Institute of Transportation Studies
University of California at Berkeley

Improving the Representation of Human Error in the Use of the Flight Crew Human Factors Integration Tool

Geoffrey D. Gosling
Karlene H. Roberts
Arpana Jayaswal

RESEARCH REPORT
UCB-ITS-RR-98-5

NATIONAL CENTER OF EXCELLENCE FOR
NEXTOR
AVIATION OPERATIONS RESEARCH

NEXTOR Research Report RR-98-12

August 1998
ISSN 0192 4095

Preface and Acknowledgments

This report documents research undertaken by the National Center of Excellence for Aviation Operations Research, under Federal Aviation Administration Research Contract Number DTFA03-97-D-00004, Delivery Order DTFA03-97-F-UC007, *Human Factors Support to the FAA Office of System Safety for the Global Analysis and Information Network*. Any opinions expressed herein do not necessarily reflect those of the Federal Aviation Administration (FAA) or the U.S. Department of Transportation.

This report is one of three reports documenting the various tasks in the Delivery Order. The other two reports address *Implementation of Analysis Methods and Training Needs Assessment* and *Proposed Functional Enhancements for the Flight Crew Human Factors Integration Tool.*

The discussion of individual, team and organizational factors in chapter 3 has been adapted from prior work by Martha Grabowski of Rensselear Polytechnic University and Karlene Roberts of the University of California at Berkeley. The development of the flight operations risk management questionnaire in chapter 4 has been adapted from prior work by Carolyn Libuser of the University of California at Los Angeles and Karlene Roberts.

The authors wish to acknowledge the support and suggestions provided by Jack Wojciech of the FAA Office of System Safety, as well as the assistance of Andy Muir of Abacus Technology Corporation in providing background information for the analysis described in chapter 5. The discussion of the proposed risk management questionnaire in chapter 4 benefitted from feedback on the concept by William Shontz of Boeing.

Table of Contents

List of Figures and Tables

Executive Summary

In May 1996, the FAA announced a new and innovative approach to reach a goal of “zero accidents,” known as the Global Analysis and Information Network (GAIN). This would be a privately owned and operated international information infrastructure for the collection, analysis, and dissemination of aviation safety information, that would involve the use of a broad variety of worldwide aviation data sources, coupled with comprehensive analytical techniques, to facilitate the identification of existing and emerging aviation safety problems.

A major component of the GAIN approach is the application of innovative analysis capabilities to identify the types of human error that contribute to aviation accidents and incidents in order to develop prevention strategies. As part of its Flight Crew Accident and Incident Human Factors Project, the FAA Office of System Safety has developed a new process that uses a prototype website-based Integration Tool (IT) to access, integrate, and analyze flight crew human factors data relevant to safety. In September 1996, the FAA Office of System Safety funded the National Center of Excellence for Aviation Operations Research to initiate a program of research to provide human factors support for the GAIN concept. The first phase of this research performed a technical review of the results achieved to date by the flight crew human factors project and developed a strategic plan to lay the foundations for a sound scientific approach to the analysis of human factors issues within the framework of the GAIN concept.

This report documents follow-on research activities directed at improving the representation of human error within the Integration Tool and developing better ways to identify error reduction strategies. While the current version of the IT performs a useful function by identifying specific records in a large database that meet certain criteria, and then allowing the user to display the contents of the database records for further review, its usefulness in analyzing the underlying causes of flight crew error and hence identifying strategies to reduce the frequency of occurrence of those errors is presently limited by several constraints.

These constraints may be addressed in one of two ways: by improved functionality of the IT itself, and by a richer representation of human errors and how they occur. These two aspects go hand in hand, since the ability to support a richer representation of human error depends on improved functionality of the IT, while enhanced functionality of the IT will be of greater use if it can support a better representation of how errors are committed. As part of the current project, enhancements to the prototype version of the IT have been made, that provide additional capabilities to download the information presented by the prototype version of the IT, in order to perform more extensive statistical analysis. It is of course not necessary for an improved understanding of the causal factors behind human errors to be encoded in the logic of the IT, as long as the analyst has the capability to specify how the IT will select records for further analysis. Indeed, the more flexibility that the IT gives the analyst to specify the search criteria, the more useful the tool is likely to be. However, this requires the analyst not only to have a clear idea of what to look for, but also to know how to express this to the IT. Therefore the more that can be done to incorporate an improved representation of human error in the logic of the IT, the more useful it is likely to be to the analyst.

The approach to these issues presented in this report consisted of two activities. The first examined the recent literature on human error to identify how to better characterize the context of such errors, including how to address individual, team, and organizational behavior. This effort included the development of an instrument for collecting empirical data on these behavioral constructs and incorporating them in aviation safety databases.

The second activity adopted a case-study approach to the analysis of the data presently included in the FAA Pilot Deviation System (PDS) database. This analysis built on a prior study that had been undertaken by the FAA Office of System Safety to examine the causal factors behind one of the most serious safety issues currently being faced by the FAA, namely the growing frequency of runway incursion incidents. The objective of this analysis was not just to improve the understanding of the causal factors behind runway incursion incidents, but to demonstrate how the IT can be used to gain a better understanding of the possible causes of flight crew error, to examine the utility of the IT in performing this analysis, and to identify how enhanced functionality of the IT could improve its usefulness.

The results of this analysis largely confirm the findings of the earlier FAA study, particularly the importance of effective pilot communication and airport familiarity in reducing runway incursions. Since airport familiarity depends on the prior use of the airport by the flight crew, which generally is not something that can be changed, it is important that appropriate procedures are developed and followed to compensate for this when flight crew are using unfamiliar airports. Similarly, effective pilot communication comes from both training and habit. While it may be easy to identify a failure of effective communication as a contributing factor to a runway incursion, it is much harder to determine why that failure occurred and thus what can be done to reduce the likelihood of such errors in the future. This is limited by the information currently available in the PDS database. Therefore efforts to reduce pilot surface deviations need to address the information available to be analyzed as much as the results of the analysis that can be performed.

The analysis of the runway incursion reports in the PDS database has demonstrated how enhanced functionality of the Integration Tool could greatly assist in analyzing the aviation safety data accessible with the tool, particularly the ability to select specific types of incident for analysis and to utilize the information contained in the report narratives.

In addition to the need for improved representation of the context of human error, and the inclusion of appropriate data in safety databases, the study concluded that the utility of the prototype Integration Tool will be greatly enhanced by additional functionality that provides the users with the capabilities to define their own categories of error, merge data from multiple databases, and make greater use of the information in those databases to select the records for analysis. While ultimately it is the insight and experience of aviation safety experts that will identify effective strategies to reduce the occurrence of flight crew error, the availability of effective tools to search and organize the information will enhance their ability to focus on the critical issues, and recognize the relevant patterns amid the vast amount of data that can potentially be generated by recent advances in information technology.

The challenge of reducing the fatal accident rate in U.S. aviation by 80 percent by 2007, established as a goal in the latest FAA Strategic Plan, will require a sustained commitment to developing effective tools to integrate, manage and analyze the growing volume of aviation safety data. The success of the Global Analysis and Information Network will depend not only on the ability to address the concerns over sharing proprietary or sensitive data, but also the availability of tools to manage and analyze those data.

The current version of the Integration Tool provides a useful platform from which to address these issues. However, further enhancements to the structure and logic of the IT are needed, so that it can provide users with greater functionality and access to a broader array of aviation safety data. Central to this are the capability to allow users to define their own human error models, using a rule-based format that can access any desired field in the underlying databases, and the ability to access other databases over the Internet using secure methods for the transmission of sensitive data. It is recommended that these enhancements be pursued as soon as sufficient resources can be made available.

As part of the current study, a survey was performed of the data access and analysis needs of potential users of the IT, and the prospects for cost-sharing support for developing functional enhancements for the IT. The survey results and proposed development strategy for the IT is presented in a separate report *Proposed Functional Enhancements for the Flight Crew Human Factors Integration Tool*. The survey found that an enhanced version of the Integration Tool, incorporating the features discussed above, might be able to attract significant financial support from the user community.

1. Introduction

On May 9, 1996, the FAA announced a new and innovative approach to reach the Administrator's goal of "zero accidents," known as the Global Analysis and Information Network (GAIN). GAIN would be a privately owned and operated international information infrastructure for the collection, analysis, and dissemination of aviation safety information. It would involve the use of a broad variety of worldwide aviation data sources, coupled with comprehensive analytical techniques, to facilitate the identification of existing and emerging aviation safety problems.

A major component of the GAIN approach is the application of innovative analysis capabilities to identify the types of human error that contribute to aviation accidents and incidents in order to develop prevention strategies. As part of its Flight Crew Accident and Incident Human Factors Project, the Office of System Safety has developed a new process that uses a website-based prototype Integration Tool (IT) to access, integrate, and analyze flight crew human factors data relevant to safety. The initial process applies two human error models to the NTSB accident database and the FAA Pilot Deviation System (PDS) incident database and generates human factors patterns and trends. Safety analysts in the Office of System Safety began to use the initial process in October 1996.

In September 1996, the FAA Office of System Safety funded a research grant to the National Center of Excellence for Aviation Operations Research to initiate a program of research to provide human factors support for the GAIN concept. The first phase of this research, consisted of two tasks; first to continue the application and improvement of the IT and lay the foundations for a sound scientific approach to the analysis of human factors issues within the framework of the GAIN concept; and second to review the results achieved to date by the flight crew human factors data contractor and integrate recommendations from this technical review into a strategic plan.

This report documents research activities directed at improving the representation of human error within the Integration Tool and developing better ways to identify error reduction strategies, that have been undertaken as follow-on activities to Phase I to address further development of the IT to implement the recommendations of the technical review.

Need for Improved Representation of Human Error

The current version of the Integration Tool applies two models of human error to classify events contained in the National Transportation Safety Board Accident and Incident Database (NTSB/AID) and the FAA National Airspace Incident Monitoring System Pilot Deviation System (NAIMS/PDS) database. The first error model (Human Error Model 1) is based on the paradigm advanced by Norman (1981, 1983), and attempts to classify the errors that caused the incidents as either slips or mistakes, where slips are unintentional actions and mistakes are intentional actions. The second model (Human Error Model 2) draws on the work of Rasmussen (1982, 1986) and Reason (1990) to refine the classification of errors into skill-based slips, rule-based mistakes and knowledge-based mistakes (Dolan, *et al.*, 1996). The prototype IT allows the user to select subsets of the database for analysis, and presents the number of occurrences of each type of error in various domains of interest (NTSB) or by year (PDS). The user can then list the record numbers corresponding to a given cell of the resulting table, and display a somewhat shortened version of each record for further review and analysis. Further details of the operation of the prototype IT are described in Appendix A.

While the current version of the IT performs a useful function by identifying specific records in a large database that meet certain criteria, and then allowing the user to display the contents of the database records for further review, its usefulness in analyzing the underlying causes of flight crew error and hence identifying strategies to reduce the frequency of occurrence of those errors is presently limited by several constraints, including:

1. The current algorithms for classifying the errors are only able to classify a small proportion of the events in the databases.

2. The characterization of the errors into slips and mistakes, or the distinction between skill-based slips, rule-based mistakes and knowledge-based mistakes, provides limited guidance as to what might be done to prevent these errors. The analysts needs to read through the information on each incident that can be displayed by the IT and attempt to identify common themes or recurring problems.

3. The existing databases accessible to the IT provide limited information on the context of the error, in terms of both the preceding sequence of events and the background and training of those involved. While the NTSB database includes information on the sequence of events involved in the accident or incident itself, these tend not to address the circumstances of the flight that led up to the accident or incident, although it may be possible to infer this information from the narratives or other fields.

4. Once a subset of records has been identified, there is no convenient way to perform statistical analysis on the information in those records. The information is presented as website pages, with no way to save the information in a format for statistical analysis.

These constraints may be addressed in one of two ways: by improved functionality of the IT itself, and by a richer representation of human errors and how they occur. These two aspects go hand in hand, since the ability to support a richer representation of human error depends on improved functionality of the IT, while enhanced functionality of the IT will be of greater use if it can support a better representation of how errors get made. For example, the capability to perform text analysis of the content of narrative fields in the databases would add significantly to the functionality of the IT. However, for this capability to be useful, it is necessary to know what to look for in the narrative fields. It is of course not necessary for an improved understanding of the causal factors behind human errors to be encoded in the logic of the IT, as long as the analyst has the capability to specify how the IT will select records for further analysis. Indeed, the more flexibility that the IT gives the analyst to specify the search criteria, the more useful the tool is likely to be. However, this requires the analyst not only to have a clear idea of what to look for, but also to know how to express this to the IT. Therefore the more that can be done to incorporate an improved representation of human error in the logic of the IT, the more useful it is likely to be to the analyst.

Research Approach

The approach to these issues presented in this report consisted of two activities. The first examined the recent literature on human error to identify how to better characterize the context of such errors. This included an attempt to draw from the set of well researched individual, team, and organizational behavior constructs those variables that need to be included in existing aircraft incident databases in order to expand on Reason's three-part paradigm of slips, lapses, and mistakes. This effort included the development of an instrument for collecting empirical data on these behavioral constructs and incorporating them in aviation safety databases.

The second activity adopted a case-study approach to the analysis of the data presently included in the FAA PDS database. This analysis built on a prior study that had been undertaken by the FAA Office of System Safety to examine the causal factors behind one of the most serious safety issues currently being faced by the FAA, namely the growing frequency of runway incursion incidents. The objective of this analysis was not just to obtain an improved understanding of the causal factors behind the runway incursion incidents, but to demonstrate how the IT can be used to gain a better understanding of the possible causes of flight crew error, to examine the utility of the IT in performing this analysis, and to identify how enhanced functionality of the IT could improve its usefulness.

Structure of this Report

The remainder of this report consists of five chapters. Chapter 2 discusses the need to understand the context of human error and reviews recent literature on analyzing the causes of human error in aviation. Chapter 3 addresses the importance of considering individual, team and organizational factors in the analysis of human error. The following chapter discusses the development of a survey instrument to collect quantitative data on these factors for inclusion in aviation safety databases. Chapter 5 describes the analysis that was performed using the current version of the Integration Tool to better understand the causal factors underlying runway incursion incidents. The following chapter examines how the results of this phase of the research can be used to enhance the role of the Integration Tool in identifying and evaluating strategies to reduce flight crew human error. Finally Chapter 7 presents the conclusions from the research and recommendations for further actions to implement the findings.

2. Understanding the Context of Human Error

The value of the Integration Tool lies in its ability to classify accident and incident data in terms of the type of human errors involved, and present information that allows analysts to develop strategies to reduce the likelihood of occurrence of these errors. In order to provide a richer characterization of human error that can help identify the causal factors behind these errors, it has been increasingly recognized that errors need to be understood in the context within which they occur. What may be an entirely appropriate action or decision in one context, can become a catastrophic error in a similar, but critically different one. Flight crew decisions are recognized as the result of information processing activities (Wickens & Flach, 1988). Thus efforts to understand how errors get made, and what can be done to reduce this, need to address the way in which information is processed by the flight crew and how this is influenced both by their training and experience, as well as the sequence of events that precede each decision. According to the four-stage model of information processing described by Wickens and Flach, input from external stimuli are retained in a short-term sensory store, and examined using a process of pattern recognition that organizes the information into a meaningful structure. This structure then informs a decision process and selection of an appropriate response. Finally, the chosen response is executed.

Comparing this model to the sequential algorithm for classifying information processing failures adapted by O'Hare *et al.* (1994) from earlier work by Rasmussen (1982) and shown in Figure 2-1, suggests that the first two types of pilot error:

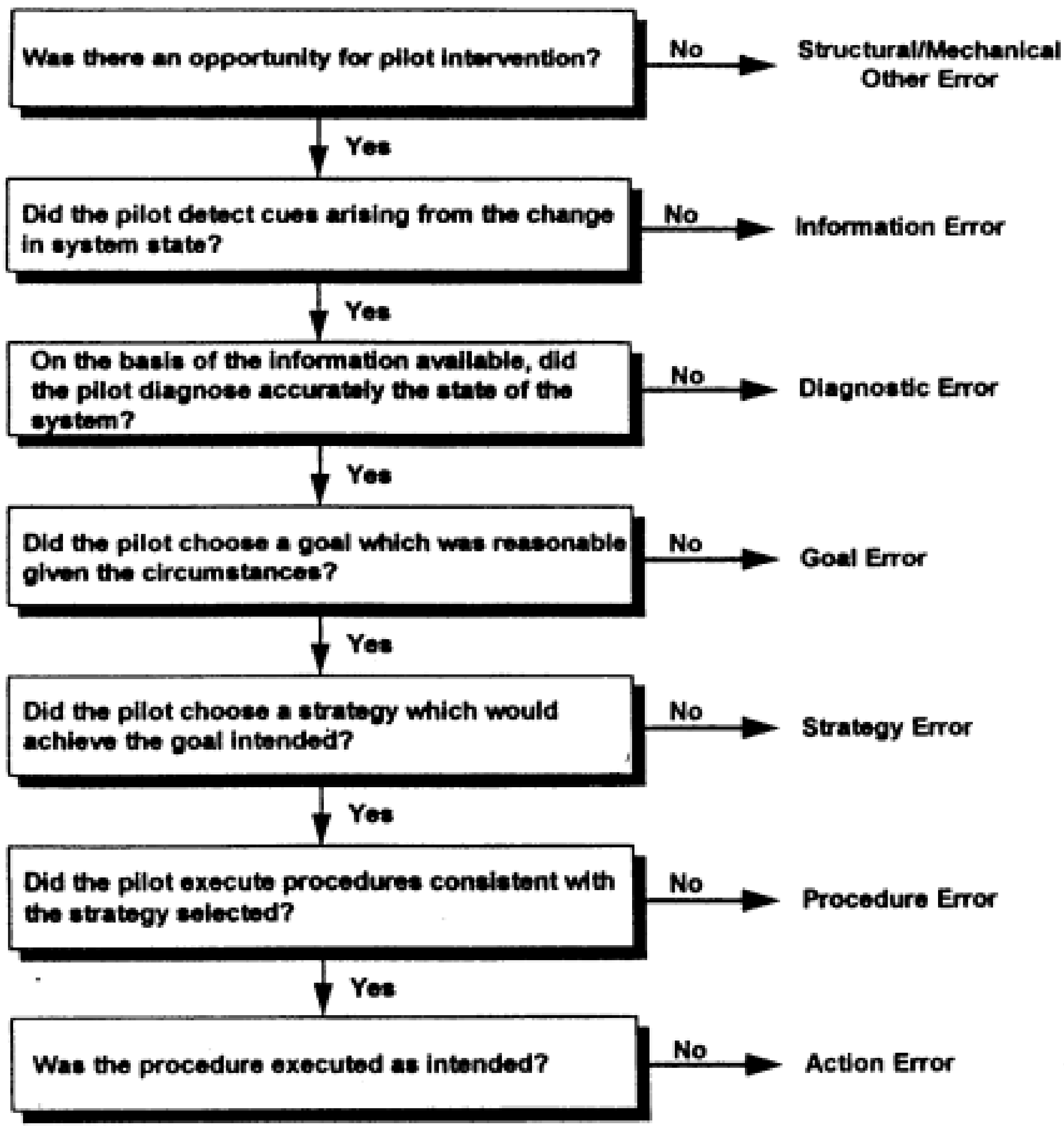
- information error
- diagnostic error

correspond to the pattern recognition stage, while the next three:

- goal error
- strategy error

- procedure error
- correspond to the decision process. Finally the last type of error:
- action error

•



SOURCE: O'Hare *et al.*, 1994; Adapted from Rasmussen's (1982) taxonomic algorithm for classifying information processing failures, as reported by Shappell & Wiegmann (1997).

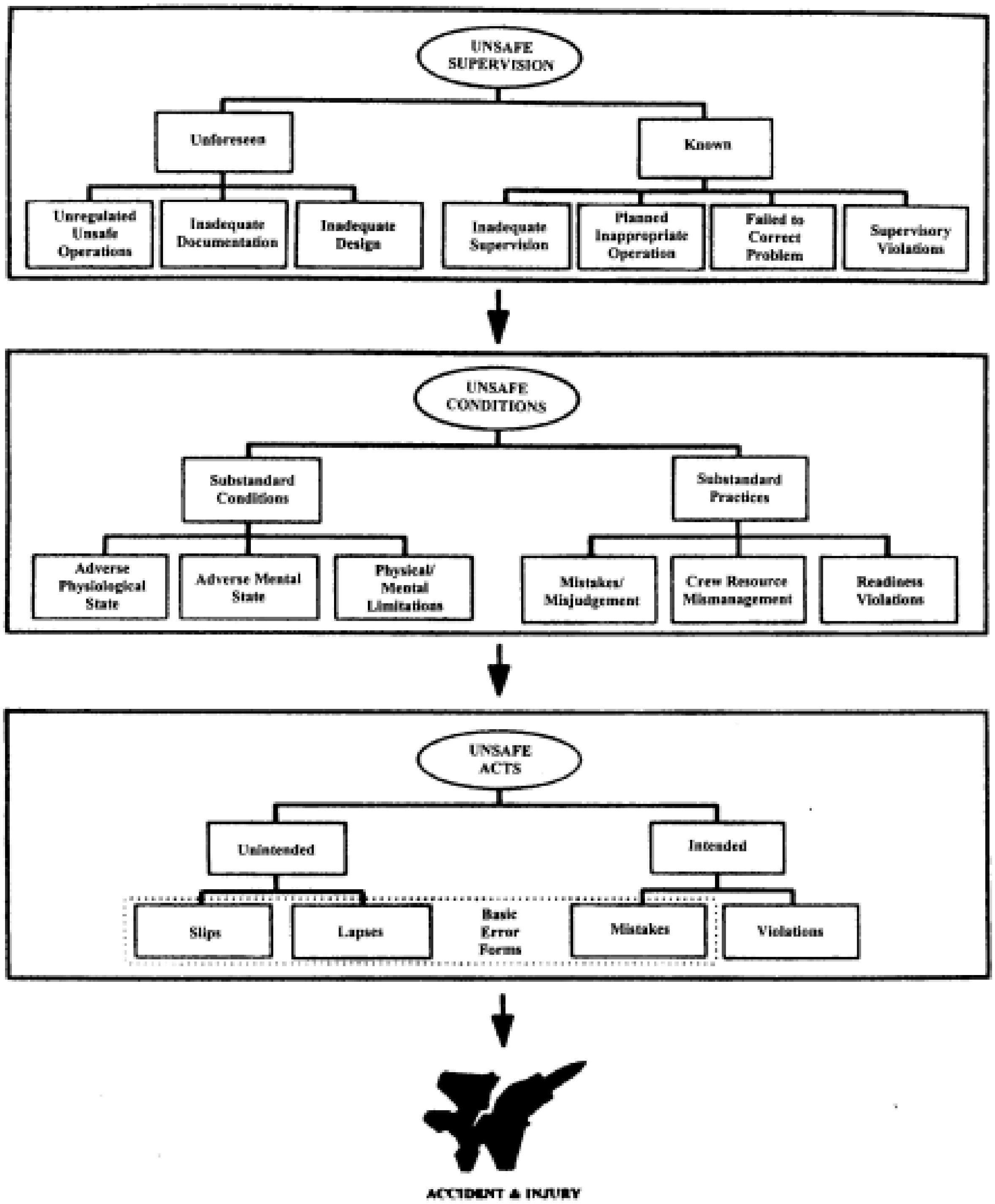
Figure 2-1 **Taxonomic Classification of Information Processing Failures** corresponds to the response execution stage. It should be noted that while the last type of error may be viewed as a slip or lapse in Reason's classification of unsafe acts (Reason, 1990), and the previous three types of error can be viewed as mistakes, the first two are not really acts at all, but rather the results of the environment within which the cockpit crew were operating, the completeness of the information available to them, and their training at interpreting that information.

Wiegmann and Shappell (1997) examined 1,970 pilot-related mishaps that occurred between 1977 and 1992 to U.S. Navy and Marine Corps aircraft, and for which accident investigation records were maintained at the U.S. Naval Safety Center in Norfolk, Virginia. These records used a standardized set of pilot-causal factors, which were reclassified into the five components of the information processing model and the six error types defined by O'Hare *et al.*, as well as the categories in Reason's model of unsafe acts. The proportions of each error type were found to vary significantly with the severity of the mishap. However, the authors noted that several contributing factors, such as the physiological or mental condition of the pilot or supervisory errors, were not reflected in the error classification schemes.

The importance of understanding the physical and environmental context within which human decisions are made has been articulated by Edwards (1988) in the SHEL model of the four components of system design:

1. Software - the rules, regulations and procedures that govern operations
2. Hardware - equipment, material and other physical resources
3. Environmental conditions
4. Liveware - the humans in the system.

In order to account for the effect of supervisory practices and operating conditions, Shappell and Wiegmann (1997) defined the *Taxonomy of Unsafe Operations* illustrated in Figure 2-2. In their paper, the authors state that failures at any of the three levels can lead to accidents or mishaps, and expand on each of the elements shown in the figure, as summarized in Table 2-1.



SOURCE: Shappell & Wiegmann, 1997.

Figure 2-2 **The Taxonomy of Unsafe Operations**
Table 2-1

Classification of Unsafe Operations

Classification of Unsafe Supervision

Unforeseen Unsafe Supervision	*Known Unsafe Supervision*
Failure to recognize unsafe operations Loss of supervisory situational awareness Unseen or unsafe conditions and hazards Unrecognized adverse aeromedical conditions Life changes such as: divorce; death in family; legal, financial, or personal problems	Inadequate supervision Failure to administer proper training Lack of professional guidance Planned inappropriate operations Improper work tempo
Lack of documentation and procedures Lack of technical specifications, instruction, regulations, etc.	Failed to correct known problem Failure to correct inappropriate behavior Failure to correct safety hazard
Inadequate design Equipment design that contributes to the accident	Supervisory violations Not adhering to rules and regulations Willful disregard for authority by supervisors

Classification of Unsafe Conditions of the Operator

Substandard Conditions of the Operator	*Substandard Practices of the Operator*
Adverse physiological states Spatial disorientation Hypoxia Visual illusions Physical fatigue Motion sickness Medical illness Intoxication	Mistakes-Misjudgments Poor dietary practices Overexertion while off duty Crew resource mismanagement Not working as a team Poor aircrew coordination Improper briefing before a mission Inadequate coordination of flight
Adverse mental states Loss of situational awareness Circadian dysrhythmia Alertness (drowsiness) Overconfidence Complacency	Readiness violation Not adhering to regulations regarding crew rest, alcohol consumption, or medications

Physical and / or mental limitation	
Lack of sensory input	
Limited reaction time	
Insufficient physical capabilities	
Insufficient intelligence	

Table 2-1 (cont.)

Classification of Unsafe Acts of the Operator

Unintended Actions	*Intended Actions*
Slips (attention failures)	Mistakes
Intrusion	Rule-based
Omission	Misapplication of a good rule
Reversal	Application of a bad rule
Misordering	Knowledge-based
Mistiming	Inaccurate or incomplete mental model of the problem space
Lapses (memory failures)	Violations
Omitting planned items	Routine
Place-losing	Habitual departures from rules and regulations condoned by
Forgetting intentions	management
	Exceptional
	Isolated departures from rules and regulations not condoned
	by management

SOURCE: Shappell & Wiegmann, 1997; adapted from Reason (1990).

Precursor Events

While each of the factors identified by Shappell and Wiegmann could have a bearing on any particular flight crew error, decisions are not made in isolation but take place in the context of a sequence of previous events and prior decisions. These events and decisions may have occurred in the previous few minutes, earlier in the flight, or at some past time in the training and experience of the flight crew involved. This information, or perhaps more important, the flight crew's perception and recollection of this information, shapes the interpretation of the current stimuli and pattern recognition process. Thus if a flight crew had noticed unusual temperature or oil pressure indications in one of the engines earlier in the flight, when faced with a sudden loss of power at a critical moment, there will be a tendency to jump to the conclusion that the problem is with the same engine and act accordingly, rather than conduct a dispassionate review of the information available to them. Likewise, if the crew is preoccupied with performing some unexpected task or suddenly find themselves having to undertake a procedure out of the usual sequence or in less time than they usually have, they may have difficulty recognizing or interpreting the sensory cues they are receiving. In the American Airlines accident at Cali, the crew decided to accept a different approach offered by the controller late in the descent and, in the confusion over resetting the flight management system, failed to realize that they had selected the wrong navigation aid and were turning toward the adjacent mountains.

Therefore in order to understand why erroneous decisions were made, and what might be done to reduce the likelihood of such errors in the future, it is important to have data on the sequence of events leading up to the error. While this type of information is often obtained during accident investigations, and may appear in the narrative reports, it is not a simple matter to know how to code it so that general findings can be inferred from the analysis of a large sample of incidents. Of course, any analysis can only be as good as the information contained in the database. If this type of information has not been recorded, the ability to understand why the error occurred will be severely limited.

3. Individual, Team and Organizational Factors

As suggested by the work of Shappell and Wiegmann, discussed in the previous chapter, a fuller understanding of flight crew human error requires that the actions of the flight crew be understood in the context of the culture of the organization of which they are part, as well as their training, experience, and supervision. These issues are important not only to obtain a better explanation of why errors are made, but also because they address the means by which these errors can be reduced.

As it stands now, the various databases accessible with the prototype IT provide limited information on individual, team, and organizational factors behind incidents and accidents, and give no attention to organizations tied together as systems. Nor are alternative sources of these data readily available. Yet organizations and individuals are increasingly recognized as being part of larger industrial, manufacturing, regulatory, or environmental systems (Grabowski & Roberts, 1996). Considering organizations as systems, and as parts of systems, is thus important if we are to understand how they work, and how best to mitigate risk in them. The aviation industry, with its many organizations and regulators, is an example of a large scale system.

Large-scale human-machine systems are composed of networks of humans and technical resources (i.e., computers, machines, communications equipment, etc.) that perform tasks and support the missions and goals of more than one organization. What often differentiates large-scale systems from other kinds of groupings is the attention paid to and importance given to interfaces, interconnections, and interdependence among system elements (Mayntz & Hughes, 1988; Perrow, 1984).

Interactions between members of the flight crew, between the flight crew and the aircraft systems, and between the flight crew and the external environment are all recognized as important determinants of flightdeck performance (Foushee & Helmreich, 1988; Diehl, 1989; O'Hare & Roscoe, 1990). Timely response to change and surprise by individuals as well as organizations is required in any system that seeks to mitigate risk. As numerous National Transportation Safety Board investigations show, a large percentage of aircraft accidents happen when flight crews lose situational awareness (Sarter & Woods, 1991; Gilson, Garland & Koonce, 1996; Orasanu, 1997).

How Systems Might Mitigate Risk

Previous research has found that four processes present major challenges to mitigating risk. They are variations in organizational structures, challenges to developing strong cultures and barriers to communication and trust. In this section, we synthesize our observations of how systems might mitigate risk.

Organizational systems are characterized by multiple organizational structures. With careful attention to design, these structures can be rendered sufficiently malleable to provide flexibility and functionality in simple as well as complex modes, depending on the simplicity or complexity of the environment (Weick, 1990; 1993). High reliability requires such fluid organizational structures with the ability to restructure and regroup to respond to changes in their environments.

By their nature, reliability-enhancing systems are more diffuse than are single reliability enhancing organizations, which may contribute to the existence of overlapping roles across the whole of the system. For example, the air traffic system in the United States is comprised of the System Command Center, air route traffic control centers, terminal radar approach controls, and airport control towers; each performing different yet coordinated roles in a spatially nested structure. Geographically dispersed people are concerned both simultaneously and sequentially with the progress of each aircraft through the system. By managing this dispersion appropriately, participants can understand other participants operations, constraints, goals, and contributions, as well as the role each plays in the system's shared mission. Flexibility in structure not only permits organizations to adapt their structures to variances in tempo and complexity, but also provides opportunities for members with overlapping roles to clarify those roles and responsibilities so everyone knows what to do as events unfold.

The communications that accompany these structural changes are critical to the success of the system, as they provide opportunities for members to understand roles and responsibilities as the organization changes, and to learn the utility of various organizational structures in different environmental conditions.

The use of multiple organizational structures--tight and loose coupling (Weick, 1979)--enhances reliability. Organizational theorists suggest that when organizations are tightly coupled (and consequently fairly centralized), they become brittle and are unable to respond to changing environments (Daft & Weick, 1984; Perrow, 1984). Loose coupling is often called for so the organization exhibits flexibility and can respond to changing requirements and conditions. However, both tight and loose coupling have been observed in reliability enhancing organizations that failed (e.g. Medvedev, 1990; Vaughan, 1996). The simultaneous existence of tight and loose coupling may be seen more often in systems than in other organizations simply because they are composites of organizations, each with their own coupling characteristics. Managers must explicitly decide what needs to be tightly and loosely coupled and design organizational structures with appropriate levels of flexibility and fluidity.

Shared cultures are essential to the success of reliability enhancing systems. However, simply espousing common values does not result in shared values, assumptions, or understandings. Rather, careful attention to communication processes at the system's interfaces fosters the development of such shared values by creating opportunities for members to interact, to understand one another, and to develop shared mental models of how to achieve high reliability. For instance, investigations of many aviation accidents show that flight deck and air traffic control personnel did not share the same mental models about what transpired. Risk mitigation is also dependent on effective communication processes at system interfaces where members are defined to each other and to the outside world. Such communications transmit cultures, and are particularly important when organizations are distributed across geographical areas. In traditional organizations, the focus of communication is on effective talk among individuals within an organization. In distributed organizations, the focus shifts to communications across system interfaces. This is underscored in distributed systems with risk mitigation mandates.

Risk mitigation in systems requires special attention to their peculiar characteristics. Because of the pervasiveness of distributed information technology, and the shared processes that underlie the organization, interactions and interdependencies among its members define the organization. Those interdependencies are also related to risk mitigation processes. For instance, fluid organizational structures alone may or may not dampen risk. However, organizational structures that provide flexibility in response options as well as communication opportunities for organizational members have much to do with risk mitigation (Weick, 1993). Similarly, communication processes at the interfaces that work to develop a shared culture of reliability and trust also have much to do with risk mitigation. The challenge is to harness the shared functional processes and distributed information technology in a way that permits effective utilization of flexible organizational structures, that permits effective communication of a shared culture across interfaces, and that promotes the development of trust among members. In the next section, we discuss a theoretical and research agenda associated with these goals.

Theoretical and Research Agenda

Since so little research on organizational systems exists, a host of research issues suggest themselves on the way to deciding which system processes to represent in the IT. We suggest a series of research assertions that should be tested. They are generic to systems in general but as important to the aviation system as to any other system.

Structuring

We propose that systems will structure themselves to obtain maximum flexibility and adaptability. Researchers may want to adopt some of the rich structural metaphors currently being discussed (e.g. Fulk & De Sanctis, 1995; Senge, 1990; Volberda, 1996; Orlikowski, 1996) in developing propositions about system structuring. We need to examine the extent to which one or another form best describes the unfolding of a system and how these forms change over time. With regard to risk mitigation, one might investigate such assertions as:

- Risk mitigating systems develop recognizable mechanisms that increase internal structure fluidity.

- Air traffic management systems change their structuring as they move from normal to crisis modes of operation. They also change their structuring as they move from crisis to normal modes of operation.

- Systems composed of aircraft manufacturers, airlines, and air traffic control facilities engage in network extension to meet increased variation in their environment.

- The use of lateral organizational forms enhances sensitivity to risk propensity and the development of risk reduction strategies because these activities are more apt to occur in situations in which there are strong lateral liaisons.

- The cognitive frameworks of managers in successful risk mitigation systems (e.g. NASA at the time of Apollo 13) are relatively more "nimble" than are the cognitive frameworks of managers in less successful ones (e.g. NASA and its contractors before the Challenger accident) because of the necessity for flexibility in achieving restructuring.

A major discussion in the organizational structure literature concerns the inappropriateness of tight coupling for reliability enhancement. However, empirical research suggests that loosely coupled or entirely disconnected systems can cause accidents as readily as can tight coupling. From these observations, the following assertions might be tested:

- Tight and loose coupling are both appropriate in different parts of systems. Core functions (aircraft production) must be tightly coupled. Environmental sensing functions (e.g. air traffic control) must be loosely coupled.

- Loose coupling of inter-unit interactions contributes to reliability enhancement.

Studies of network dynamics and evolution (Stokman & Doreian, 1996) provide some descriptions of change in networks, as well as of mechanisms that determine change. New, more specific theories of networks and emerging organizations are needed that describe both system characteristics (Salancik, 1995) and processes that give rise to their evolution (Brass, 1995; Monge & Eisenberg, 1987). Further theoretical and empirical work on redundancy (e.g. Landau, 1969; Roberts, 1990; Vaughan, 1996) needs to be done to clarify what kind of redundancy works and what does not.

Culture

Organizational culture studies typically focus on one organization. A myriad of issues suggests themselves here. Recently, some research attention has been devoted to understanding how organizations learn (e.g. Attwell, 1992; March, Sproul, & Tamuz, 1991; Schein, 1992; Wishart, Elam, & Robey, 1996). How organizations learn certainly influences the cultures they develop. A major challenge is to identify where the system cultures must be strong and unified and where "a thousand flowers" can be allowed to bloom. A related challenge is to develop ways to insure that an appropriate culture adhesive is in place in those parts of the system in which it is needed. This suggests the following assertions might be tested:

- Strong cultures are required at the system interfaces to ensure reliability enhancement (air traffic control operators and pilots working for commercial airlines).
- Risk mitigating systems develop strategies for oversight as well as checks and balances in their cultural fabrics (e.g. airline operations).
- Member goals, roles, and responsibilities are more carefully articulated in risk mitigating systems than in other types of systems.
- Clarifications of roles, responsibilities, and interdependencies with others by system members will pinpoint those places in need of strong cultures.

- Content analysis of electronic mail in risk mitigating systems should disclose more messages about concerns, findings, hypotheses, and goals than in other systems (inviting a comparison of some part of the aviation system and non-risk mitigation systems).

- A diversity of cultures is desired in engineering units concerned with things like space vehicle launches and units dealing with weather characteristics for these launches (because the whole is more likely to uncover all potential risk than is either part).

- A desirable diversity of cultures will be supported only under conditions of high trust and open communications.

- Incentives and control systems in risk mitigating systems should directly address behaviors desired to obtain low risk operations.

Communication

Studies of communication in large-scale systems often focus on the impact of technology on communications (e.g. Steeb & Johnston, 1981; Gallupe, De Sanctis, & Dickson, 1988; Clemons & Row, 1992; Hart & Saunders, 1997), or on the relationships between communication and participation (e.g. Gallupe, et al., 1988; Steeb & Johnston, 1981). Few studies address system-wide communication, its collective impact on a system, or the impacts of communication on system performance. We suggest the following possibilities:

- Risk mitigating systems are characterized by communications that clarify their goals, relationships, and responsibilities.

- Communication in risk mitigating systems is characterized by large amounts of content addressing safety issues.

- In systems with good risk mitigation histories, redundancy is built into communication lines.

- In systems with good risk mitigation histories, the degree of communication richness reflects the requisite variety of the environment, not of any particular point in time (inviting a comparison of Valujet before the accident and United Airlines' Flight 232 into Sioux City, Iowa).

Trust

While trust has long been a major issue in the organizational literature, there is little systematic research on its impact on risk mitigation behaviors. Our previous discussion suggests assertions like the following might be examined:

- Risk mitigating systems devote significant numbers and types of activities to building trust. These activities may take the form of training, encouraging interpersonal interaction, and increasing inter-organizational linkages (inviting a comparison between air traffic control and travel agents or any other non-risk mitigating organization)

- Risk mitigating systems engage in activities that encourage shared commitment as one element of building trust.

- In systems in which risk mitigation is high, group meetings using lateral organization forms are used to further the development of trust.

- In systems with good risk mitigation histories, interpersonal trust is higher than in systems with poor risk mitigation histories.

We have identified several general areas for research in systems seeking to mitigate risk. What makes their exploration critical is the paucity of empirical or theoretical work done in any systems, at the same time that there are increasing demands for higher levels of safety and performance in them, as in air travel.

Relevance to the Integration Tool Development

The foregoing sections have laid out a broadly based research agenda to address the role of organizational factors in achieving higher levels of safety in aviation. A key aspect of such an agenda is developing appropriate data sources to support empirical research, as discussed in the following chapter. These issues are critical to the successful continued development of analytical techniques to improve aviation safety, such as the IT. As safety levels in the industry improve, achieving further improvements will require an increasingly sophisticated understanding of the causes of human error, and the analytical tools to support this. It is unrealistic to expect that this can be accomplished without a solid foundation of basic research upon which to build. It is equally unrealistic to expect that this research can be “fast-tracked” to make up for lost time, if these issues are ignored until circumstances force them to be recognized. Thus a balanced development strategy for the IT would include an appropriate allocation of resources between fundamental research to improve the understanding of the causal factors involved in human error and the continued development of analytical techniques to take advantage of the results of that research.

4. Development of the ITOF Instrument

The effectiveness of the use of the Integration Tool to analyze flight crew human error ultimately depends on access to data that captures the full range of factors that shape flight crew decisions and actions, and hence the likelihood of error. There is a growing recognition of the need to integrate cognitive analysis of the actions of those involved in accidents and incidents with the organizational and regulatory context within which their decisions are made. However, much of the information on this broader context is not available in current accident and incident databases, nor is likely to become so in the foreseeable future. What is needed is a way to integrate information from many sources. This of course is the objective of the Integration Tool. However, this also requires that the information exists and is accessible. The previous chapter discussed the importance of understanding the role of individual, team and organizational factors in managing and reducing risk. This chapter explores how information on these factors could be obtained, to support a more integrated approach to analyzing flight crew error.

Aircraft flight crew decisions are made in the context of a complex interplay of team and organizational factors. Even pilots of single-pilot aircraft must interact with air traffic controllers, and in military aviation commonly with other aircraft and ground-based support units. All airline operations involve flight deck crews of two or more. Organizations establish training and operating procedures, provide real-time support, and create the culture within which individuals perform their duties. The importance of understanding the role of team and organizational behavior in shaping the decisions of individuals, and in turn the consequences of this for reducing risk and maintaining safe operations, is increasingly being recognized. At the level of the flight crew team, the value of crew resource management (CRM) programs has become widely recognized and is now a central principle of airline flight crew training. Less attention has been given to date to organizational factors.

While team and organizational factors shape flight crew decisions, so does the experience, training, background and personality characteristics of the individuals involved. While some of these factors cannot be changed in the short run, or perhaps at all, some can and others can be mitigated or taken advantage of, provided they are well understood. Others can be addressed through longer term training efforts. CRM programs are not just about interpersonal interactions, but also about individuals recognizing how they respond to different situations, and how to effectively use the team to compensate for their own limitations.

In order to understand the role of individual, team and organizational factors in flight crew errors, and how to develop programs to reduce the risk of such errors, it is necessary to develop appropriate databases of relevant information that can be applied to the analysis of safety-related events, that can span the spectrum from accident investigations to monitoring an individual's progress in training programs. Without such data, efforts to understand how these factors have influenced the outcome of the event become speculative and subjective. This chapter presents a proposed framework for collecting and managing such data, together with an instrument that can be used to measure the safety posture of an organization and identify issues that may need further investigation.

The result of collecting and analyzing these data is not prescriptive, in the sense of providing guidance on steps to be taken to further reduce risk. However, the data are intended to provide the underlying information resources to support research into the effectiveness of alternative strategies. Without such information, studies of this type are simply impossible to perform, and the effectiveness of efforts to improve safety are often judged on the basis of the occurrence of a few, highly visible, incidents. Meanwhile, the underlying risks continue largely unaffected, until a chain of unusual circumstances conspires to escalate a situation into the next accident.

A Framework for Risk Management

Although an airline or other aircraft operator is dealing with a very different set of problems from a nuclear power plant, hospital, or even a bank, the underlying organizational factors that shape its success at managing the risks inherent in its activities are determined by similar principles. Following the approach developed by

Libuser (1994), the issues that contribute toward the safety posture of an organization engaged in flight operations can be grouped in five categories:

- Process Auditing
- Reward System
- Quality of Operations
- Risk Perception
- Management Procedures.

Process Auditing: This aspect addresses formal and informal procedures to examine the conduct of routine operations, in order to identify potential risks or unsound practices, and to ensure that remedies are identified and applied. Formal procedures could involve Flight Operations Quality Assurance (FOQA) programs, reporting and analysis of operational incidents, and flight crew check rides. Informal procedures could include management or union safety committees.

Reward System: This aspect addresses the signals that the organization sends to its officers and employees about the importance of minimizing risk through the way that performance is rewarded, and reports of mistakes and problems are handled. This includes the way in which the organization balances safety concerns with accomplishing its flight operations mission.

Quality of Operations: This aspect addresses the importance given to performing operational procedures in a way that minimizes risk, as well as the sense of responsibility of individuals for the quality of the overall performance of the organization. It also addresses how the performance of the organization compares to similar organizations.

Risk Perception: This aspect addresses the extent to which the risks inherent in flight operations are understood and communicated within the organization, and the nature of circumstances or conditions that can increase risk are recognized. It also addresses employees' perceptions of the importance given by the organization to identifying and minimizing risk.

Management Procedures: This aspect covers the existence of written policy and procedures manuals, and how closely these procedures are followed in practice. It also addresses such factors as how much redundancy is built into the system, how well senior management is kept informed about safety issues, the resources devoted to maintaining safe operations, and the training provided to employees.

Data Collection

The survey instrument shown in Appendix B has been designed to provide a means to collect quantitative data on the foregoing issues. The survey is designed to be completed by employees at all levels, using a five-point Likert scale, ranging from Strongly Agree to Strongly Disagree. responses can (and should) be deidentified, although job position information should be provided in a way that does not identify the respondent. It may also be desirable to provide some information on the geographical location of the respondent, so that variations from one part of the organization to another (e.g. across different regions or crew bases) can be analyzed. The survey instrument questions have been designed with the functions of airline flight crews in mind, although it can be fairly easily adapted to other operational functions that impact flight safety.

Use of the Survey Information

The purpose of the survey is not just to collect data on a broad range of organizational factors, but to express this information in a way that separates the responses of individuals from the characteristics of the organization as a whole. Thus one might, for example, want to compare the incidence of certain types of flight crew error with the emphasis given to CRM training in different organizations. Obviously, if it can be shown that the flight crews of those organizations with a stronger commitment to such training experience fewer errors resulting from poor crew coordination, then strategies to reduce such errors could include identifying what it is that the successful organizations do to achieve that commitment that the less successful ones do not.

The importance of deidentification of the data should not be overlooked. What is needed are honest assessments. People are not going to make such assessments if they think that they may be punished for it. Similarly, organizations will not willingly make such information on their operations available to others if this information may be used against them in the future. Yet only by collecting data on their own performance and comparing their performance to that of others can organizations hope to learn where to focus their efforts to improve their performance.

The challenge in a competitive airline industry is to figure out how to share this information in a way that contributes to improving safety without creating undue risk for unintended economic or legal consequences. One way may lie in sharing deidentified data through the Global Analysis and Information Network, combined with making appropriate analysis tools available within the organizations to take advantage of the deidentified data. This is no simple task, since the harder it is to identify the source of the information, the fewer useful conclusions can be drawn from it. One approach might be to allow each organization to be able to identify its own data, but not know the source of the information on other carriers. This would allow it to determine how its own people view the organization and the success of its own safety programs, and compare that to the performance of the industry as a whole. It would thus be able to use the information internally to improve its own procedures and performance.

To gain the trust of those providing the information, it will also be necessary to establish firewalls between the collection of the information and enforcement procedures, whether within the organization or by the regulatory authorities, such as the Federal Aviation Administration. One possible way that this could be achieved is through the involvement of a neutral third party, such as the NASA Aviation Safety Reporting System or the pilot associations. Concerns over possible hostile use of the information in litigation could be addressed through legislation protecting the information, providing certain safeguards are met. Of course, concerns over legal liability can cut two ways. An airline that collects data on its operations in order to identify potential areas of concern, and then implements programs to address these concerns, could use this as a defense against liability, even if it could be shown that its performance was initially below that of the industry as a whole. Conversely, an airline that elects not to seek such information, on the grounds that it might be used against it in the future, could be viewed as negligent in not pursuing all reasonable avenues to improve the safety of its operations.

Role of the Integration Tool

In principle, the design of the Integration Tool could permit analysts to combine information on organizational and regulatory factors with the data typically available from accident investigations, provided the former information is structured in a form that can be related to specific incidents. This will require both enhanced capabilities within the Integration Tool to merge data from different datasets, including data at the level of organizations rather than incidents, as well as a significant effort to develop appropriate techniques to document the organizational and regulatory environment within which an accident of incident occurred. The type of information derived from the risk management survey discussed in this chapter could form one part of this documentation. However, for this to occur it will be necessary to have this information at the level of the organization, since incidents occur in specific organizations and corrective strategies are likely to vary across organizations, if only because some organizations are already implementing them.

The challenge of how to maintain the anonymity of deidentified data while still preserving enough specificity to be useful in analyzing the causal factors behind specific incidents clearly will require significant additional work to resolve. This work will need to address two issues. The first is the institutional constraints on collecting and sharing information, and the second is the value of having this information available in the first place. The second issue can be addressed through carefully designed proof-of-concept studies, that can be structured to protect the confidentiality of those involved. If the value of the information can be demonstrated, it may be easier to address the institutional issues involved in its wider application.

5. Analysis of Flight Crew Human Error

In order to demonstrate the application of the prototype Integration Tool to the analysis of flight crew human error, and to identify how enhanced functionality of the IT could improve its usefulness, a case-study analysis was undertaken of the data presently included in the FAA Pilot Deviation System (PDS) database. This analysis built on a prior study that had been performed for the FAA Office of System Safety to examine the causal factors behind one of the most serious safety issues currently being faced by the FAA, namely the growing frequency of runway incursion incidents (Wojciech, *et al.*, 1997). The objective of the analysis was not just to obtain an improved understanding of the causal factors behind the runway incursion incidents, but to demonstrate how the IT can be used to gain a better understanding of the possible causes of flight crew errors involved in these incidents, and to examine the utility of the IT in performing this analysis.

Runway Incursions

A runway incursion is defined as any occurrence at an airport involving an aircraft, vehicle, person, or object on the ground that creates a collision hazard or results in loss of separation with an aircraft taking off, intending to take off, landing, or intending to land. At controlled airports, runway incursions typically occur when an aircraft makes an unauthorized takeoff or landing or an aircraft, vehicle or pedestrian makes an unauthorized entry onto an active runway. Of the various types of incursion, aircraft and vehicle incursions are obviously more serious than pedestrian incursions, and several recent major accidents have been due to aircraft incursions. In fact, the accident with the greatest loss of life in aviation history, the collision between two Boeing 747 aircraft at Tenerife in the Canary Islands in March 1977 was a classic runway incursion accident, as were several of the most recent accidents in the U.S. involving air carrier aircraft. The issue has been receiving increased attention in recent years, since while overall accident rate has been declining, the number of reported runway incursions has been increasing (Duke, 1997). In October 1997, the FAA sponsored a Safety Roundtable on Runway Incursion Prevention (Kelley & Schreckengast, 1997) to examine the results of a survey of airline pilots conducted by the MITRE Corporation in late 1992 and early 1993 (Adam *et al.*, 1994; Adam & Kelley, 1996) and to discuss strategies to reduce the incidence of such events.

While runway incursions are due to a large number of factors, pilot error in one form or another is one of the most common. Where these occur at an airport with an operating control tower, they usually generate a Pilot Deviation report. These reports therefore form a valuable data source that can be used to better understand the causal factors behind these errors.

Human Factors Analysis of Pilot Deviation Runway Incursions

In 1996 an analysis of the Pilot Deviation System (PDS) database was carried out by the FAA Office of System Safety, with assistance from Abacus Technology Corporation and Galaxy Scientific Corporation, to study the causal factors involved in pilot deviation runway incursions. The Pilot Deviation Runway Incursion (PD RI) reports for all airspace users were analyzed to identify frequent flight crew errors, the causal factors associated with them, and the frequency of occurrence of those factors. A detailed analysis of flight profiles was carried out for general aviation (GA) operations, since the PD RIs for these operations were increasing at a significant rate.

The PD RI reports associated with the different operator types were reviewed and an effort was made to identify the types of flight crew errors that may have occurred, the causal/contributing factors that are stated or implied in the reports, the high frequency factors, and the corresponding flight profiles for RIs involving GA operations. The prototype Integration Tool (IT), recently developed by a team from the Office of System Safety, MITRE Corporation, Galaxy Scientific and Abacus Technology, was applied to the PDS database to classify the types of flight crew errors involved in runway incursion incidents into slips (execution errors) and mistakes (planning errors). Over 90% of the PD RI reports for all airspace users were found to involve a slip. After a review of the PD RI reports, thirty-eight causal/contributing factors were identified, mainly derived from the prior MITRE survey of airline pilots (Adam *et al.*, 1994; Adam & Kelley, 1996). These were then grouped into six categories: orientation, communication, memory, attention, compliance with Federal Aviation Regulations or ATC clearances, and other. It was found that for GA operations, inadequate or inappropriate pilot communications, lack of airport familiarity, and inadequate or inefficient use of cockpit procedures for maintaining orientation were the most predominant factors responsible for RI incidents. It was also found that for US air carrier, foreign air carrier, air taxi, and commuter operations, these factors were not nearly as conspicuous as for general aviation. For the analysis of GA incidents, 97 randomly selected reports (28%) were reviewed out of which 59 had at least one of the 38 factors and 50 had at least one of the three main factors. The flight profile data corresponding to these 50 reports was entered into a database for further analysis.

Summary of the Study Findings

The results of the study may be summarized as follows:

- Over 90% of the runway incursions were found to be a result of slips as opposed to mistakes.

- Inadequate or inappropriate pilot communications, lack of airport familiarity, inadequate or ineffective use of cockpit procedures for maintaining orientation, problems with intra-cockpit communications for crew coordination on ATC instructions, inadequate or inappropriate ATC communications, and lack of cockpit procedures for periodically checking adherence to ATC instructions during taxi, were found to be the six most frequent causal/contributing factors. The last three factors were much less frequent than the first three.

- The most probable flight profile associated with runway incursions for GA was identified to be a low performance aircraft in its taxi phase at a low activity airport between 1400-1800 local time under VFR conditions, being flown by a private certificate pilot with less than 500 total flight hours experience. The most frequently occurring surface deviation type was found to be an entry onto the taxiway/runway without clearance.

Extension of the FAA Human Factors Analysis

The FAA study did not analyze all general aviation runway incursion incidents in the PDS database but selected a 28% sample of the GA reports to examine in detail. A larger data set would improve the reliability of the final results so it was decided to expand this analysis to include the full set of GA reports and to further extend it to other airspace users. This suggested the need to automate the process of analysis since there are several hundred runway incursion reports to be analyzed and the earlier work was done by reading each of the reports in the sample and assigning causal factors on the basis of the information in the reports. Moreover although the FAA study noted that the pilot deviations that result in runway incursions for GA operations have more than doubled from 1994 to 1996, it did not address which factors appeared to have contributed to this increase. So this was another area which it appeared worth exploring.

Methodology

As a first step in the automation of the analysis procedure, the accident and incident data contained in the prototype Integration Tool PDS database were accessed using Microsoft Query running within Excel to interface with the Oracle Workgroup Server software used to access the data tables comprising this database. The four database tables containing the information used for the analysis of pilot deviation runway incursions were PD1_AIRCRAFT_LIST, PD1_EVENT_DATA, PD1_REPORT_DATA, and PD1_PILOT_LIST (Schreckengast & Fogle, 1996). The required data fields from these tables were selected and the data was imported into Microsoft Excel spreadsheets. After importing the data into four files from the four tables, the files were merged into a single spreadsheet.

With the exception of the AIRCRAFT_LIST each of the tables retrieved 5,840 reports from 1992 onwards. In the AIRCRAFT_LIST, about 8,491 items were retrieved because of multiple copies of the same report. These multiple copies had some data fields marked as ‘N’, while the rest did not contain any information at all. These were deleted resulting in a set of 5,840 reports corresponding to the other tables. The four files were then merged. All incident reports which had no surface deviation involved (SFC_DEV_FLAG=N) were subsequently removed, resulting in a set of 1,396 reports. At this stage the spreadsheet had both final and preliminary reports. The next step was to delete the preliminary reports, leaving 1,279 reports that could be used for surface deviation analysis. Since runway incursions were the focus of study, this set of reports were further reduced to the 328 reports that documented runway incursion incidents.

Multiple data fields were combined into a single column of data to make the spreadsheet compact and easy to analyze. For example the data fields PHASE_LNDG, PHASE_TAXI, PHASE_TKOF, and PHASE_UNKN from the EVENT_DATA_TABLE were combined to get a column entitled phase of flight. The same was done for pilot certificate (PLT_CERT) and for the type of surface deviation (SFC_DEV_TYPE). The local time of the event (EVENT _LCL_TIME) was divided into six ranges of four hours each, 0000-0400, 0401-0800 and so on. Similarly the total hours of flight for a pilot was divided into five groups: not indicated, 0-500, 501-2000, 2001-7000, and 7000+. The EVENT_UTC_DATE was modified to get the year of occurrence of the event. The data on aircraft type (ACFT_TYPE) was classified as a low, medium, or high performance aircraft. A sample sheet of the final dataset is as shown in Table 5-1.

Runway Incursion Trends

The number of runway incursion reports by type of operator for each year is shown in Table 5-2. After declining from 1992 to 1994, the total number of reports jumped dramatically in 1995. The PDS data for January to March 1996 accessible with the current version of the IT only included 3 runway incursion reports. However, rather than representing a reduction in runway incursion incidents, it is more likely that this simply reflects a reporting lag. General aviation operations accounted for about 70 percent of the RI incidents, 14 percent resulted from U.S. air carrier operations while each of the other operator types accounted for 4 percent or less of the RI incidents. Although the relatively low number of incidents for each category of operator other than GA and U.S. air carrier make any apparent trends in these data statistically insignificant, the data appear to show two noteworthy trends for GA and U.S. air carrier operations. The first is the progressive increase in U.S.

air carrier incidents between 1992 and 1996 and the second is the sharp increase in GA incidents in 1995, following a progressive decrease during the previous three years.

However, it should be noted that if foreign air carrier incursion incidents are combined with those for U.S. air carriers, the increase from 1992 to 1995 is less and in fact there was no change from 1994 to 1995. Including commuter air carriers as well further reduces the increase from 1992 to 1995, but still suggests a progressively increasing trend over the period.

Although the prototype IT does not allow runway incursion incidents to be specifically selected to classify the type of human error involved, it does identify the report numbers for each type of error for those subsets of the data that it can classify. By comparing the list of report numbers for all types of incidents with the runway incursion incidents identified in the database, it was possible to classify the runway incursion incidents, as shown in Table 5-3. Using Human Error Model 1, it was found that almost all the errors were classified as slips. Furthermore, almost all the runway incursion reports were able to be classified by the criteria used in the error model.

Table 5-1 **Partial Dataset for Runway Incursion Analysis**

EVENT_KEY	RPT_NBR	SfcDevtype	Loc_Arpt_id	FLT_RULE	Phase	ACFT_TYPE	OPRTR_TYPE	Event_Year	Cetificate	Plt hr rang
1060001134	PNETBED92A01	Entered Rwy/Twy	BED	VFR	Lndg/taxi	Low	G/A	1992	CFICOML	not indicate
1060001254	PGLRCLE92002	Entered Rwy/Twy	CLE	VFR	Taxi		G/A	1992	STDNT	0-500
1060001310	PSWRSAT92012	Entered Rwy/Twy	SAT	VFR	Taxi		OTHER	1992	COML	2001-700
1060001338	PSORATL92012	Entered Rwy/Twy	ATL	IFR	Taxi	Med/High	COM	1992	ATP	>7000
1060001397	PNMTBFI92002	Entered Rwy/Twy	BFI	VFR	Taxi	Low	G/A	1992	COML	2001-700
1060001405	PWPRLAS92001	Entered Rwy/Twy	LAS	VFR	Taxi	Low	G/A	1992	PVT	not indicate
1060001426	PWPTRNO92001		RNO	VFR	Lndg	Low	G/A	1992	PVT	0-500
1060001481	PEATPHL92017	Entered Rwy/Twy	PHL	IFR	Taxi	Med/High	G/A	1992	PVT	2001-700
1060001561	PGLTFSD92A01	Entered Rwy/Twy	FSD	IFR	Taxi	Med/High	USA/C	1992	ATP	>7000
1060001631	PSORMCO92010	Entered Rwy/Twy	MCO	IFR	Taxi	Med/High	USA/C	1992	ATP	>7000
1060001657	PSOTCLT92A01	Entered Rwy/Twy	CLT	IFR	Taxi	Med/High	G/A	1992		not indicate
1060001703	PSWTRVS92A01	Entered Rwy/Twy	RVS	VFR	Taxi	Low	G/A	1992	CFISTDNT	not indicate
1060001704	PWPTSEE92002	Entered Rwy/Twy	SEE	VFR	Taxi	Low	G/A	1992	PVT	501-2000
1060001712	PEATSYR92A02	Entered Rwy/Twy	SYR	VFR	Taxi	Low	G/A	1992	UNKN	2001-700
1060001724	PCETOMA92A01	Entered Rwy/Twy	OMA	VFR	Taxi	Med/High	G/A	1992	ATP	>7000
1060001942	PWPTHNL92A01	Entered Rwy/Twy	HNL	UNK	Taxi/tkof	Low	G/A	1992	COML	501-2000
1060001977	PWPTPOC92001		POC	VFR		Low	G/A	1992	CFICOML	501-2000
1060002051	PEATPHL92012	Entered Rwy/Twy	PHL	VFR	Taxi	Med/High	A/C	1992	FRGN	not indicate
1060002222	PGLTCMH92001	Tkof w/o clnc	CMH	VFR	Tkof	Low	G/A	1992	PVT	0-500
1060002274	PSOTMGM92A01	Entered Rwy/Twy	MGM	VFR	Taxi	Med/High	G/A	1992	COML	2001-700
1060002351	PGLTARR92001	Lndg w/o clnc	ARR	VFR	Lndg	Low	G/A	1992	PVT	0-500
1060002440	PGLTHUF92042	Entered Rwy/Twy	HUF	IFR	Taxi	Med/High	G/A	1992	COML	0-500
1060002467	PCETFOE92001	Entered Rwy/Twy	FOE	IFR	Taxi	Low	G/A	1992	PVT	501-2000
1060002502	PWPTDVT92002	Entered Rwy/Twy	DVT	VFR	Taxi	Low	G/A	1992	PVT	not indicate
1060002648	PNETBOS92002	Entered Rwy/Twy	BOS	VFR	Taxi	Med/High	USA/C	1992	ATP	>7000
1060002708	PWPTLAX92267	Entered Rwy/Twy	LAX	VFR	Taxi	Med/High	A/C	1992	FRGN	>7000
1060002726	PWPTPRC92A01	Entered Rwy/Twy	PRC	IFR		Low	G/A	1992	STDNT	0-500
1060002788	PWPTLVK92058	Entered Rwy/Twy	LVK	VFR	Taxi	Low	G/A	1992	PVT	0-500
1060002793	PWPTMYF92002	Entered Rwy/Twy	MYF	VFR	Lndg	Low	G/A	1992	PVT	501-2000
1060002833	PGLTOSH92002		OSH	VFR	Tkof	Low	G/A	1992	COML	>7000
1060002892	PEATCDW92004	Entered Rwy/Twy	CDW	VFR	Tkof	Other	G/A	1992	ATPCFIOTRP	>7000
1060002908	PNETBOS92001	Entered Rwy/Twy	BOS	VFR	Taxi	Med/High	USA/C	1992	ATP	>7000
1060002929	PNMTBFI92007	Entered Rwy/Twy	BFI	VFR	Taxi		G/A	1992	PVT	0-500
1060002930	PNMTBFI92006	Tkof w/o clnc	BFI	VFR	Tkof	Low	G/A	1992	CFICOML	0-500
1060003024	PNMTBFI92005	Entered Rwy/Twy	BFI	VFR	Taxi	Low	G/A	1992	PVT	501-2000
1060003056	PNETGON92001	Entered Rwy/Twy	GON	VFR	Taxi	Low	COM	1992	COML	501-2000
1060003076	PWPTSBA92002	Entered Rwy/Twy	SBA	VFR	Taxi	Med/High	G/A	1992	PVT	2001-700
1060003200	PNETBDL92002	Entered Rwy/Twy	BDL	IFR	Lndg	Med/High	COM	1992	ATPOTR	>7000
1060003221	PGLTMSP92004	Entered Rwy/Twy	MSP	IFR	Lndg	Med/High	USA/C	1992	ATP	not indicate

Table 5-2

Runway Incursion Pilot Deviation Reports

	1992	1993	1994	1995	1996	Total
Type of Operator						
U.S. Air Carrier	8	9	13	16		46
Foreign Air Carrier	3	3	4	1		11
Commuter Air Carrier	5	4	1	3		13
Air Taxi		1	6	3		10
General Aviation	63	58	37	71	3	232
Other Operator	4		1	6		11
Unknown	1	2		2		5
Total	84	77	62	102	3	328

NOTE: Data for 1996 is through March 1996 and appears to be incomplete.

Table 5-3

Classification of Pilot Deviation Runway Incursion Errors

All Airspace Users

	1992	1993	1994	1995	1996	Total
Human Error Model 1						
Slips	78	74	62	96	2	312
Mistakes					1	1
Slips and Mistakes	2	2	-	2	-	6
Unclassified	4	1	-	3	1	9
Total	84	77	62	102	3	328

NOTE: Data for 1996 is through March 1996 and appears to be incomplete.

Flight

In order to better understand the conditions under which these errors occurred, an analysis was performed of the distribution of flight conditions associated with the incidents. Flight profile was defined in the FAA study as the flight conditions associated with a runway incursion including airport traffic level, aircraft performance, pilot certificate(s), pilot total hours, type of RI, time of day, and phase of flight. The categories used in the analysis were the same as those used in the FAA study, with the exception of the airport traffic level.

Table 5-4 presents the flight profiles for the two major categories of airspace user involved in runway incursions: GA and U.S. air carrier. The most frequent flight profile for GA was consistent with that found in the earlier study, which only examined GA flight profiles. For U.S. air carriers the most probable flight profile was an aircraft in its taxi phase between 1601-2000 local time under IFR conditions being flown by a airline transport certificate pilot with an experience of more than 7,000 flight hours. Similar flight profiles were also obtained for air taxi and commuter, the only difference being in the total flight hours for air taxi pilots. However, due to the small sample size, these results are less reliable.

Causal and Contributing Factors

The previous FAA analysis identified a number of causal and contributing factors that may have contributed to the runway incursion, including problems with orientation, communication, memory, and attention. These 38 causal and contributing factors, which were based on the survey of airline pilots by the MITRE Center for Advanced Aviation System Development (Adam *et al.*, 1994, Adam & Kelley, 1996), were grouped by the FAA study into six major categories: orientation, communication, memory, attention, FAR/compliance with ATC, and other. The current analysis used the same causal and contributing factors. The FAA analysis made use of a combination of data fields, narratives, and comments to classify reports into each category. There are some factors for which the FAA documentation on the study clearly specifies the data fields used. For a few of the others, we were able to identify the relevant data fields and for the rest we have assumed that the information was obtained from the narrative, although this was not clearly stated in the report. Table 5-5 shows the data source corresponding to each causal factor. The empty cells in the table imply that the source was not explicitly identified but can be assumed to be the narrative.

Table 5-4

Flight Profiles for Runway Incursion Incidents

		Percent
US Air Carrier (46 reports out of 328 total PD RI reports)		
Aircraft Performance	High/Medium	91
Pilot Certificate	Airline Transport	89
Pilot Total Hours	> 7000	74
Type of Runway Incursion	Entered taxiway/runway without clearance	85
	Takeoff without clearance	9
Local Time of Day	1601-2000	37
	2001-2400	22
Phase of Flight	Taxi	70
	Takeoff	11
	Landing	11
Flight Rules	VFR	74
	IFR	22
General Aviation (232 reports out of 328 total PD RI reports)		
Aircraft Performance	High/Medium	20
	Low	73
Pilot Certificate	Commercial	28
	Private	48
	Student	12
Pilot Total Hours	0-500	42
	501-2000	24
	2001-7000	15
Type of Runway Incursion	Entered taxiway/runway without clearance	50
	Takeoff without clearance	21
	Landed without clearance	15
Local Time of Day	1201-1600	32
	1601-2000	30
	2001-2400	29
Phase of Flight	Taxi	44
	Takeoff	22

	Landing	22
Flight Rules	VFR	85
	IFR	14

Table 5-5 **Data Fields for Causal/Contributing Factors**

	Data fields	Explanation
Orientation		
Lack of airport familiarity	plt_inadqt_arpt_flag	Pilot had inadequate knowledge/experience with airport
Inadequate and/or ineffctive use of cockpit procedures	plt_lost_flag	Pilot was disoriented or lost
	plt_inadqt_crew_flag	Pilot - Inadequate knowledge/experience: crew coordination
Inadequate and/or ineffective use of signs/markings/lighting		
Inadquate and/or ineffective use of airport charts	plt_inadqt_aip_flag	Pilot had inadequate knowledge/experience with approach pl
Did not ask for progressive taxi instructions	narrative	Derived from reading the narrative
Pilot disorientation caused by airport layout	plt_inadqt_arpt_flag	Pilot had inadequate knowledge/experience with airport
Pilot disorientation caused by obsruction to vision	plt_lost_flag	Pilot was disoriented or lost
Communication		
Inadequate or inappropriate ATC communications	fctr_equip_com_flag	Equipment malfunction contributed to PD: Communication
Inadequate or inappropriate pilot communications	plt_inadqt_atc_flag	Pilot had inadequate knowledge/experience with ATC proced
	plt_inadqt_english_flag	Pilot had inadequate knowledge of English language
	plt_inadqt_termnlgy_flag	Pilot had inadequate knowledge of ATC terminology
Discrepancy in ATC terminology and charts/signs	plt_atc_instrn_flag	Pilot did not follow ATC instructions
Problems knowing what ATC frequency to monitor		
Cockpit tasks conflicting w/ ATC-pilot communications		
Problems w/ readback		
Inability to read instructions back to ATC - congested freq		
Problems w/crew coordination on ATC instructions	plt_inadqt_crew_flag	Pilot - Inadequate knowledge/experience: crew coordination
	narrative	Derived from reading the narrative
Memory		
Effects of airport unfamiliarity		
Pilot's use of memory aids		
Prob w/content or timing of ATC instructions		
Use of readbacks as memory reinforcers		
Demanding cockpit tasks disrupt memory		
Standard taxi routes not used		

Profile Analysis

The three most common causal or contributing factors were identified by the earlier FAA study to be:

- inadequate or inappropriate pilot communications
- lack of airport familiarity
- inadequate or ineffective use of cockpit procedures for maintaining orientation.

Each of these factors could be identified from the data fields in the PDS records, without needing to read and interpret the narrative fields. It would of course be desirable to be able to make use of the information in the narrative fields as well, but that was beyond the scope of the current analysis.

The number of records in the 328 runway incursion reports extracted from the PDS database that were found to involve these three factors are shown in Table 5-6. One or more of these factors were present in about 40 percent of the GA incursion reports and in about 28 percent of the U.S. air carrier incursion reports. Perhaps not surprisingly, pilot communication problems were identified as a factor in almost half of the runway incursion reports involving foreign air carriers. Pilot communication problems were also the most frequent of the three factors identified for GA incursion incidents.

The corresponding flight profiles for the GA incursion incidents for each of the three factors are shown in Table 5-7. Incursions involving inadequate or inappropriate pilot communication tend to involve a higher proportion of VFR operations by student or private pilots with less than 500 hours experience. They also involve a much higher proportion of incidents during landing and takeoff, including landing or takeoff without clearance or on the wrong runway. Incursions involving inadequate or ineffective use of cockpit procedures tend to involve a higher proportion of more experienced pilots and higher performance aircraft, and mostly involve entering a taxiway or runway without clearance.

The change in the number of GA incursion incidents involving the three factors from 1992 to 1995 is shown in Table 5-8. The proportion of reports identifying at least one of these factors increased from 30 percent in 1992 to about 50 percent in 1994, before decreasing to about 42 percent in 1995. Whether this decrease is due to an increase in the proportion of other factors, or simply an increase in the proportion of incidents for which causal and contributing factors could not be assigned, cannot be determined without further analysis. However, the data do appear to suggest that inadequate or inappropriate pilot communications was a significant contributing factor to the increase in GA runway incursions from 1994 to 1995.

Table 5-6

Occurrence of Major Causal or Contributing Factors

	Pilot Communication	Airport Familiarity	Cockpit Procedures	One or More Factors
Type of Operator				
U.S. Air Carrier	5	5	7	13
Foreign Air Carrier	5	3		8
Commuter Air Carrier	3	1	1	4
Air Taxi		3		3
General Aviation	60	36	15	93
Other Operator	4			4
Unknown	2			2
Total	79	48	23	127

Discussion of Results

The results of the current analysis largely confirm the findings of the earlier FAA study, with some differences in the detailed flight profiles for the three most important causal or contributing factors, principally for incidents involving inadequate or ineffective use of cockpit procedures for maintaining orientation. This was the smallest group of reports, involving 17 reports in the FAA sample and 23 reports in the current analysis. However, because the FAA was able to classify a higher proportion of the reports by use of the information in the narratives, it is quite likely that the 23 reports in the current study included only some of the 17 reports used in the earlier findings. Given this limited sample size, it is clear that some differences in the distribution across the various aspects of the flight profiles is to be expected.

Table 5-7

Flight Profiles for Major Causal or Contributing Factors

General Aviation Runway Incursion Reports

		Percent
Inadequate or Inappropriate Pilot Communication (60 reports)		
Aircraft Performance	High/Medium	14
	Low	85
Pilot Certificate	Commercial	27
	Private	50
	Student	22
Pilot Total Hours	0-500	65
	501-2000	21
Type of Runway Incursion	Entered taxiway/runway without clearance	45
	Takeoff without clearance	29
Local Time of Day	0801-1200	35
	1201-1600	33
	1601-2000	27
Phase of Flight	Taxi	45
	Takeoff	30
	Landing	22
Flight Rules	VFR	25
	IFR	5
Lack of Airport Familiarity (36 reports)		
Aircraft Performance	High/Medium	16
	Low	84
Pilot Certificate	Commercial	25
	Private	53
	Student	17
Pilot Total Hours	0-500	50
	501-2000	25
	2001-7000	25
Type of Runway Incursion	Entered taxiway/runway without clearance	74
	Landed without clearance	11

Local Time of Day	0801-1200	25
	1201-1600	31
	1601-2000	31

Table 5-7 (cont.)

		Percent
Lack of Airport Familiarity (cont.) (36 reports)		
Phase of Flight	Taxi	72
	Takeoff	16
	Landing	12
Flight Rules	VFR	81
	IFR	19
Inadequate or Ineffective Use of Cockpit Procedures (15 reports)		
Aircraft Performance	High/Medium	36
	Low	64
Pilot Certificate	Airline Transport	20
	Commercial	33
	Private	47
Pilot Total Hours	0-500	45
	501-2000	27
	> 7000	27
Type of Runway Incursion	Entered taxiway/runway without clearance	87
Local Time of Day	0801-1200	27
	1201-1600	27
	1601-2000	33
Phase of Flight	Taxi	92
	Takeoff	8
Flight Rules	VFR	87
	IFR	13

The findings confirm the importance of effective pilot communication and airport familiarity in reducing runway incursions. Since airport familiarity depends on the prior use of the airport by the flight crew, which generally is not something that can be changed, it is important that appropriate procedures are developed and followed to compensate for this when flight crew are using unfamiliar airports.

Table 5-8

Change in Major Causal or Contributing Factors

General Aviation Runway Incursion Reports

	1992	1993	1994	1995	Total
Causal or Contributing Factor					
Pilot Communication	11	17	10	20	58
Airport Familiarity	10	7	8	11	36
Cockpit Procedures	4	5	3	3	15
One or More Factors	19	23	19	30	91

Similarly, effective pilot communication comes from both training and habit. While it may be easy to identify a failure of effective communication as a contributing factor to a runway incursion, it is much harder to determine why that failure occurred and thus what can be done to reduce the likelihood of such errors in the future. This is limited by the information currently available in the PDS database. Therefore efforts to reduce pilot surface deviations need to address the information available to be analyzed as much as the results of the analysis that can be performed.

Conclusions

The analysis of the runway incursion reports in the PDS database has demonstrated how enhanced functionality of the Integration Tool could greatly assist in analyzing the aviation safety data accessible with the tool. Selection of specific types of incident for analysis is currently difficult with the existing version of the tool, as is the ability to download the various data fields required to examine causal and contributing factors. The current implementation of the human error models restricts the user's ability to tailor the analysis to identify specific types of causal or contributing factors, such as those discussed in the current analysis. None of these limitations are inherent in the design of the IT, and in fact can be fairly easily fixed, as discussed in the next chapter.

It was found that the automated analysis process gave reasonable results, although it should be noted that time constraints prevented use of the information in the report narratives. Since it is recognized that the narratives form a valuable source of information because they provide the flight inspector with a way to supplement the information in the prespecified fields provided on the report forms, text processing of the narratives could be a valuable area for future work.

6. Enhancement of the Role of the Integration Tool

The previous chapters have discussed ways in which the representation of human error could be improved, additional information on individual, team and organizational factors could be acquired, and explored the use of the IT to analyze flight crew human errors. This chapter discusses how functional enhancements to the IT could increase its ability to support the type of human error analysis required to better understand the causality behind the errors and what can be done to reduce the risk of these errors being made in the future.

More Flexible Representation of Human Error

The current human error models are "hard-wired" into the code of the IT. While this prevents users from applying inappropriate models to the data, it also prevents them from exploring the value of other approaches. What would provide greater flexibility in the representation of human error is to allow the users to define their own models. The best way to do this is to provide a capability to define a set of rules that reference fields in the databases. These rules would take form of:

SELECT IF {*Field*} {*Operator*} {*Value*}

where {*Operator*} would include such functions as EQUALS, LESS THAN, IS NOT, etc. The system would provide a "rule editor" that would not only allow users to modify a set of rules that they had previously defined as a user-named model, but would allow rules to be combined using Boolean (AND, OR) logic.

For consistency with existing terminology within the IT (and the human factors community) a model could consist of several different "error types", each of which would have its own set of rules. Applying the user-defined model to a database would generate a search of the relevant database fields to identify those records match the criteria for each error type. These records would then be flagged and the other features of the IT could be used to display and analyze the results.

The {*Field*} syntax can be designed to specify both the database and the field.

This will allow the IT to support human error models that use data in a wide range of databases, as well as integrate data from multiple databases in a given model. For example, pilot training data may exist in one database, while incident data resides in another. A user can then specify an error model that includes the training history of pilots involved in incidents.

Access to a Broader Set of Data Resources

It is clear that the development of a richer characterization of the causal factors underlying flight crew human error will require not only a more flexible way to define human error models, but access to a broader set of data resources. This could include data fields within the databases currently accessible to the IT, as well as other databases not currently accessible. These could include proprietary or restricted databases, given appropriate levels of security. While one of the valuable features of the IT is the user's ability to access the data via the Internet, this will require the development of appropriate techniques to transmit sensitive information, and provide access to restricted data.

Access to User-defined Data Fields

The architecture of the prototype IT makes the distinction between the existing internal databases and access to future external databases largely semantic. Requests for data within the logic of the IT generate calls to a database server running on the same machine, using a client-server architecture. However, there is no reason for the database server to be running on the same machine and the system would work just as well if the database server was running on another machine on the other side of the country, or even the world (although response times might be somewhat slower). The data requests are transmitted via industry-standard Sequential Query Language (SQL) calls, and thus any database server capable of handling SQL messages could respond to a request from the IT.

Thus once the IT logic has been modified to allow users to select any desired field in the databases the IT can currently access, extending this to allow the users to access desired fields in another database is a relatively simple step. Of course, there will be system configuration settings that will have to be addressed the first time a new database is accessed. However, these can be placed in a server accessible to all users via the Internet, so once one user has set up the connection parameters, other users can simply download the settings. Obviously, there are details of access authority that need to be resolved.

Although not essential, it would be desirable for each database to maintain a data information system in a standard format, so that users can determine what fields exist in each database, and the nature of the content of each field. A useful function of the IT would be to support Internet access to this information. Currently, the Data Information System (DIS) for the databases accessible via the IT is maintained on the IT as a series of Web pages. However, these Web pages could be created dynamically by the IT from information acquired from the DIS of the relevant database server.

Narrative Fields

Narrative fields present a number of specific issues. The first is their size. Since the content may range from a few words to many pages of text, they may need to be handled differently from other fields. This should be largely transparent to the user.

The more interesting issue is how best to provide a user with the capability to work with data contained in a narrative field. The development of such techniques could form the basis of a useful follow-on research activity, once the initial capability of accessing narrative fields has been established. A fairly simple, but potentially powerful, feature that could form the basis of an initial implementation would be to allow the user to search narrative fields for specific text strings. The ability to link strings with Boolean and logical operators (AND, OR, NOT) would greatly enhance the power of the search.

The results of such a search can be integrated into the other capabilities of the IT by providing the text search capability as an option on the Sub-matrix Query definition page that selects the conditions for which the record count is presented, as described in Appendix A. The count of the records identified by the text search will then be displayed on the resulting cross-tabulation matrix, and the record contents can then be displayed or downloaded for statistical analysis.

Of course, as with any search in textual material, care needs to be taken to make sure that the resulting records use the search strings in the way intended by the user. This may require reading every narrative identified by the search. However, this is a far different matter from reading every narrative in the database. With experience, users will learn how to use these capabilities effectively and avoid the more obvious pitfalls.

Security Issues

The ability to access proprietary or restricted databases suggests the need for fairly sophisticated security features for both access to the database servers and transmission of data over the Internet. Fortunately, the issue of secure transmission of data over the Internet is of such importance for a wide variety of applications that relatively secure techniques are becoming readily available. These techniques will require the database server to recognize the protocols. For these reasons, it may be desirable for the organization owning the database to establish a separate server that communicates directly with IT users, handles security issues and then simply retrieves the data from the primary database server and forwards it to the client application once it has validated the request.

In some cases, it may be necessary to give specific users access to particular fields within a database, but not others. A local communication server could also handle this function transparently to the user. This could be set up so that the DIS information only included the fields to which a user had access, preventing users from even being aware of what other fields exist in the database.

The provision of system configuration information on a central server could be similarly protected. The prototype Integration Tool already requires a user identification and password to access the system. Authority to download system configuration information could be restricted to specific users by the owners of the system. The information could be encoded and the decoding key provided directly to the authorized user by the system owner, as an additional safety measure.

Implementation

It is proposed that an initial implementation be developed to provide access to the NASA Aviation Safety Reporting System database. While this database is in fact publicly available and does not require the security considerations discussed above, there is no harm in providing this layer of protection. This will serve as a useful demonstration of the security capabilities of the system, and if in fact there are any security breaches during development, no harm will result. The ASRS is anyway a very valuable database for aviation safety researchers and providing access via the IT will be a useful enhancement in its own right.

7. Conclusions

The current version of the Integration Tool provides a useful initial capability to analyze aviation accident and incident databases, by identifying specific records in a large database that meet certain criteria, and then allowing the user to display the contents of the database records for further review. The concept of using human error models to assist in selecting records for events that conform to a particular type of error allows the user to focus on a subset of the data of particular interest, and may facilitate the identification of strategies to reduce the occurrence of particular types of error.

However, the human error models currently implemented in the IT provide limited guidance as to what might be done to address these errors. Furthermore, the human error models as currently implemented are only able to classify a small proportion of the records in the two databases accessible with the tool. What is needed is a richer characterization of human error, that identifies not only the type of error, but the context within which the error was made and the contribution of organizational and environmental factors to the error. The research described in this report has reviewed the recent literature on human error and strategies to reduce the risk of such errors. It is increasingly recognized that both the sequence of precursor events, as well as the institutional environment within which the flight crew operate, are important factors in shaping whether an error is made, and in determining whether errors are rapidly detected and corrected, or whether they are allowed to escalate into an accident.

For these ideas to be applied in the context of an analysis tool such as the IT, it is necessary to be able to access a broader range of information than is currently available in the databases accessible by the IT. Some of the required information exists within the databases, such as in the narrative fields, but is not currently accessible to the user of the IT except by reading the content of each record. Other information exists in other databases, which the IT currently has no way to access. Finally, some of the required information is not currently collected at all. In particular, data on the safety culture of the organization, and the perceptions of those in the organization of the importance placed on eliminating the possibility of error, is increasingly being recognized as a useful complement to traditional incident investigation in a broad range of safety-critical organizations. The use of a risk management questionnaire, tailored to the issues of importance in the organization being studied, has been found in other organizational contexts to be an effective way to assemble quantitative data that address these issues. While this technique has not yet been widely adopted in the aviation industry, the U.S. Navy has recently commenced a program to apply this approach to naval aviation squadrons. As part of the research under this project, discussions have been commenced with several airlines and other industry organizations to explore the application of a similar approach within civilian aviation.

In addition to the improved representation of the context of human error, and the inclusion of appropriate data in safety databases, the utility of the Integration Tool will be greatly enhanced by additional functionality that provides the users with the capabilities to define their own categories of error, merge data from multiple databases, and make greater use of the information in those databases to select the records for analysis. While ultimately it is the insight and experience of aviation safety experts that will identify effective strategies to reduce the occurrence of flight crew error, the availability of effective tools to search and organize the information will enhance their ability to focus on the critical issues, and recognize the relevant patterns amid the vast amount of data that can potentially be generated by recent advances in information technology.

The challenge of reducing the fatal accident rate in U.S. aviation by 80 percent by 2007, established as a goal in the latest FAA Strategic Plan, will require a sustained commitment to developing effective tools to integrate, manage and analyze the growing volume of aviation safety data. The success of the Global Analysis and Information Network will depend not only on the ability to address the concerns over sharing proprietary or sensitive data, but also the availability of tools to manage and analyze those data.

The current version of the Integration Tool provides a useful platform from which to address these issues. However, for this to occur, further enhancements to the structure and logic of the IT are needed,. so that it can provide users with greater functionality and access to a broader array of aviation safety data. Central to this are two capabilities:

- the provision of the ability for users to define their own human error models, using a rule-based format that can access any desired field in the underlying databases;

- the ability to access other databases over the Internet using secure methods for the transmission of sensitive data.

It is recommended that these enhancements be pursued as soon as sufficient resources can be made available.

As part of the current study, a survey was performed of the data access and analysis needs of potential users of the IT, and the prospects for cost-sharing support for developing functional enhancements for the IT (Gosling, 1998). This survey found that an enhanced version of the Integration Tool, incorporating the features discussed above, might be able to attract significant financial support from the user community.

References

Adam, G.L., Kelley, D.R. & Steinbacher, J.G. (1994). Reports by airline pilots on airport surface operations: Part1. Identified problems and proposed solutions for surface navigation and communications, Executive summary. Report MTR 94W0000060, Center for Advanced Aviation System Development, MITRE Corporation, McLean, Virginia.

Adam, G.L. & Kelley, D.R. (1996). Reports by airline pilots on airport surface operations: Part2. Identified problems and proposed solutions for surface operational procedures and factors affecting pilot performance, Executive summary. Report MTR 94W00000060.v2, Center for Advanced Aviation System Development, MITRE Corporation, McLean, Virginia.

Attwell, P. (1992). Technology diffusion and organizational learning: The case of business computing. Organization Science. **3**, 1-19.

Brass, D.J. (1995). A social network perspective on human resources management. Research in Personnel and Human Resources Management, **13**, 39-79.

Clemons, E.K. & Row, M.C. (1992). Information technology and industrial cooperation. Journal of Management Information Systems. **9**, 9-28.

Daft, R.L. & Weick, K.E. (1984). Toward a model of organizations as interpretation systems. Academy of Management Review. **9**, 284-295.

Diehl, A. (1989),.Human performance aspects of aircraft accidents. In R. Jensen (Ed.) Aviation psychology. Aldershot, England: Gower Press.

Dolan, N., Brasher, J., Fischer, D. & Fogle, M. (1996). Breakdown of human error models, Prepared for the FAA Office of System Safety, Galaxy Scientific Corporation, Egg Harbor Township, New Jersey.

Duke, T. (1997). Preventing runway incursions. Air Line Pilot, Part 1, June/July; Part 2, August.

Edwards, E. (1988). Introductory overview. In E.L. Wiener & D.C. Nagel (Eds.) Human factors in aviation, San Diego, CA: Academic Press, 3-25.

Foushee, H.C. & Helmreich, R.L (1988). Group interaction and flight crew performance. In E.L. Wiener & D.C. Nagel (Eds.) Human factors in aviation, San Diego, CA: Academic Press, 189-228.

Fulk, J. and De Sanctis, G. (1995). Electronic communication and changing organizational Forms. Organization Science. **6**, 387-349.

Gallupe, R.B., DeSanctis, G., and Dickson, G.W. (1988). The impact of computer-based support on the processes and outcomes of group decision-making. MIS Quarterly, **12**, 277-296.

Gosling, Geoffrey D. (1998). Proposed functional enhancements for the flight crew human factors Integration Tool, Working Paper UCB-ITS-WP-98-2, Institute of Transportation Studies, University of California, Berkeley.

Gilson, R.D., Garland, D.J., & Koonce, J.M. (Eds.) (1994). Situation awareness in complex systems. Daytona Beach, FL: Embry-Riddle Aeronautical University Press.

Grabowski, M. & Roberts, K.H. (1996). Human and organizational error in large-scale systems. IEEE Transactions on Systems, Man, and Cybernetics. **26**, 2-16.

Hart, P. & Saunders, C. (1997). Power and trust: Critical factors in the adoption and use of electronic data interchange. Organization Science, **8**, 23-42.

Kelley, D.R. & Schreckengast, S.W. (1997). Safety roundtable on runway incursion prevention, Working Note WN 97W0000108, Center for Advanced Aviation System Development, MITRE Corporation, McLean, Virginia.

Landau, M. (1969) Redundancy, rationality, and the problem of duplication and overlap. Public Administration Review, **29**, 336-358.

Libuser, C. (1994). Organizational structure and risk mitigation, Ph.D. dissertation, Los Angeles, CA: University of California at Los Angeles.

March, J.G., Sproul, L., and M. Tamuz. (1991). Learning from samples of one or fewer. Organization Science, **2**, 1-14.

Mayntz, R. & Hughes, T.P. (1988) (Eds.) The development of large technical systems. Boulder, CO: Westview Press.

Medvedev, Z. (1990) The legacy of Chernobyl. New York: W.W. Norton.

Monge, P. & Eisenberg, E.M. (1987). Emergent communication networks. in F.M.Jablin, L.L. Putnam, K.H. Roberts, & L.W. Porter, (Eds.) Handbook of organizational communication. Newbury Park, CA: Sage, 304-342.

Norman, D.A. (1981). Categorization of action slips. Psychological Review, **88**, 1-15.

Norman, D.A. (1983). Position paper on human error. NATO Advanced Research Workshop on Human Error. Bellagio, Italy.

O'Hare, D. & Roscoe, S. (1990), Flightdeck performance: The human factor. Ames, Iowa: Iowa State University Press.

O'Hare, D., Wiggins, M., Batt, R. & Morrison, D. (1994). Cognitive failure analysis for aircraft accident investigation. Ergonomics, **37**, 1855-1869.

Orasanu, J. (1997). Situation awareness: Its role in flight crew decision making. NASA Ames Research Center Report. Also at http://olias.arc.nasa.gov/publications/OSU_Orasanu/AvPs-SA.txt.html.

Orlikowski, W.J. (1996). Improvising organizational transformation over time: A situated perspective. Information Systems Research. **7**, March, 63-92.

Perrow, C. (1984). Normal accidents: Living with high risk technologies. New York: Basic Books.

Rasmussen, J. (1982). Human errors: A taxonomy for describing human malfunction in industrial installations. Journal of Occupational Accidents, **4**, 311-333.

Rasmussen, J. (1986). Information processing and human machine interaction: An approach to cognitive engineering, New York: North-Holland.

Reason, J. (1990). Human error, New York: Cambridge University Press.

Roberts, K.H. (1990). Some characteristics of high reliability organizations. Organization Science. **1**, 160-177.

Salancik, G.R. (1995). Wanted: A good network theory of organization. Administrative Science Quarterly. **40**, 345-349.

Sarter, N.B. & Woods, D.D. (1991). Situation awareness: A critical but ill-defined phenomenon. International Journal of Aviation Psychology. **1**, 45-57.

Schein, E.A. (1992) Organizational culture and leadership. 2nd edition. San Francisco: Jossey-Bass.

Schreckengast, S. & Fogle, M. (1996). Flight crew accident and incident human factors: Data project technical specifications, Center for Advanced Aviation System Development, MITRE Corporation, McLean, Virginia.

Senge, P.M. (1990). The fifth discipline: The art and practice of the learning organization. New York: Doubleday.

Shappell, S.A. & Wiegmann, D.A. (1997). A human error approach to accident investigation: The taxonomy of unsafe operations. The International Journal of Aviation Psychology, 7:1, 67-81.

Steeb, R. and Johnston, S.C. A Computer-based Interactive System for Group Decision-Making, IEEE Transactions on Systems, Man, and Cybernetics, SMC-11:8, August 1981, 544-552.

Stokman, F.N. & Doreian, P. (1996). Concluding remarks. Journal of Mathematical Sociology. **21**, 197-199.

Vaughan, D. (1996). The Challenger launch decision: Risky technology, culture, and deviance at NASA. Chicago: University of Chicago Press.

Volberda, H.W. (1996). Toward the flexible form: How to remain vital in hypercompetitive environments. Organization Science. 7, 359-374.

Weick, K.E., (1979). The social psychology of organizing. 2nd edition. Reading, MA: Addison-Wesley.

Weick, K.E. (1990). The vulnerable system: An analysis of the Tenerife air disaster. Journal of Management. **16**, 571-593.

Weick, K.E. (1993). The collapse of sense making in organizations: The Mann Gulch disaster. Administrative Science Quarterly. **38**, 628-652.

Wickens, C.D. & Flach, J.M. (1988). Information processing. In Wiener, E.L. & Nagel, D.C. (Eds.), Human factors in aviation, San Diego, CA: Academic Press, 111-155.

Wiegmann, D.A. & Shappell, S.A. (1997). Human Factors analysis of postaccident data: Applying theoretical taxonomies of human error. The International Journal of Aviation Psychology, 7:1, 67-81.

Wishart, N.A., Elam, J.J. & Robey, D. (1996). Redrawing the portrait of a learning organization: Inside Knight Ridder, Inc. Academy of Management Executive. **10**, 7-20.

Wojciech, J., Prasse, P., Muir, A. & Brasher, J. (1997). Human factors analysis of pilot deviation runway incursions. Interim report to the FAA Runway Incursion Program Manager, Office of System Safety, Federal Aviation Administration, Washington, D.C.

Appendix A

Introduction to the Prototype Integration Tool

FEDERAL AVIATION ADMINISTRATION

Office of System Safety

Prototype Integration Tool

The prototype Integration Tool (IT) permits safety analysts, accident investigators, human factors professionals, and others to remotely apply two human error models to the NTSB accident/incident and FAA National Airspace Incident Monitoring System (NAIMS)/Pilot Deviation System (PDS) incident databases in a consistent and timely manner. For the NTSB database, the prototype IT produces a cross-tabulation matrix of Type of Flight Crew Error (e.g. slips and mistakes) and the Domain of Flight Crew Error (e.g. aircraft system and weather conditions) during which the error occurred. For the PDS database, the prototype IT produces a matrix of Type of Flight Crew Error and year of the PDS event. For each database-model pair selected the IT will generate a Master Matrix. The user can then create sub-matrices from the master matrix by selecting any combination of year, weather condition, airspace user, aircraft manufacturer (make), phase of flight, and pilot's total hours flown

Each NTSB and PDS cross-tabulation matrix is considered to represent a pattern of human factors across accidents and incidents for a specific population. By comparing population matrices for the same database-model pair, differences or similarities in accident and incident human factors patterns can be observed. By comparing matrices for the same population over time, trends can be detected.

The number in the cells of a matrix represents the frequency of error events. By clicking on an error type-domain matrix cell, the associated report numbers will be displayed. NTSB report numbers include the date of occurrence and airport location. The PDS report numbers indicate the FAA region and facility location along with the date of the incident. By clicking on any one of the report numbers, the analyst can call up the actual report to verify the presence of the type of human error, and to understand more about the context and causality of the accident or incident.

Human Error Models

Two human error models were chosen from the available literature and adopted by the project team for the prototype Integration Tool. The object of these models is to identify and classify human error events in the databases. A series of If-Then decision rules corresponding to the HEM selected look at *all* database records contained in the selected database. The rules are based on coded fields, i.e. fixed data formats, in each database. An accident or incident record may have more than one human error event.

Human Error Model One (HEM1) classifies accident and incident events as either *slips* or *mistakes* resulting from the intent to act. If the data does not identify intent, and there is human error present, the event is designated as *unclassified*. Slips occur when the actions do not go as planned and are therefore considered execution errors. Mistakes result when the actions go as planned, but fail to achieve the desired outcome. Thus, mistakes are categorized as planning errors.

Human Error Model Two (HEM2) classifies accident and incident records as either *knowledge- based*, *rule-based*, or *skill-based* errors. If the data does not identify these errors, and there is human error present, the event is designated as *unclassified*. If the data does not show human involvement, the event is classified as *unknown* and do not appear on the matrices. Skill-based slips represent failures with automatic, routine, and familiar behaviors often resulting from the lack of attention or distraction. Rule-based mistakes occur upon the selection of an inappropriate rule set that dictates or governs behavior. Knowledge-based mistakes result from behavior that requires real-time planning in an unfamiliar situation, often occurring when there is incomplete or incorrect knowledge.

Domain of Flight Crew Error

Seven domains of flight crew error have been identified for the NTSB database. These domains are the subjects for the primary non-people related findings associated with the human error event. They include:

- Aircraft System/Components
    - Structure (flight controls, rotors, fuselage)
    - Systems (electrical, hydraulic, oxygen)
    - Powerplant (engine, fuel system, propeller)
    - Miscellaneous (Fluids, Misc. Equipment, Lights, Aircraft Performance, Aerial Application Equipment, Tow/Advanced Equipment, Balloon Equipment)
- Terrain/Runway Conditions (icy, tundra, wet)
- Weather Conditions (fog, tailwind, rain)
- Light Conditions (dawn, dusk, sunglare)
- Airport
    - Facilities

    - Fire/Rescue
- Air Traffic Facilities
    - Navigational Aids
    - Radar
    - Approach Aids
    - Procedures
    - Weather
- Objects (aircraft parked, hangar, animal)

The human error events were not assigned a domain if they do not have one of the primary non-people related findings associated with them.

A PDS report addresses a single human error event (pilot deviation) but may have multiple error types and domain values. Therefore, for the PDS database the year in which the incident occurred was assigned as the domain of flight crew error.

Databases

The National Transportation Safety Board (NTSB) database reflects all the final accidents and incidents in the NTSB files which are releasable to the public. Since the NTSB database contains over 700 data elements, many of which are clerical in nature, the number of useful data elements was reduced to a subset of approximately 200 elements including the narratives in order to minimize the required time to complete a data query. Privacy Act considerations have been made to remove the identity of individuals, both involved with and investigating the event. The IT presently contains 35,190 records from the NTSB database from 1983 through March 1996.

The FAA National Airspace Incident Monitoring System (NAIMS) Pilot Deviation System (PDS) database reflects pilot deviation incidents which are releasable to the public. These include altitude excursions, unauthorized entry into controlled airspace, and failure to follow command. Privacy Act considerations have been made to remove the identity of the individuals, both involved in and investigating the incident. Prior to 1992, the fields for human factors were not available. The IT presently contains 5,840 records from the NAIMS-PDS database from January 1992 through March 1996.

Databases are provided through the FAA, Safety Data Services Division, ASY-100, National Aviation Safety Data Analysis Center (NASDAC). The data is updated periodically, and the results are annotated with the date when the data was received from NASDAC.

Appendix B

Flight Operations Risk Management Questionnaire

NOTE: The Flight Operations Risk Management Questionnaire included in this appendix is intended to provide sample questions to illustrate the concept, and would need to be expanded and tailored to the needs of a specific organization before being used. The sample questions and format are based on copyrighted material by Carolyn Libuser, and should not be reproduced without permission.

FLIGHT OPERATIONS RISK MANAGEMENT QUESTIONNAIRE

National Center of Excellence for Aviation Operations Research
Institute of Transportation Studies
University of California
Berkeley, CA 94720

Please answer the following questions using a 5 point scale:
Strongly Agree; Agree; Neither Agree nor Disagree; Disagree; Strongly Disagree

PROCESS AUDITING:

Q1. The company makes it hard for flight crew to cover-up or hide mistakes

Q2. The company takes recommendations of the pilot association safety committee very seriously

Q3. Flight crew are discouraged from reporting incidents to the NASA Aviation Safety Reporting System

Q4. The airline safety committee generally does a good job of identifying safety problems

Q5. Company safety bulletins contain valuable and timely information

Q6. The company does a good job of identifying flight crew who tend to make mistakes or take risks

REWARD SYSTEM:

Q7. The company does not reward flight crew who identify safety problems or report mistakes

Q8. Flight crew often feel pressured to achieve an on-time departure against their better judgment

Q9. Flight crew who make serious mistakes are usually punished

Q10. I feel comfortable reporting a serious mistake or safety problem to the airline safety committee

Q11. Flight crew with good cockpit resource management skills are promoted faster

Q12. I personally know of flights that took place with inoperative equipment that in my view should have been canceled or delayed until the problem was fixed

QUALITY OF OPERATIONS:

Q13. This airline is one of the safest to fly

Q14. Compared to our competitors, this airline cares more about making money than the quality of service it provides

Q15. I am proud to tell my friends which airline I work for

Q16. Safety is the most important consideration in every flight crew decision

Q17. The company makes every employee feel that their efforts contribute directly to its success

Q18. Compared to our competitors, this airline devotes more resources to safety programs

RISK PERCEPTION:

Q19. Flight crew are well aware of the risks involved in flying

Q20. Flight crew receive good information about hazardous weather that they might encounter

Q21. Information about safety incidents is rapidly disseminated to flight crew

Q22. Regular training adequately prepares flight crew to handle emergency situations

Q23. I personally know of at least one pilot that I would not want to fly with

Q24. The company takes active steps to identify and minimize risks

MANAGEMENT PROCEDURES:

Q25. Company safety policies, rules and procedures are written down in a manual that I can refer to at any time

Q26. I think that this airline has too many rules, procedures and protocols.

Q27. Many of the company rules get in the way of safe operations.

Q28. Senior management is well informed about safety problems

Q29. When flight schedules get disrupted by bad weather, the company has adequate reserve flight personnel to operate safely

Q30. I think that I am trained well enough to do my job.