilitate additional "corner cutting" of safety margins. Query, for example, whether new in-cockpit systems that show the pilot the location of higher terrain and other airplanes may encourage illegal flight in clouds. Conversely, some improvements may reduce error tolerance. For example, improvements that allow aircraft to reach higher altitudes reduce the tolerance for cabin pressurization system error because of the longer time needed for descent to an oxygen-safe altitude in the event of failure. If the system risks are affected by new technologies, system safety principles call for a review of the hazards and the acceptability of the associated risks.

98,000 people die each year from medical mistakes,[4] the IOM proposed the systematic collection and analysis of information about "near-miss" mistakes – mishap precursors – in order to learn more about how to identify them and develop remedies. They recommended a proactive information approach because:

> Preventing errors means designing the health care system at all levels to make it safer. Building safety into processes of care is a much more effective way to reduce errors than blaming individuals . . . . The focus must shift from blaming individuals for past errors to a focus on preventing future errors by designing safety into the system. . . . [W]hen an error occurs, blaming an individual does little to make the system safer and prevent someone else from committing the same error.[5]

Improving the system is not trivial because, to its credit, most commercial aviation systems enjoy robust backups, redundancies, and safeguards, and mishaps rarely result from a single problem. Usually several things must go wrong, as "links in the accident chain," for a mishap to occur. However, the absence of any single weak point means that there is no single easily identifiable point to intervene with a remedy. A Boeing study reveals accident chains with as many as twenty links, each of which is an event that, with a different outcome, could have interrupted the accident chain (Boeing Commercial Airplane Group 1995),

This scenario can be represented by a box containing several spinning disks with holes, with a light shining into the box (Figure 1). The disks are defenses against mishaps, and the holes are breaches in the defenses. Each breach may occur without harmful result; but when the links combine in the wrong way – when the holes in the disks line up – the light emerges from the box and a mishap occurs. This borrows from the Swiss cheese analogy created by Prof. James Reason of Manchester University in the United Kingdom – a mishap occurs when the holes in a stack of cheese slices line up (Reason 1990 p. 208). The spinning disks portray the dynamic and interactive nature of the aviation system that is not as apparent with cheese.

[4] As suggested by this large range of estimates (more than a factor of two), the actual number of fatalities is not known and is a matter of considerable controversy.

[5] Id., at pp. 4-5.

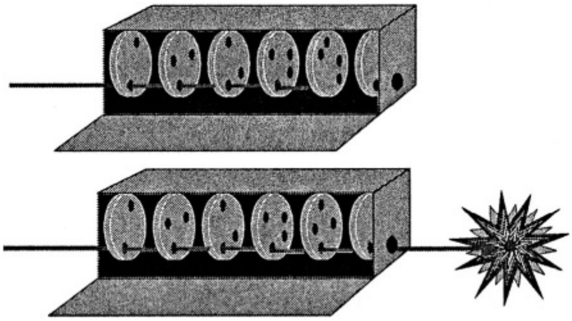

Figure 1. The Spinning Disks

Following the analogy created by Prof. Reason, the disks toward the right end of the box relate to "active" problems, e.g., the pilot's confusion about the approach chart. The disks toward the left end relate to more "latent" problems that may infect the system for years before they manifest themselves in a mishap, e.g., inadequate management focus on safety.

Many of the disks involve various parts of the system interacting with each other. Nonetheless, accident investigations have frequently placed the cause upon the person who made the "final" mistake – most often the pilots. This placement of causation ignores the fact that the person who made the final mistake probably had little or no control over most of the spinning disks to the left of the last disk, those that interacted to help create a scenario for a mishap. Fixing only the last disk unduly focuses on the individual who happened to be in the wrong place at the wrong time. In order to be more proactive, we will have to focus more on the entire system, which involves addressing all of the disks.

3. OBTAINING BETTER INFORMATION

Because of the robustness of the defenses against mishaps, the aviation community mishap scenario can be depicted by the Heinrich Pyramid (Figure 2).[6] The Heinrich Pyramid shows that for every fatal accident, there will be 3-5 non-fatal accidents, 10-15 incidents, and *hundreds* of unreported occurrences (the exact ratios vary with the nature of the endeavor).

[6] Heinrich, H.W., Industrial Accident Prevention (First Edition, McGraw Hill, 1931)

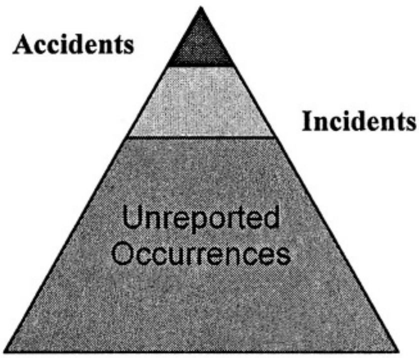

Figure 2. The Heinrich Pyramid

Usually these occurrences were not reported because each one, alone, was innocuous and did not result in a mishap. Today's unreported occurrences, however, are the "building blocks" of tomorrow's mishaps. When they happen to combine with other unreported occurrence "building blocks," they may someday result in a mishap.

In response to this situation, many industries are developing processes to collect and analyze information about precursors before they result in mishaps. All too often, the "hands-on" people on the "front lines" reveal, *after* a mishap, that, "We all knew about that problem." The challenge is to get the information that "we all knew about" and do something about it *before* it results in mishaps.

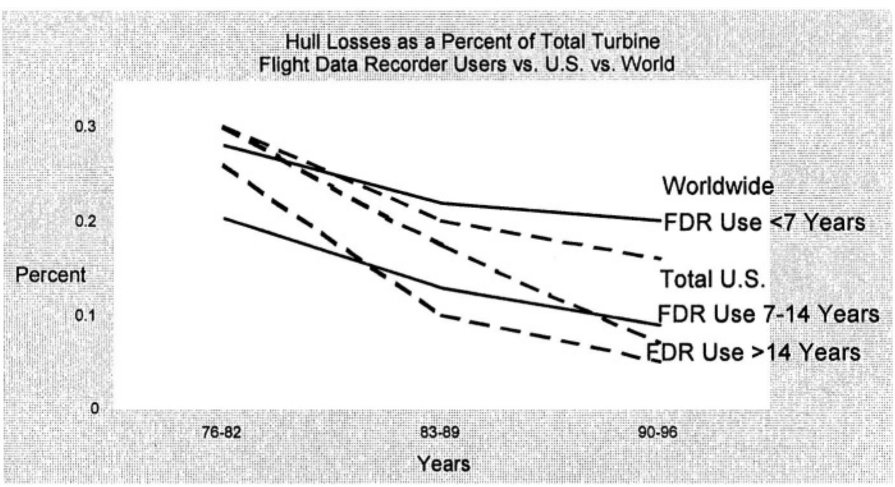

Figure 3. Effectiveness of FDR Use (Source: Total U.S. – FAA NASDAC; Other – Skandia Insurance Co., Ltd.)

In the aviation community, reporting about events near the top of the pyramid is usually mandatory, and reporting about events in the larger part of the pyramid is usually voluntary. Although mandating reporting may increase the amount of information collected, there is no reasonable way to mandate the reporting of occurrences – such as a misunderstood approach chart, as discussed above – that do not rise to the level of mishaps or potential regulatory violations. Instead, short of a mishap, the system will generally have to rely upon *voluntary* reporting, mostly from front-line workers, to learn about these types of problems. Voluntary reporting will not occur, however, unless legal and cultural barriers that deter such reporting are addressed.

1. Legal Concerns. In most countries, most or all of the following four legal concerns discourage the development of systems that would enable and encourage front-line workers – whose voluntary reporting is most important – to come forth with information.

First, potential information providers may be concerned that company management and/or regulatory authorities might use the information for punitive and/or enforcement purposes. Thus, a worker might be reluctant to report about a problem that resulted from a confusing process, fearing that management and/or the government might disagree that the process is confusing (especially if management and/or the government created the process), and punish the worker instead.

A second concern in some countries is that reporting potential problems to government regulatory agencies may result in public access to the information (including media access), and such access could be embarrassing, bad for business, or worse.

A third concern is potential criminal prosecution, and a fourth concern is that collected information may be used against the source in civil litigation.

With help from GAIN, excellent progress has been made in the U.S. on these issues, following examples set years ago by the U.K. Civil Aviation Authority. In addition, GAIN is working through the International Civil Aviation Organization (ICAO), the aviation arm of the United Nations, to get all of its 188 member countries to review their legal and regulatory structures and make modifications as needed. As a result, ICAO has taken several actions that are helping to address these legal issues worldwide.

2. Cultural Issues. Although aviation community leaders often pronounce that safety is their most important goal, the most important goal for most hands-on workers – for the advancement of their careers – is to satisfy their immediate supervisor. More often than not, however, the supervisor's career future depends upon satisfying *production, capacity, and/or efficiency* goals. If a safety concern from the hands-on workers may

undercut any of these supervisor goals, the supervisor may implicitly or explicitly discourage the reporting of potential safety concerns. Thus, one of the most significant cultural barriers is the tension that sometimes occurs between safety goals and the production, capacity, and/or efficiency goals. This is a potential problem in *all* types of aviation community entities, including airlines, manufacturers, air traffic control organizations, and government regulators.

As a result, even if the head of the organization and the hands-on workers agree that safety is important, the organization's culture will not encourage the reporting of potential safety issues by the hands-on workers unless safety is one of the supervisor's job requirements.

3. Improved Analytical Tools. Once the legal and cultural issues are addressed enough to facilitate more systematic collection of potential precursor information, the aviation community will face another major obstacle – the need for more sophisticated analytical tools to convert large quantities of data into useful information, i.e., to "separate sparse quantities of gold from large quantities of gravel." These tools will not solve problems automatically, but they must generally be able to help experienced safety professionals (a) identify potential safety issues, (b) prioritize them, (c) develop solutions, and (d) determine whether the solutions are having the desired outcome without creating any undesired effects. Tools will be needed for both digital data and textual data.

In the course of identifying and resolving concerns, with the help of more data and better analytical tools, the aviation community will have to respond in a way that is significantly different than how it has responded in the past. First and foremost, as discussed above, will be the need to expand beyond operator-focused remedies – such as blaming, punishing, and re-training – to system-focused remedies.

As safety professionals focus more on improving the system, they will need to incorporate the following two concepts into the analytical mix.

- System-Wide Interventions. First, improvements to the system have frequently related to individual components of the system. However, because the components of the system are tightly coupled and interdependent, as noted above, safety professionals will have to become better at addressing problems on a system-wide basis, not only on a component-centric level. Existing safety risk management methods are flexible enough to be applied at every level – from subcomponent to system-wide – but the aviation community does not yet have much experience applying them at system-wide levels.[7]

- Human Factors. Second, designers must learn more about creating systems and processes that account appropriately for the human factors involved. Many industries, including aviation, are studying human factors issues to varying degrees, but most are still early on the learning curve.

4. The Importance of Sharing. The collection and analysis of information can result in benefits even if the information is not shared, but the benefits increase significantly if the information is shared – not only laterally, among competing members in the aviation community, but also between various components of the community. Sharing makes the whole much greater than the sum of the parts because it allows the entire community to benefit from the experiences of every member.

Thus, if any member of the community experiences a problem and fixes it, other members can address the problem proactively, before encountering it themselves. Moreover, problems that appear to be isolated instances can much more quickly be identified as system trends of importance when the information is shared among members of the community.

The benefits of sharing, in turn, increase the importance of more sophisticated analytical tools because there is little need, desire, or capability to share raw data, except "virtual" sharing, as discussed below. What will usually be shared is *analyzed* data, or information.[8] Thus, meaningful sharing will probably not occur until data are converted by analytical tools into useful information.

"Virtual" sharing is the electronic sharing of data without the data leaving the owner. Thus, if an airline wanted to know if another airline had encountered a certain problem, it could seek permission of other airlines to apply its search tools to their databases. Database owners would always control who could search for what in their databases, and they could give different levels of permission to different users.

Both types of sharing are facilitated by the network infrastructure that GAIN has proposed, as discussed below. In order for this concept to work, however, industry, labor, and governments must work together to encourage (a) the establishment of more programs to collect and analyze information,

[7] Experience has shown that analysis of individual entity data is best conducted, in the first instance, by the entity itself because it understands the context in which the data were created. Yet to be determined is how system-wide data will be collected and analyzed.

[8] The shared information will also be de-identified because the benefit of sharing information about precursors usually outweighs any need to identify the source.

and (b) more systematic sharing of information. Governments must help facilitate collection and sharing by assuring that their laws, regulations, and policies do not discourage such activities, and by funding research to develop better analytical tools for using large quantities of data effectively.

Last, but not least, meaningful sharing requires *trust*. Because industry, labor, and governments must work effectively together in order for the aviation system to work, they must realize that blaming each other when something goes wrong is tantamount to saying that, "Your end of the ship is sinking." In order to make a safe system even safer, industry, labor, and governments must learn to trust each other and work better together to develop system solutions for system problems.

4. THE GAIN CONCEPT

In order to accomplish this information collection, analysis, and sharing to learn about the potential individual links in an accident chain, the FAA proposed the Global Aviation Information Network (GAIN). GAIN was proposed by the FAA to be a privately owned and operated worldwide information infrastructure,[9] and as hoped, it has evolved into an international coalition of aviation community members – airlines, manufacturers, unions, and governments.

GAIN is helping to promote and facilitate the voluntary collection, analysis, and sharing of safety information in the international aviation community in two ways. First, GAIN is helping to create legal and cultural environments that encourage and facilitate the collection of large quantities of data. Second, GAIN is creating tools and processes to help aviation safety professionals convert that data into useful information. With a voluntary, privately owned and operated global network of data collection and exchange systems – thus the word "Network" in the name – government, industry, and labor can cooperate with each other, to their mutual benefit, to make a safe system safer (Figure 4).

[9] If this proactive information concept reduces costs and helps to improve safety, as expected, then the aviation community will *want* to own it, and the savings will create a strong incentive to improve safety. Thus, private ownership would operate GAIN far more efficiently and effectively than a government agency because – without criticizing any government agency – private industry has both (a) greater ability to respond quickly and precisely to issues that arise, and (b) more direct economic incentive to do so. As ancillary benefits, private ownership of GAIN would help alleviate concerns that GAIN is a guise for gathering information to be used by regulatory agencies for enforcement, as well as concerns about public access to sensitive data.

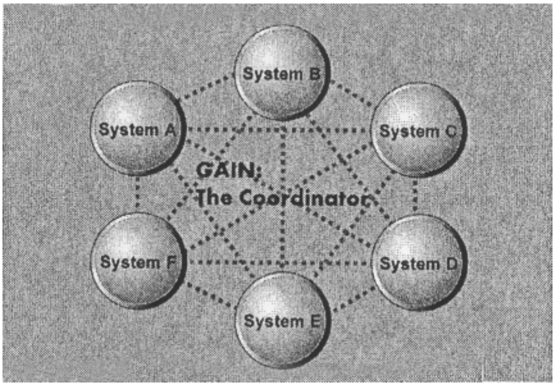

Figure 4. GAIN as a Network of Systems

Although proactive aviation information activities have been underway in some countries for years, the FAA proposed GAIN in an effort to bring many of these programs together into a more unified and systematic international network. Among the world leaders in this endeavor are the U.K. and some of its airlines, where flight data recorders have been routinely accessed as a source of valuable information for several decades.[10]

In addition, in 1996, the French Academie Nationale de L'Air et de L'Espace published a document entitled "Feedback From Experience in Civil Transport Aviation" that recommended a proposal to collect, analyze, and disseminate aviation safety information, which GAIN closely resembles. Some Scandinavian countries have been reading flight data recorders routinely for many years; Japan Airlines has had a proactive flight monitoring information program for several years; and the former Soviet Union had commenced various proactive safety information activities.

More systematic collection, analysis, and sharing of information can be a win-win for everyone involved. Private industry wins because of fewer mishaps. Labor wins because, instead of being the brunt of blame and punishment, front-line employees become a valuable source of information about potential problems and proposed solutions to accomplish what everyone wants – fewer mishaps. This presents a significant opportunity to change the relationship between labor and management from adversarial – blaming each other when things go wrong – to partners who are working together to improve safety. Government regulators win because the more they understand the problems, the more precise they can be about proposing

[10] One of the most widely used flight data analysis software packages in the worldwide aviation community is BASIS, the British Airways Safety Information System.

remedies, which makes the remedies both more effective and more credible. This further benefits industry because improved effectiveness of remedies means greater "bang for the buck" on implementing the remedies. Last but not least, the public wins because of fewer mishaps.

5. POTENTIAL BENEFITS IN ADDITION TO SAFETY

As more aviation community members implement GAIN concepts, experience is demonstrating unforeseen potential for applicability to many other industries, and for generating significant immediate economic benefits.

1. Breadth of Applicability. As in commercial aviation, many industries and endeavors, including most transportation modes, chemical manufacturing, public utilities, nuclear power, and most notably, health care, have enjoyed a declining mishap rate for several years. Many of those industries, however, are recently finding that their mishap rate decline is becoming flatter. As they explore proactive information programs to identify mishap precursors and remedy them in an effort to resume the rate reduction, it is becoming apparent that many of the reasons for the flatter decline, as well as many of the solutions, are common to most or all of these industries. Accordingly, although one size does not fit all, the opportunity exists as never before for these industries to work together and exchange notes about problems and solutions, to the benefit of all involved.

Also potentially benefiting are national security and information infrastructure protection.

GAIN is actively exploring the opportunities with these and other industries in order to avoid "reinventing the same wheel."

2. Immediate Economic Benefits? Not yet clear is whether all of these industries will also enjoy a benefit that is becoming apparent in the aviation community. Airline safety professionals have sometimes encountered difficulty "selling" proactive information programs to their management because of the commendably low fatal accident rate in commercial aviation, combined with the impossibility of proving that an accident was prevented. Fortunately, the first few airlines that implemented proactive information programs quickly started reporting *immediate* and sometimes *major* savings in operations and maintenance costs as a result of information from their safety programs. It is not yet clear whether other industries, most notably health care, will enjoy such immediate savings from their information programs, but conceptually the likelihood seems high.

Immediacy of economic benefits, if demonstrated, could be a very significant development for mishap prevention programs, by converting them to immediate and sometimes major profit centers, rather than mere “motherhood and apple pie” good ideas with potential statistically likely future economic benefits.

6. CONCLUSION

As the worldwide aviation community becomes more complex and endeavors to improve an already commendable safety record, its most difficult challenge is addressing human error, i.e., making the system less error prone and more error tolerant. Rapid advances in information technologies are providing opportunities as never before to collect, analyze, and share information to further improve the safety of the aviation system. GAIN is assisting these efforts by (a) helping to create legal and cultural environments around the world in which proactive information collection and sharing activities can flourish, and (b) developing tools and processes to help the worldwide aviation community take advantage of the major technological advances in its ability to collect, analyze, and share safety information.

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