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ASSESSING HUMAN FACTORS RISKS IN AIR TRAFFIC MANAGEMENT RESEARCH

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This paper describes guidance for assessing human factors risks of research capabilities. The risk scales in the present study were used to assess concepts of the FAA Target System Description, part of the National Airspace System architecture. Results help identify areas where human factors analyses are needed and strengthen the business case for human factors assessments. Repeated high risk ratings provide R&D managers with additional information about whether or not to proceed with specific capabilities.

Introduction

The Federal Aviation Administration (FAA) System Engineering Manual defines risk as "a future event or situation with a realistic (non-zero nor 100 per cent) likelihood of occurring and an *unfavorable consequence/impact* to the successful accomplishment of the well-defined program goals if it occurs" (2004a). Relative to the FAA's definition, a consistent and more quantitative approach to human factors risk management is needed for application to research and development (R&D) on air traffic management. This paper describes the guidance developed for assessing human factors risks of R&D capabilities.

Previous research (Krois, Mogford, and Rehmann, 2003) posed that select human factors study areas should be incrementally addressed as an R&D prototype matures. That research also validated the need to consider all human factors study areas defined in the FAA Job Aid (2003a) by the time a research prototype is tested in a laboratory with representative users. These findings provided programmatic guidance for early, realistic assessments of innovative concepts and emerging technologies for use in an integrated National Airspace System (NAS). The research described in this paper poses that from a risk standpoint, the same human factors study areas could be assessed to better gauge and understand potential program impacts of research capabilities.

The human factors study areas pose potential risks in relation to the conceptual service improvements comprising the FAA Target System Description (TSD), which is part of the NAS architecture (FAA, 2004b). Researchers need help to strengthen the business case for human factors studies that resolve risks. This includes assessments that use complex human in the loop (HITL) simulation. Resolution of high risk areas provide R&D managers with additional information about whether or not to continue with development of specific capabilities.

Technical Readiness Levels

One approach for assessing the maturation of capabilities from laboratory to field implementation is the Technology Readiness Level (TRLs) model. TRLs are described in the FAA/NASA Integrated Plan for Air Traffic Management Research and Technology Development, Version 7.0 (FAA, 2003b). The TRL model intends an orderly transfer process from R&D to deployment and has been used by NASA and FAA to define transitions between stages of R&D leading to NAS implementation. FAA recognizes the need to manage more efficiently the transition of R&D capabilities, promote understanding of human factors risks, and make informed program decisions. The TRL model helps researchers from different organizations coordinate objectives and outputs and assess research maturation.

TRLs 1-6 pertain to concept exploration and concept development phases and consist of the following. TRL 1 Basic Principles Observed/Reported is the stage at which a capability is initially identified and described. In TRL 2 Technology Concept and/or Application Formulated a research plan is developed that defines the technical solution to the deficiency identified in TRL 1. This plan identifies activities, schedule, and resources necessary to address issues with the capability. In TRL 3 Analytical/ Experimental Critical Functions or Characteristic Proof of Concept, a conceptual prototype of the capability is developed and initial requirements are defined. The use of metrics to assess benefits should show an improvement over the baseline. TRL 4

Component or Integrated Components Tested in a Laboratory Environment is the stage where a research prototype of the capability is developed and evaluated by representative users. The laboratory real time simulation environment is at a higher fidelity level than at TRL 3. In TRL 5 Components/Subsystems Verified in a Relevant Environment, a pre-development prototype is prepared and evaluated. The evaluation environment should be at a high fidelity. The FAA assumes "ownership" of the operational concept and initiates activities to transition the capability to the acquisition product team. In TRL 6 System Demonstrated/ Verified in a Relevant Environment, an operational demonstration of the pre-production prototype system is conducted in an FAA field facility.

Human-System Interaction Research

Human factors research addresses human-system interaction (HSI) as R&D capabilities mature. This is shown through technical reviews of ATC modernization improvements planned in different operational environments, lower-fidelity assessments such as cognitive walkthroughs, and complex HITL simulations including integrated air-ground simulations.

As one example, "allocation of function" is one of the earliest human factors considerations effecting successful HSI. Inadequate consideration of allocation of function was evidenced in an operational evaluation of a controller decision support tool called passive Final Approach Spacing Tool (pFAST). In the evaluation, controllers found some advisories problematic but were instructed to use them anyway unless the non-use was approved by supervisors. Unfortunately, pFAST was found to work best when all controllers followed all advisories, i.e., pFAST performance degraded when advisories were not used. With pFAST the flexibility in decision making that controllers routinely exercised became constrained (Cardosi, 2002).

Trends suggest that information management demands associated with effective HSI are changing from being based on procedural requirements to controller workload impacts. Automation poses the risk of tunneling the attention resources of the controller and molding the application of those resources so as to be opaque to unforeseen and subtle events and incidents. Experience with another controller decision support tool called URET indicates that controllers make decreased use of trial planning as workload increases, and that use of the traffic management advisor (TMA) metering list decreases when workload is high. Such "automation shedding" moves the controller into a manual control mode that poses a hysteresis effect for returning to use of automated tools, e.g., the controller has to restart building a new mental picture of the traffic situation and not reverting to a previous mental state.

Human Factors Study Areas

Human factors study areas used to assess research risks are taken directly from the FAA Human Factors Job Aid and consist of the following.

- Allocation of Function: Assigning those roles/functions/tasks for which the human or equipment performs better while enabling the human to maintain awareness of the operational situation.
- Anthropometrics and Biomechanics: Accommodating the physical attributes of its user population (e.g., from the 1st through 99th percentile levels).
- Computer-Human Interaction (CHI): Employing effective and consistent user dialogues, interfaces, and procedures across system functions.
- Communications and Teamwork: Applying system design considerations to enhance required user communications and teamwork.
- Culture: Addressing the organizational and sociological environment into which any change, including new technologies and procedures, will be introduced.
- Displays and Controls: Designing and arranging displays and controls to be consistent with the operator's and maintainer's tasks and actions.
- Documentation: Preparing user documentation and technical manuals in a suitable format of information presentation, at the appropriate reading level, and with the required degree of technical sophistication and clarity.
- Environment: Accommodating environmental factors (including extremes) to which the system will be subjected and understanding the associated effects on human-system performance.
- Functional Design: Applying human-centered design for usability and compatibility with operational and maintenance concepts.
- Human Error: Examining design and contextual conditions (including supervisory and organizational influences) as causal factors contributing to human error, and consideration of objectives for error tolerance, error prevention, and error correction/recovery.
- Information Presentation: Enhancing operator and maintainer performance through the use of effective and consistent labels, symbols, colors, terms, acronyms, abbreviations, formats, and data fields.
- Information Requirements: Ensuring the availability and usability of information needed by the operator

and maintainer for a specific task when it is needed, and in a form that is directly usable.
- Input/Output (I/O) Devices: Selecting I/O methods and devices that allow operators or maintainers to perform tasks, especially critical tasks, quickly and accurately.
- Knowledge, Skills and Abilities (KSAs): Measuring the KSAs required to perform job-related tasks, and determining appropriate selection requirements for users.
- Operational Suitability: Ensuring that the system appropriately supports the user in performing intended functions while maintaining interoperability and consistency with other system elements or support systems.
- Procedures: Designing operation and maintenance procedures for simplicity, consistency, and ease of use.
- Safety and Health: Preventing/reducing operator and maintainer exposure to safety and health hazards.
- Situational Awareness: Enabling operators or maintainers to perceive and understand elements of the current situation, and project them to future operational situations.
- Special Skills and Tools: Minimizing the need for special or unique operator or maintainer skills, abilities, tools, or characteristics.
- Staffing: Accommodating constraints and efficiencies for staffing levels and organizational structures.
- Training: Applying methods to enhance operator or maintainer acquisition of the knowledge and skills needed to interface with the system, and designing that system so that these skills are easily learned and retained.
- Visual/Auditory Alerts: Designing visual and auditory alerts (including error messages) to invoke the necessary operator and maintainer response.
- Workload: Assessing the net demands or impacts upon the physical, cognitive, and decision-making resources of an operator or maintainer using objective and subjective performance measures.
- Work Space: Designing adequate work space for personnel and their tools or equipment, and providing sufficient space for the movements and actions that personnel perform during operational and maintenance tasks under normal, adverse, and emergency conditions.

FAA Target System Description (TSD)

FAA is modernizing the NAS, nominally to achieve the Joint Concept of Operations (CONOPS) as described by the RTCA (2002). The TSD describes improvements to NAS service capabilities expected by 2015. It includes descriptions of systems to be implemented, services provided, and operational capabilities that will be achieved. Together the NAS Architecture and the TSD provide a roadmap to guide the evolution of automation, surveillance, navigation, and communication systems to ensure NAS modernization is achieved.

The TSD, like the NAS architecture, is organized into 9 service areas including flight planning; separation assurance; tactical traffic flow; strategic flow; advisory services; emergency and alerting; navigation; airspace management; and infrastructure and information management. These are further decomposed into service improvement areas identified later in this paper.

Key HSI characteristics of TSD operational improvements consist of the following.
- A system wide information management system (SWIM) will serve as the central depository for all NAS information.
- Wide-spread, real-time distribution of NAS data.
- A standard automation platform (SAP) will be used by both terminal and en route controllers.
- Decision support systems (DSS) and intelligent agents will be common.
- Maximum use of digital communications.
- Maximum use of ADS-B for surveillance.
- Traffic managed gate to gate.
- Integrated ATM/CNS provides seamless airspace (Surface, Terminal, En Route and Ocean).
- Flexible airspace to match the dynamics of demand.
- Three mile separation used throughout the airspace.
- Pilots participate in managing aircraft separation.
- Airborne and ground conflict alerting.
- Auto-negotiations to develop flight profiles.

Methodology

We conducted an analysis to assess the viability of using specially developed scales for the 24 human factors study areas in helping to gauge risks associated with the TSDs. The resultant risk ratings reflect an average response as determined by human factors subject matter experts who participated in the analysis.

Human Factors Risk Scales

Risk scales used a five point scale based upon similar scales in the FAA System Engineering Manual (FAA, 2004a) and a safety risk assessment approach developed for military product improvements (Naylor, 2000). A low risk associated with the human factors study area is assigned a numerical value of 1; accordingly, if there is a minor risk, the value assigned is 2; a moderate risk is assigned a value of 3; a significant risk was assigned a value of 4; and a high risk associated was assigned a value of 5. A sample risk scale is as follows.

Allocation of Function: System design reflects assignment of operational roles, functions, tasks to humans or equipment while maintaining the human's awareness of the operational situation.
Low: Allocation of function of the proposed R&D capability does not change the current roles, functions, and tasks presently assigned to humans or equipment nor changes the operator's situation awareness.
Minor: Integration of the R&D capability into the present work environment may result in limited changes to current roles, functions, and tasks presently assigned to humans or equipment and may slightly alter the operator's situation awareness.
Moderate: Integration of the R&D capability into the present work environment alters current roles, functions, and tasks presently assigned to humans or equipment, and impacts the operator's situation awareness.
Significant: Integration of the R&D capability into the present work environment significantly alters current roles, functions, and tasks presently assigned to humans or equipment, and significantly impacts the operator's situation awareness.
High: Allocation of function of the proposed R&D capability alters completely the current roles, functions, and tasks presently assigned to humans or equipment and changes completely the operator's situation awareness such that how an operator's 'mental picture' is formed no longer exists.

Results

It should be noted that the data and its analysis are notional and illustrate one approach to help identify human factors risks. Average scores for the 24 human factors study areas are shown in Figure 1, based on ratings across the 19 service improvement areas. Results showed the topmost risks as Allocation of Function, Communication and Teamwork, Procedures, Information Requirements, Workload, Human Error, Culture, Information Presentation, and Situation Awareness.

The average scores for the 19 service improvement areas are shown in Figure 2. Results suggest a clustering of a small number of areas posing the highest total human factors risk consisting of Aircraft-Aircraft Separation and Flight Data Management. Another cluster with a large number of areas of high risk included Airspace Management, Traffic Advisories, Surface Separation, Monitoring and Maintenance, Flight Plan Support, Airborne Synchronization, Airspace Design, Alerting Support, Aircraft-Terrain Separation, Surface Synchronization, and Weather Advisories.

In the course of assessing the service improvement areas, questions, issues, and potential interdependencies influencing human factors risk were identified to help clarify the basis for ratings.

Several questions/concerns raised by human factors experts help clarify ratings of 4 or 5. For example, for the aircraft/aircraft separation service improvement, human factors questions include the following considerations:
- Communications and Teamwork: What is the impact associated with changing roles and responsibilities and how will separation authority transition between controller and pilot?
- Culture: What is the impact from divergence of operating norms and business cultures between FAA air traffic controllers and multiple unique airlines?
- Functional Design: How compatible are the alerting logic algorithms among airborne and ground systems and what will be the impact on pilot and controller decision making?
- Human Error: What is the potential for pilot and air traffic controller task performance error during critical operations?
- Information Presentation: How will information be displayed?
- Information Requirements: What information is needed?
- Procedures: How will tasks and procedures change?
- Situation Awareness: What are the impacts on controllers' situation awareness?
- Special Skills and Tools: What human performance considerations are associated with reduced separation?
- Visual/Auditory Alerts: Will air and ground trajectory models and conflict prediction algorithms be integrated?
- Workload: What are the workload impacts on air traffic controllers of using new automation and decision support tools for reduced separation tasks?

Discussion

Assessment of human factors risks shows that higher risk ratings occur in relation to the degree to which roles and responsibilities of controllers and pilots change. Our understanding of this relationship should improve as service improvements are further defined and implemented. For example, the role of the controller will drive operational requirements for information. This information is used in accordance with new procedures that pose changes in workload and communications, as well as the potential for human error.

Previous research yielded guidance that as a research capability matures and progresses from TRL-1 to TRL-6, the set of human factors issue areas increases and becomes more critical (Krois, Mogford & Rehmann, 2003). In contrast, the efficacy of research is proportional to human factors risks being addressed and attenuated as the capability progresses across the TRLs. The argument to graduate a research capability beyond TRL-6 is strengthened by the extent that human factors issues/risks are identified, assessed, and resolved within the context of interoperability with the baseline operational system.

The integration of human factors tools and techniques in the TRL model is important to the smooth transition of capabilities from research concepts to field-ready systems and procedures. FAA has found that while human performance issues may or may not impose constraints on cost and schedule, they will be the limiting factor in achieving system performance, thus impacting successful deployment. In the Standard Terminal Automation Replacement (STARS) program, for example, FAA found that system design and system development efforts can lose sight of the human-system performance impacts on end users (operators, maintainers, and support personnel), especially those related to cognitive tasks. History has taught us that if these elements are closely attended to during system development and prototyping, FAA has estimated saving a few months to up to 18 months in program development time and savings of up to 20% of program costs (FAA STARS Human Factors Evaluation, 1998).

Conclusions

It is important for research to have a risk management strategy in place to help identify mitigation strategies that may be employed. The transition from research and operational prototypes to development and fielding is complex. It is not only important to have specific criteria that define a concept's readiness to transition from one state to the next but also to have a means of assessing potential human factors risks especially when the capabilities and technologies entail new roles for controllers and pilots. The risk scales developed for this study are intended to serve as a tool to researchers to help them better understand and quantify the impact of specific human factors risks as research progresses.

Disclaimer - The views expressed are those of the authors and do not represent the FAA.

Acknowledgement - An analysis of the TSDs was previously conducted by the FAA Human Factors Research and Engineering Division.

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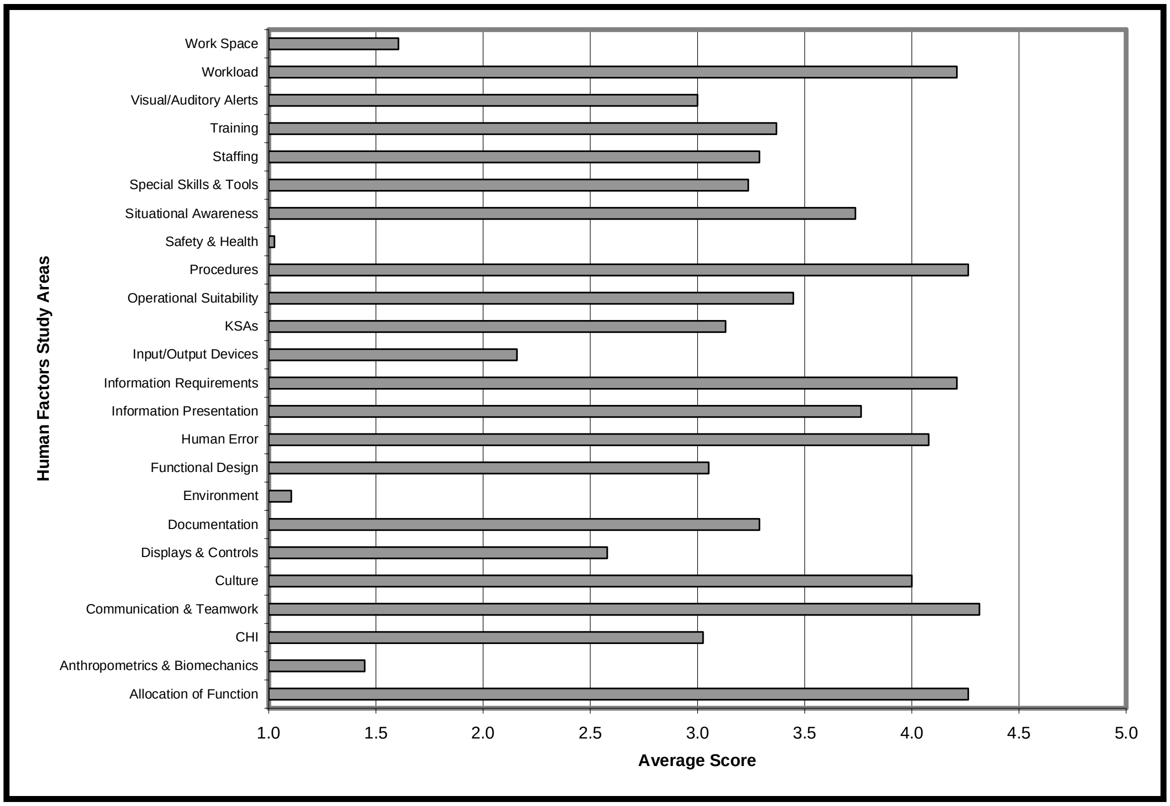

Figure 1. *Average risk ratings for 24 human factors study areas.*

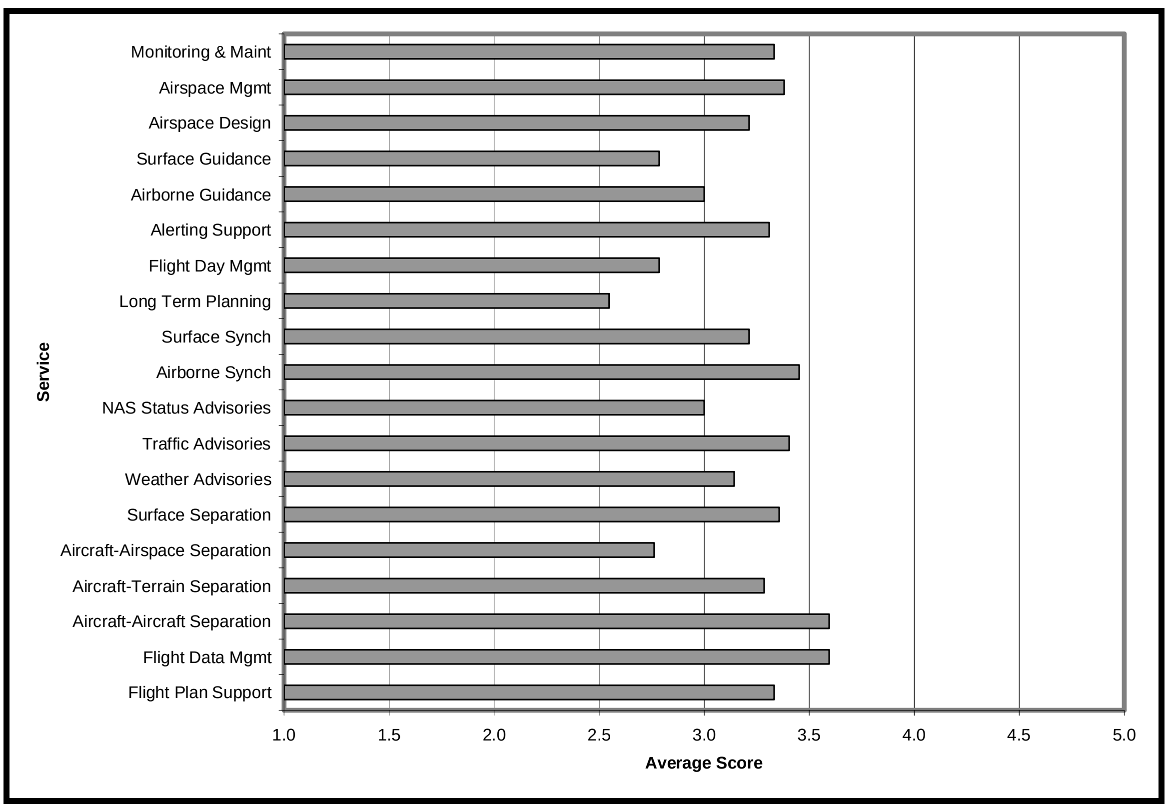

Figure 2. *Average risk ratings for 19 service improvement areas.*