AIR TRAFFIC MANAGEMENT FOR COMMERCIAL AND MILITARY SYSTEMS INTEGRATING HUMAN FACTORS IN AIR TRAFFIC CONTROL RESEARCH AND ACQUISITION

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Abstract

The Federal Aviation Administration (FAA) and the National Astronautics and Space Administration (NASA) have partnered their research efforts through the Interagency Air Traffic Management Integrated Product Team (IAIPT). The IAIPT's mission is to integrate research addressing air traffic control (ATC) and Air Traffic Management (ATM) decision support tools, concepts, and procedures. As a crosscutting area, integrating human factors research intends to systematically identify and coordinate research and acquisition efforts in developing and assessing advanced ATM and communication, navigation and surveillance (CNS) capabilities relative to human performance limitations and capabilities.

Introduction

In September 1995, the FAA and NASA formalized their partnership by signing a Memorandum of Understanding initiating the formation of the FAA/NASA Interagency Air Traffic Management Integrated Product team (IAIPT). The mission of the IAIPT is to plan and conduct integrated research related to air based and ground-based air traffic control (ATC) and air traffic management (ATM) decision support tools and procedures. Oversight for IAIPT activities is provided by the FAA's Research, Engineering, and Development Advisory Committee and NASA's Aeronautics and Space Transportation Technology Advisory Committee. The IAIPT strengthens an important relationship between FAA and NASA to ensure our shared research provides a pipeline of new technologies, procedures, and concepts of use for the National Airspace System (NAS).

Background

IAIPT research areas are organized according to the following categories. ***Traffic flow management*** covers strategic resource allocation and flow management. ***Surface*** focuses on operations on an airport's surface. ***Terminal*** research is focused on operations in airspace surrounding one or more closely spaced airports where a Terminal Radar Approach Control (TRACON) facility or comparable military facility provides services. ***En route*** research focuses on operations in airspace between airports where an Air Route Traffic Control Center (ARTCC) provides services and transition airspace between the en route and terminal environments. ***Oceanic*** includes operations in airspace over international waters where an oceanic ARTCC provides services. Finally, ***System/Cross-Cutting*** covers system-wide initiatives including the initial definition of concepts and assessment methodologies, demonstrations of cross-domain systems integration, and human factors.

The IAIPT provides the pipeline for how emerging and maturing research concepts and prototypes are fed into the FAA acquisition management system. The IAIPT facilitates communications by which the FAA requirements and acquisition offices can monitor, support, and manage these transitions from research outputs to acquisition products. Progression of concepts through exploration and development is tracked using Technology Readiness Levels. Research outputs range from decision aids that could be integrated as product improvements of baseline ATC systems to separate sub-systems.

Coordinated research initiatives are described in joint research project descriptions (JRPDs) that define objectives, approach, responsibilities, mission relevance, goals, and outcomes. JRPD 12 is key to ensuring that relevant human factors research issues, methods, metrics, and findings of individual programs are made known to and can be leveraged by the larger research community including FAA, NASA, the aviation industry, and academia.

The emphasis on human factors remains strong at FAA. Goal 2 of the Associate Administrator for Research and Acquisitions states that "by 2005, ensure human factors policies, processes, and best practices are integrated in the research and acquisition of 100% of FAA aviation systems and applications. Management direction and support is clear and the business case certainly argues for itself. Moreover, in the RTCA/FAA "National Airspace System Concept of Operations" a vision for the future NAS is articulated as follows:

> "It is important to remember that the existing NAS continues to reflect its origins as a system in which aircraft flew directly from Navigational Aid (NAVAID) to NAVAID along a set of FAA defined routes. The airspace structure and boundary restrictions strongly reflect the constraints that the communication and computational systems imposed when the NAS was developed. For this system to progress toward meeting the NAS user needs and requirements, there must be changes in procedures, roles and responsibilities, equipment, and automation functions to evolve into a structure that accommodates greater user flexibility in planning and conducting flights. This operational concept provides a basis for the NAS architectural decisions and strategies needed to complete this transition." [1]

The NAS concept of operations reflects a shift in operator roles and responsibilities and will require intense and ongoing collaboration among human factors professionals. These changes in operator roles and responsibilities will potentially impact human performance, error, workload, situation awareness, communications, training, and procedures as new capabilities are integrated in baseline systems and shift or add demands upon the operators.

In support of this, JRPD 12 objectives provide a framework to systematically identify, coordinate, and integrate human factors efforts in the research and development of advanced ATC/ATM/CNS automation, technologies, concepts and procedures. The span of human factors issue areas can be conceptualized as shown in Table 1 [2].

Table 1. Spectrum of Human Factors Issue Areas

Anthropometrics	Interoperability
CHI Consistency	Procedures
Communications and Teamwork	Safety and Health
Information Presentation	Situation Awareness
Displays and Controls	Skills and Tools
Documentation	Staffing
Environment	Training
Functional Design	Visual/Auditory Alerts
Human Error	Work Space
Information Requirements	Workload

The technical information meetings (TIMs) sponsored by JRPD 12 have been successful in ensuring that relevant human factors research is shared. For the past 4 years, human factors practitioners from FAA, NASA, research offices, various aviation-related industries, and academia have met to exchange research findings and lessons learned, as shown in Figure 1. Focusing our efforts on specific topics has led to even greater payoffs as issues, challenges, and lessons learned are shared, helping us to avoid the problems of the past and identifying future human factors research requirements.

Figure 1. Technical Interchange Meeting

Recent topics covered the following areas: measures of human performance in the NAS, human factors techniques in system acquisition, human error measurement, human performance modeling, and user-centered automation. An integrated summary of the results and lessons learned is presented below.

Results

Measures of Performance in the NAS

A key presentation addressed a framework for the evaluation of human-system issues in the development of new aviation safety technologies for towered airports [3]. This framework considers how the conflict detection system and total system interact with controller performance such as relative to situation awareness and workload. Several methodologies were discussed including fuzzy signal detection theory [4]. Use of quantitative methodologies for assessing human-system integration issues supports evaluation of intended safety and efficiency benefits from incremental levels of surface safety systems capabilities.

Validation of operational concepts of future ATC operations encourages human factors researchers to develop and use common methods and metrics that provide data to assess operational benefits intended from new capabilities and procedures. This validation strategy builds upon a joint FAA/EUROCONTROL research plan for validating the performance, reliability, and safety of ATM systems. FAA and EUROCONTROL are working to define and develop a robust suite of system performance measures and best practices for human-in-the-loop simulation that provide part of the framework for a validation data repository. Development and subsequent use of these best practices will allow for sharing of information and comparison of research results.

NASA is working toward developing a set of human performance metrics as well. NASA researchers presented a literature review of human performance metrics used in ATM research. This task will identify a set of metrics for use in NASA's Distributed Air-Ground (DAG) research initiative. The metrics database consists of system-level metrics and human performance metrics, shown in Table2.

Table 2. Database Metrics

System-Level Metrics	Human Performance Metrics
Capacity	Conflicts
Complexity	Situation Awareness
Efficiency	Usability
Flexibility	Communications
Safety	Error
Simulation Fidelity	Workload
	Task Performance

Over 200 detailed metrics have been identified for inclusion in the database. Additional research is needed for metrics related to trust in automation and in other agents, shared situation awareness, and distributed and team decision-making.

A preliminary analysis of measures derived from routinely recorded air traffic control data has assessed a set of over 20 measures of controller task load. This analysis has found significant relationships between subjective workload ratings and objective task load measures. Objective measures would provide a useful adjunct in the assessment of new ATC systems and procedures beyond controller workload ratings, which may be subject to rater bias, as well as over-the-shoulder performance assessments by subject matter experts that has the potential for influencing controller performance.

Human Factors Techniques in System Acquisitions

FAA human factors practitioners presented an overview of acquisition human factors methodologies used to support FAA Integrated Product Teams (IPTs). These methods include task analyses, usability assessments, iterative rapid prototyping, early user involvement events, ergonomic assessments, computer-human interface (CHI) verification and validation, workstation and facility layout design evaluation using virtual reality modeling, human-in-the-loop simulation, and operational evaluations.

Estimating the cost of human factors in NAS modernization intends to build a business case that varies with each program. Human factors costs, some examples of which are shown in Table 3, can be estimated using expert judgment, parametric cost estimation, or a heuristics approach.

Table 3. Example Human Factors Costs

Human factors staff cost	Fast time modeling cost
User needs assessment cost	Human in the loop simulation cost
Concept studies cost	Study plan development cost
Prototype and usability assessment cost	Data collection and analysis cost

An important insight is that human factors risk analyses and human performance data generation should occur during the mission analysis and investment analysis phases of the acquisition lifecycle. Understanding human factors issues, ranging from staffing and training to information management and display, will help estimate and direct program resource expenditures to mitigate human performance aspects of the system.

Development of human factors requirements has lead to the identification of lessons learned including a historical context. Development of human factors requirements for FAA acquisition programs has been a repeatedly problematic risk. Clear and specific definition of human performance considerations is recommended in concepts of use and requirements documents. Without such clarity and detail, requirements changes or additions later on in the acquisition cycle can add costs and adversely impact schedules. More importantly, commercial off-the-shelf (COTS) acquisitions do not eliminate the need for crisp and comprehensive human factors information requirements. FAA experience with requirements issues and lessons learned can be mapped according to areas of deficiency, specific deficiencies, and appropriate fixes, with an example shown in Figure 2.

As the NAS evolves and new systems, decision support tools, and airspace changes are added, the question of interoperability needs must be addressed. In the near future, the en route controller sector team workstation will evolve with three collocated tools: the User Request Evaluation Tool (URET), Traffic Management Advisor (TMA), and Controller-Pilot Data Link Communications (CPDLC). A cognitive walkthrough by operational subject matter experts (SMEs) addressed workload, situation awareness, and modal changes during task performance. The results indicate that collocation of systems presents a complex human factors challenge and addressing these challenges is critical to the success of system acquisition programs.

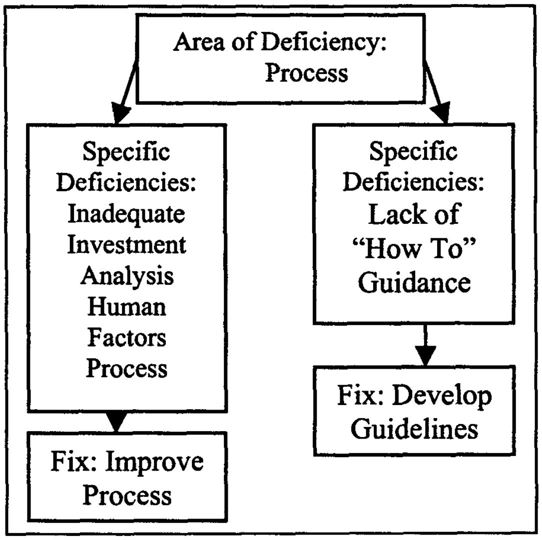

Figure 2. Example Requirements Issue

Human Error Measurement

This session highlighted three important dimensions at which human error is being addressed by FAA and NASA. Human error in today's airport operations is being addressed through the analysis of runway incursion statistics related to controller operational errors, pilot deviations, and vehicle/pedestrian deviations.

FAA researchers discussed research enumerating the causal and contributory factors leading to human error and operational errors in air traffic control. Some of this research is being accomplished in collaboration with EUROCONTROL in order to leverage experience and results under a broader set of conditions. Several techniques have been developed to provide more informative and diagnostic understanding of errors: the Human Factors Analysis and Classification System (HFACS), which was originally developed to classify factors in aviation mishaps, and the Human Error Reduction in ATM (HERA) technique that was developed to identify cognitive and perceptual failures [5]. Harmonization of HFACS and HERA takes advantage of HERA's detailed methodology and HFACS broad categorical approach, with increased detail in such areas as teamwork, supervision and management, and organizational contributory factors [6]. Performance in a complex ATC system is shaped by a range of causal factors that can contribute to the degradation of performance and the incidence of human error, as shown in Figure 3. The harmonized technique, called JANUS, is undergoing beta testing and the resulting data will be assessed and validated against current investigation techniques.

NASA's focus includes predictive or prospective error to provide guidance to system designers regarding error tolerant system development. Their research has focused on development of a technique for identifying relationships between internal and external error models as well as psychological error mechanisms. An assessment of potential error and error modes in conflict detection and resolution is being conducted this fiscal year (2002).

Human Performance Modeling

Researchers agree that human performance modeling is relatively mature but the difficulty is in modeling an inherently unstable system. Human error modeling is an especially difficult problem and understanding what aspects of human behavior cause errors provides valuable clues about what to include in human performance models.

The process of linking computational human performance models with fast time simulation models was discussed and specific architectures and examples of links were addressed. Researchers have concluded that human performance and full airspace representation models can be successfully linked and models that are designed from the outset to be run together reduce the overhead of individual model management [7].

Researchers have also found that only a few efforts exist aimed specifically at the prediction of human error. While human performance modeling is relatively mature, human error modeling is a difficult modeling problem. Different modeling approaches, such as network models, vision models, and cognitive models can be used depending upon the nature of the modeling question and the complexity of integration with hardware and software applications.

Modeling of dynamic density has examined impacts on controller workload [8]. Factors influencing airspace complexity include traffic flow, growth in air traffic, and airspace design, with dynamic density defined as the weighted sum of traffic density and number of aircraft undergoing heading, speed, and altitude changes as well as separation between aircraft. Variables important to predicting controller workload include modeling accuracy and predictability of controller workload.

User-Centered Automation

The FAA's Safe Flight 21 human factors program was reviewed and included current status and lessons learned. Safe Flight 21 is a joint industry/government program designed to expedite deployment of new operational capabilities for communication, navigation, and surveillance intended to improve system safety. All of these capabilities are based upon emerging broadcast data communications technologies and most of these rely upon a cockpit display of traffic information (CDTI). The nine specific data link applications are shown in Table 4.

Table 4. Safe Flight 21 Data Link Applications

Linkage	Benefit
Ground to Ground	Improved navigation on taxiways
	Enhanced controller management of surface traffic
Air to Ground	Affordable reduction of controlled flight into terrain (CFIT)
	Surveillance coverage in non-radar airspace
Ground to Air	Weather and other data to the cockpit

Linkage	Benefit
Air to Air	Improved separation standards
	Improved low visibility approaches
	Enhanced see and avoid
	Enhanced en route operations with delegated responsibility for separation

A review of practical human factors issues in the design of a CDTI covered the need to address situation awareness, display clutter, conflict alerting, and conflict resolution as key to evaluations leading up to CDTI certification. An example CDTI for surface navigation is shown in Figure 3. CDTI design constraints include integration with the Traffic Collision and Avoidance System (TCAS), Flight Management System, Flight Deck Alerting System, and the Primary Flight Display with its Navigational Display.

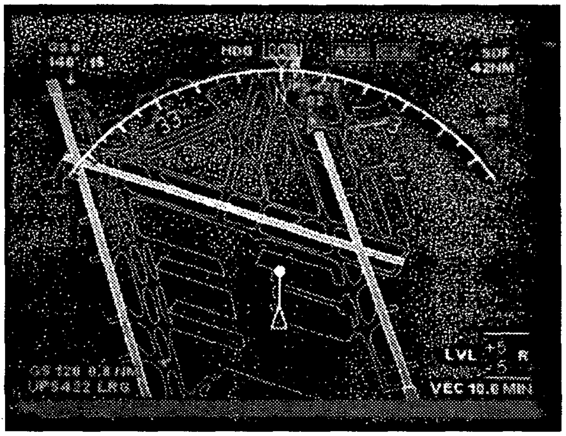

Figure 3. Honeywell CDTI

A preliminary assessment of distributed air-ground traffic management examined pilot decision-making and flight performance in a constrained en route environment. The objective was to ascertain whether pilots could meet operational constraints involving flow constraints (mean required time of arrival), airspace constraints (remain clear of weather and special use airspace), and economic constraints (maximize flight efficiency and passenger comfort). In a part-task simulation, results indicated pilots could equally use strategic and tactical conflict detection and resolution to meet these constraints while ensuring flight safety.

Lessons and Challenges

During the past four years many lessons learned have surfaced that have helped structure and focus our human factors initiatives:

- Decision support tools and automation aids are being developed for a variety of uses; it is important that we look beyond a 'stovepipe' approach in the development of these tools to address interoperability concerns in an operational environment.
- Changes in roles and responsibilities between the flight deck and the air traffic control environment, as well as among controllers on a sector team, associated with use of new capabilities and implementation of new concepts of operation need to be understood and assessed.
- More air-ground integration research is called for in which we can address the evolution from today's air traffic control system to mature free flight.
- Decision support tools and automation aids will change how controllers work, and the cumulative and incremental integration of multiple tools may have some unintended ripple effects on operational practices.
- We need to address human error analysis especially in the design of research prototypes and focus on both predictive/prospective error models to provide guidance to system designers about error tolerant development and to users about error reduction strategies.
- The CHI on the controller workstation will need to be standardized with a goal toward maintaining a consistent CHI in which new features are a natural extension of a tool currently in use.
- The transition from research and operational prototypes to development and fielding is complex. The

establishment of specific criteria to help define a concept's readiness to transition from one stage to the next is key to a smooth transition.

To ensure proper attention to human factors issues, it is important to establish human factors focal points in acquisition offices to help ensure the integration of human factors principles and methods throughout the acquisition life cycle. Given the unique operational environment in the FAA, it is also critical to ensure early union involvement throughout research and acquisition phases and activities, and manage user expectations about commercial product capabilities.

Human Factors and Technology Transitions

Human factors guidance is needed to facilitate the transition of research concepts and capabilities through the pipeline from research and operational prototypes to development and fielding of mature tools. FAA has defined, together with NASA, technical readiness levels (TRLs) to structure and track maturation of concepts along a development continuum. The IAIPT plans and manages concept exploration and concept development phases across TRL 1 through 6, which can be conceptualized from a human factors standpoint as shown in Table 5.

Table 5 Human Factors View of Early TRLs

TRL	Goal
6	System-level demonstration of highly functional prototype in a high fidelity environment
5	Concept validation at sub-system or component-level in a high fidelity environment
4	Concept validation in laboratory environment
3	Analytic or experimental evaluation as proof of concept
2	Formulation of technology concept and initial prototype capability
1	Definition of principles comprising basic concept

While TRL 6 represents the intended research and development program goal, considerable effort has in some cases been focused at TRL 7 that entails a system-level prototype demonstration in an operational environment. Beyond TRL 7, TRL 8 provides for qualifying a research prototype by demonstration, and at TRL 9 the actual prototype is proven in operations. Responsibilities for prototype fielding, full-scale development, deployment, and operations transfer from the IAIPT research organization to the FAA's appropriate domain IPT as the research effort matures. While some decision support tools have recently been transferred to acquisition offices as a result of achieving TRL7, this does not guarantee that the tools will be successfully developed and deployed in the acquisition phase. The correspondence of TRLs with acquisition implementation readiness levels (IRLs) has in various ways been conveyed as shown in Figure 4.

Human factors considerations are an important element in the TRLs relative to researchers identifying and assessing the human performance issues imbedded within the TRLs. That is, transitioning research concepts from exploration to development and onward to acquisition products should be accompanied by increasingly detailed assessments of information requirements, display management/integration, and human-centered automation. Assessments should use human performance measures such as workload, situation awareness, communications, and human error. These TIMs provide a basis for identifying principles and garnering experience to support development of human factors guidance for transitioning research concepts across the TRLs.

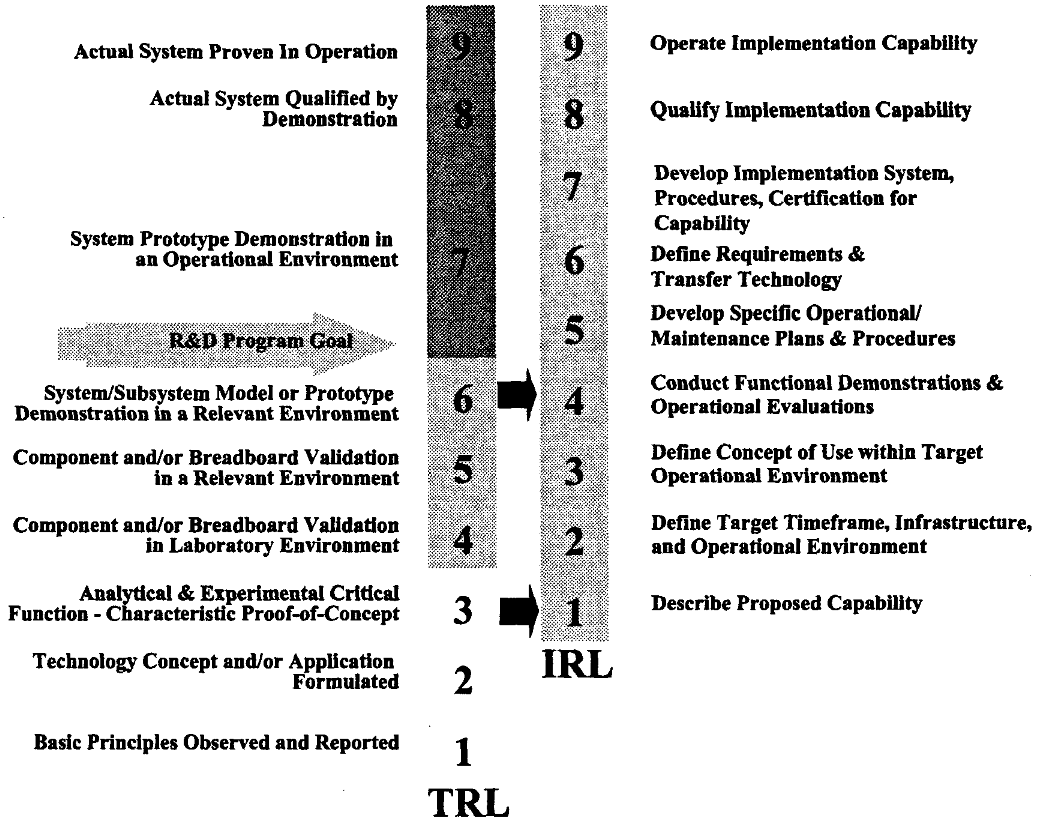

Figure 4. Technology and Implementation Readiness Levels

Conclusion

The TIM approach has proven itself over the course of four years to be an invaluable way for our human factors researchers and practitioners to share information that they might not otherwise have access to, or learn about when it is too late for them to benefit from the research. By organizing meetings according to certain research initiatives and acquisition topics, we are able to address specific areas of interest and provide an opportunity to share information at a time when limited research and development funding demands that we leverage research results across programs and organizational boundaries.

The emphasis on jointly developing validation strategies for human-in-the-loop simulations has also extended information sharing beyond our borders as we strive, with our European counterparts, for standard metrics and measures that allow us to compare results and even more fully leverage research efforts.

Briefings from recent TIMs are available via the web at:

http://rms.faa.gov/iaipt-hf/

and using a login of: iaipt

The web site is updated as appropriate relative to the conduct of future TIMs.

References

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