2003-01-2975

NASA's Aviation System Monitoring and Modeling Project

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ABSTRACT

Within NASA's Aviation Safety Program, the Aviation System Monitoring and Modeling (ASMM) Project addresses the need to provide decision makers with the tools to identify and evaluate predisposing conditions that could lead to accidents. This Project is developing a set of automated tools to facilitate efficient, comprehensive, and accurate analyses of data collected in large, heterogeneous databases throughout the National Aviation System. This report is a brief overview of the ASMM Project as an introduction to the rest of the presentations in this session on one of its key elements---the Performance Data Analysis and Reporting System (PDARS).

INTRODUCTION

Air transportation is essential to continued economic development of the world. Although it is one of the safest modes of travel, the public demands that safety levels continuously improve and that the absolute number of aviation accidents continue to decline, even as air traffic levels increase. There is a recognized need throughout the international aviation community to become even more proactive in managing safety risk as evidenced by the following statement made by the FAA Administrator, Marion Blakely at the North American Safety Conference earlier this year *"For one, we need to change one of the biggest historical characteristics of aviation safety improvements --- our reactive nature. We must get in front of accidents...anticipate them...and use hard data to detect problems and disturbing trends."*

A proactive approach to identifying and alleviating life-threatening conditions involves monitoring the system performance in a non-punitive environment, learning from normal operational experience, identifying the precursors that foreshadow most accidents, and designing appropriate interventions to minimize the risk of their occurrence. Decision-makers must be able to focus quickly on those events with the highest potential severity and likelihood of reoccurrence.

The governments and the world aviation community routinely amass large quantities of data that could be sources of information relevant to aviation safety. Increasingly, the accumulation of these data outpaces the community's ability to put them to practical use. Often safety data cannot be retrieved after they have been put into computerized storage because of the way that the data were categorized. It is difficult to combine data related to the same subject when they come from diverse, heterogeneous sources. The ability to monitor continuously, convert the collected data into reliable information, and share that information for collaborative decision making is the basis for a proactive approach to identifying and alleviating life-threatening aviation conditions and events.

THE AVIATION SYSTEM MONITORING AND MODELING PROJECT

The Aviation System Monitoring and Modeling (ASMM) project of NASA's Aviation Safety Program, addresses the need to provide decision makers with tools to assist them in identifying and correcting the predisposing conditions that could lead to accidents. (Ref. 4)

ASMM does not aim to replace human expertise with automation. Rather, it provides computational tools to minimize demands on human experts and to focus their attention on the most significant events, and help them identify the factors that distinguish unsafe operations from routine flights. It has developed tools to do tasks that presently can only be performed with much time and effort by aviation experts. The ASMM tools convert a bounty of raw aviation data drawn from many sources—aircraft flight data recorders, ATC radar tracks, maintenance logs, weather records, aviation safety incident reports, etc—into meaningful information, vividly displayed. The focus of the ASMM project is on identifying precursor conditions that elevate the probability of downstream human errors that may, in turn, contribute to aviation safety incidents or accidents.

Each of the several ASMM tools contributes to a unique insight into the complete picture of a safety event, and can be used to support a complementary and synergistic process of causal analysis and safety risk assessment from a system-wide perspective. Qualitative data sources yield information that helps the analyst understand the subjective aspects of "why" an incident occurred, while quantitative data sources help the analyst to understand the objective aspects of "what" happened.

MONITOR TO IDENTIFY SAFETY-RELATED EVENTS:

The first step in the proactive management of risk is to monitor the system continuously, and collect, codify, and classify safety incident data into repositories that can be subsequently mined for safety insights. The databases containing information relevant to aviation safety are very large, heterogeneous (textual and digital), diverse, distributed sources from which information must be extracted and merged to gain a complete picture of a situation. The information must be displayed in a way that makes it easy for the domain expert to interpret and to compare with expectations or performance standards., and to gain the insight needed to identify those events that present potential risks.

Some of the databases, such as the Aviation Safety Reporting System (ASRS) and National Transportation Safety Board (NTSB) databases deal with the national aviation system. Others archive data applicable to particular groups of users. Accordingly, the ASMM uses a dual monitoring strategy. It develops tools that help identify system-wide safety trends using existing and evolving system-level data resources (*extramural monitoring*), and it provides individual constituents of the NAS with tools that enable them to draw useful information from the data they gather (*intramural monitoring*).

Intramural Monitoring

The *Intramural Monitoring* element is intended to provide the air-service operators with the tools needed to monitor their own performance and safety continuously, effectively, and economically within their own organizations. The primary products of this activity are the Aviation Performance Measuring System (APMS) for processing flight-recorded data and the Performance Data Analysis and Reporting System (PDARS) for processing air traffic control data. The intent is to provide a suite of tools for converting data into information customized to the needs of each individual user, and, thereby, to encourage them to share their information for cooperative proactive decision making.

Intramural monitoring at the air carriers is addressed with the APMS that is the research to develop the methodologies and tools to demonstrate to US air carriers that very large quantities of flight-recorded data can be monitored, processed, and analyzed routinely, efficiently, economically, and usefully. The suite of integrated APMS tools is designed to convert flight-recorded data into information to the air-services provider for assuring the quality, reliability, and safety of performance of each company's own Flight Operations and Quality Assurance (FOQA) programs and Advanced Qualifications Programs (AQP). (Ref. 1 and 2) APMS tools go substantially beyond the capabilities of the current commercially available software programs that are mainly designed to count pre-defined exceedances. The APMS will assist an operator in understanding how its aircraft are being operated normally and routinely on the line. The flight-safety analyst will be able to identify atypical, statistically extreme, and safety-related events and trends to support safety and economic decisions.

Intramural monitoring at air traffic control is addressed with the NASA-FAA Performance Data Analysis and Reporting System (PDARS). PDARS is an ATC radar-track monitoring capability developed by NASA and the FAA that routinely collects, processes, and merges ATC data; computes quantitative performance measures; produces and disseminates daily performance-measurement reports, and archives basic operational data and performance statistics. PDARS performance measurements relate to system throughput, delays, system predictability, and other key ATC performance indicators. (Ref. 3) This project is being carried out in collaboration with the ATC community (FAA and NATCA) to obtain the users' evaluations and the identified informational needs of air traffic management.

Currently, the ATC facilities in three of the nine FAA-ATC regions plus the Command Control Center are participating in the test and evaluation of PDARS. This constitutes about thirty facilities connected to the PDARS network and receiving reports each morning about the previous day's operations that are customized to the needs of each facility. By agreement among the facilities, these reports are shared.

NASA is responsible for the implementation and maintenance of the secure, dedicated network over which PDARS reports are distributed and shared among facilities. The PDARS network provides for collecting data from each ATC site, transmitting them to the central site for processing, and delivering the results of the processed data to ATC managers at each of the sites for evaluation. (Figure 1).

The functional requirements of the FAA customers on PDARSnet focus on the need to maintain a secure and reliable path to each of the data centers, while maintaining the flexibility for future upgrades and additional sites. PDARSnet includes a two-tiered approach: the physical/logical connectivity between sites and the security mechanisms required by the proprietary nature of the ATC data. The PDARS wide-area network (WAN) connectivity requirements are met with Cisco 2524/2621 routers at each location on multiple frame relay cloud. The Frame Relay technology is a reliable cost-effective solution that also offers the benefit of logical point-to-point connectivity and bandwidth upgrades without the need to install additional equipment. PDARSnet has a Committed Information Rate (CIR) of 384 kilobytes/second between remote sites and the central processing site, guarantees availability of service at 99.8%, and maximum time to restore service is no more than 4 hours.

Security is a prime concern for this network. Therefore, many precautions are taken to ensure data confidentiality. These include the physical and logical isolation of this network from all other networks (including the internet), central management of WAN security policies and procedures, and strict enforcement of access from site LAN to PDARSnet resources. Data flow is subjected to security filters that (1) are implemented on the leaf site routers, (2) operate on source and destination addresses, and (3) act as access lists to allow only approved customer networks to traverse the PDARSnet.

At each FAA site, NASA provides, operates, and maintains the router to tap into the PDARSnet. One LAN access port is provided for each leaf site. The router password is restricted to PDARS operations. The demarcation of responsibility for the PDARSnet is at the LAN port on the router at the local site. FAA is responsible for all resolutions that extend beyond this demarcation within the site.

The PDARSnet is currently a full production network connecting about thirty sites and is expanding.

Extramural Monitoring

The *Extramural Monitoring* element complements *Intramural Monitoring* and provides a comprehensive mechanism for monitoring the performance and safety of the overall National Aviation System and for detecting and evaluating the effects of new technologies as they are inserted into the system. *Extramural Monitoring* is the "top-down" element of the dual strategy for monitoring. The primary product of this activity is the National Aviation System Operational Monitoring Service (NAOMS).

NAOMS is a comprehensive and coherent survey of the operators of the aviation system (i.e., its pilots, controllers, mechanics, dispatchers, flight attendants, and others) on a regular basis. There is proven value in viewing the aviation system through the eyes of its operators. NAOMS is a longitudinal survey that will track safety trends, monitor the impact of technological and procedural changes to the NAS, and contribute to the development of a data-driven basis for safety decisions.

The concepts and capabilities of the two approaches (i.e., top-down extramural monitoring and bottom-up intramural monitoring) have evolved independently in parallel. However, information derived from each will complement the other as well as the other elements of ASMM in the process of identifying precursors, monitoring the effects of changes, and developing predictive capability.

EVALUATE THE OPERATIONAL SIGNIFICANCE

The second step in the cycle of proactive management of risk is to evaluate the operational significance of the incident or event that was identified. Decision-makers must be able to focus quickly on those events with the highest potential for severe consequences and likelihood of reoccurrence. This evaluation requires an understanding of the contextual factors and conditions that were conducive to the identified incident so that the domain expert can ascertain the likelihood of future occurrences and assess the severity of potential consequences.

The element of the ASMM Project called *Data Analysis Tools Development* is developing a set of automated tools to facilitate efficient, comprehensive, and accurate analyses of data collected from large, heterogeneous data sources throughout the National Aviation System. These new technologies extract information from and establish meaningful linkages among both qualitative (i.e., textual) and quantitative (i.e., digital) databases, and provide visualizations of significant patterns and trends.

Information must be extracted from qualitative data sources to help the domain expert understand the subjective aspects of "why" an incident occurred, and from quantitative data sources to understand the objective aspects of "what" happened. Therefore, automated capabilities are being developed to process both textual and numeric aviation data, and to extract relevant information from diverse databases; including those derived from the activities under *Intramural* and *Extramural Monitoring*. The results of the searches of heterogeneous databases are presented in displays of meaningful information that help the analysts achieve the insight needed to understand the circumstances, focus their attention on operationally significant events, and propose mitigating actions.

Each of the tools developed are being tested and evaluated by our partners in the operational environment under *Intramural* and *Extramural Monitoring.*

The work being carried out under the element called *Modeling and Simulations* is described in the next section as it relates to the formulation of an intervention. However, fast-time simulations are also used to **Evaluate** an identified event by helping the analyst explore for its contextual factors that are conducive to failure and human error, gain insight into the operational significance of the event, and assess its potential consequences.

FORMULATE AN INTERVENTION

Having identified an operationally significant event and understood its contextual factors, the next step in the process of proactive management of risk is to formulate an intervention. It is up to the experts in industry and the FAA to **Formulate** and to **Implement** the interventions. However, an objective of the element of ASMM called *Modeling and Simulations* is to aid the decision makers in these two steps of the process.

Modeling and Simulations uses models of the NAS at a level of detail sufficient to track key safety characteristics for reliable prediction of the system-wide effects of new technologies and procedures on operations and communications. Models incorporate human performance into existing NAS modeling tools and are being validated with data obtained from *Intramural* and *Extramural Monitoring*. Techniques have been developed for representing multi-operators interacting in complex dynamic scenarios.

Fast-time simulations serve as a computational test bed for analyzing system performance, including the contributions of individual operators, individual elements of the system, the interactions among multiple agents, technologies, and large-scale system flow and control issues. Fast-time system-wide simulations enable the safety analyst to answer questions like *"Does the solution have any secondary, propagated or side effects?"* and *"Does the solution provide for graceful degradation in unanticipated operation anomalies?"* and *"Does the proposed intervention address the right question and in the right way based on an understanding of the joint cognitive system?"*

The assessment of safety risk is currently a post hoc analysis by the human expert of the statistical results of the fast-time Monte Carlo simulations. However, analytical tools are being developed in parallel with the fast-time simulations to assist the analysts in identifying the significant contextual factors of an event and in assessing the safety risks.

IMPLEMENT THE INTERVENTION

Implementation of an intervention for an identified problem is accomplished via prototypes, their effectiveness is evaluated, refinements are implemented, and then full-scale deployments are facilitated.

The step that is often missing from the cycle of proactive management of risk is that of having in place a system for monitoring in order to assess the effectiveness of the intervention measured against expectations. This is comparable to the first step in the proactive-management process called **Monitor to Identify** and closes the loop on the cycle. This step requires that those data that are needed to evaluate the intervention are appropriately collected, codified, and classified for retrospective search. The monitoring system should have been in place before the intervention to gather the baseline data for comparison of the before to the after. Once again, the relevant information in large heterogeneous, distributed databases need to be merged to gain a complete picture of the system-wide situation. All of the ASMM tools are applicable to facilitate efficient and insightful analyses of all relevant information.

IN SUM…

The ability to monitor continuously, convert the collected data into reliable information, and share that information among the stakeholders for collaborative decision making is the basis for a revolutionary, proactive approach to managing the aviation system for prevention of accidents.

The four sub-elements of ASMM (*Extramural Monitoring, Intramural Monitoring, Data Analysis Tools Development,* and *Modeling and Simulations*) are interdependent and interrelated. ASMM will merge the products of these four elements into a system-wide frame work enabling collaboration in aviation safety-risk management by policy makers whether they are in government or industry by sharing information while respecting the proprietary rights to some sources of data and sensitivities to potential misuse should they be released outside the owning organization.

Each of the ASMM Products such as APMS, PDARS, and NAOMS has stand-alone capabilities that will continue to evolve as the Data Analysis Tools are adapted to meet the evolving needs of the constituencies. However, the true and overriding value of the ASMM Products is as an integrated suite of tools to enable the achievement of a system-wide perspective on proactive management of the safety risk of the NAS.

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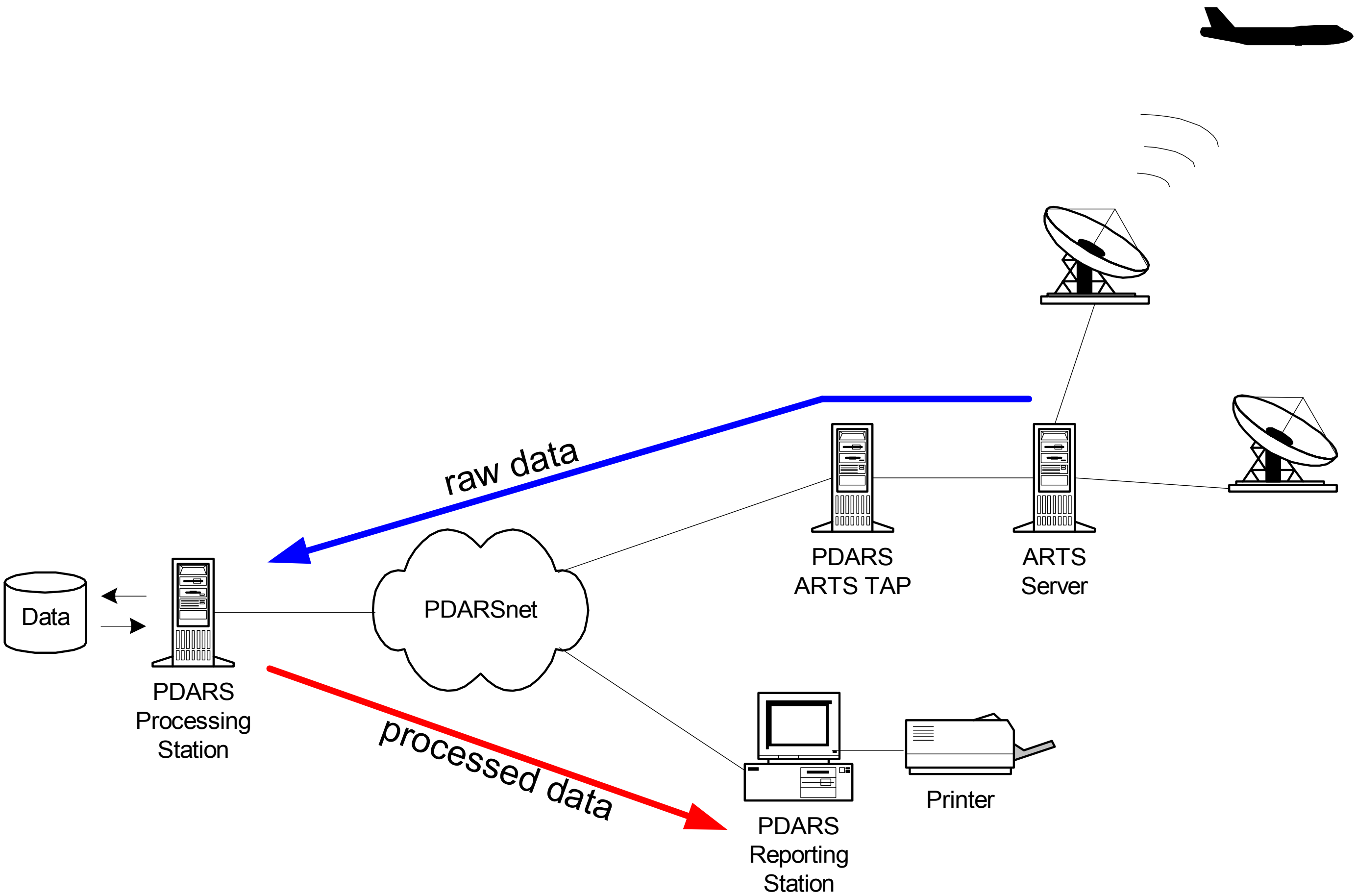

Figure 1 – PDARSnet Application Data Flow