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CAPTURING THE RESEARCH AND DEVELOPMENT PROCESS OF AVIATION SYSTEMS: CREATING A MULTI-MEDIA LIVING LEGACY

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Too often, successful system development projects fail to leave a legacy of design transfer information, beyond providing access to the mere physical descriptions of the system, or the software code itself. Yet, information about high-level design decisions, assumptions, constraints, philosophies and methodologies is often sought after by system designers, engineers, and researchers alike. Such information is critical for facilitating an understanding of the design and evaluation decisions that underlie the final design. In contrast, published articles about a given complex system are usually limited to discussions of experimental results and in applicability beyond the academic and research community. This paper presents an argument for the development of an interactive multi-media design transfer library that provides a detailed legacy of the philosophy, design rationale and supporting data behind new aviation systems and conveys important guidelines, methodologies and "lessons learned" from the course of their research and development.

Introduction

To increase the efficiency and safety of surface operations, the Taxiway Navigation and Situation Awareness (T-NASA) cockpit display suite (see Figure 1), comprised of an electronic moving map (EMM) and a scene-linked head-up display (HUD was proposed, and then subjected to an extensive human-centered design and evaluation process over a 6-year period (Andre et al. 1998; Foyle et al. 1996; McCann et al. 1998; Hooey, Foyle and Andre, 2002).

During this period, nearly every type of research activity was performed, including:

- Jump seat field observations of pilots and air traffic controllers.
- Focus group studies with pilots and air traffic controllers.
- Studies using head and eye-tracking equipment.
- Low fidelity part-task desktop design concept studies.
- Medium-fidelity part-task simulation studies.
- Full-mission high-fidelity simulation studies.
- Flight tests in NASA's B757.

The focus of the studies varied as well, to include:

- Research to determine pilot information requirements during taxi.
- Research on user interface design options.
- Research to identify factors that contribute to current-day problems (safety/efficiency).
- Research comparing future operational concepts against current conditions.
- Research focused on crew roles and procedures.
- Research focused on systems integration issues.
- Research focused on near- vs. far-term technology assumptions.
- Research focused on benchmarking and quantifying safety and efficiency benefits of T-NASA.
- Research on usage characteristics.

Figure 1. *The T-NASA System.*

The Need for Design Knowledge Capture

Looking back on the T-NASA project, the research and development team realized that there was a vast quantity of information that could be passed on to manufacturers interested in the T-NASA system, regulatory agencies such as the FAA, aviation researchers and system developers, airlines and airline purchasing agents, and others outside of aviation who might generalize the philosophy, research approach and principle-based design techniques to their non-aviation product or system projects. Moreover, this information is not traditionally made available to those outside of the research and development team. For example, design concepts that were dismissed are rarely, if ever, discussed in publications or design specifications. Yet, that information, and specifically why a given design element was not deemed applicable or optimal for a given context, could be vital information to another researcher or developer, or to a regulatory agency.

Another common problem occurs when transferring software code. Often, those on the receiving end (manufacturers, system developers, etc.) forget that there is more to a system specification than just the software code behind the interface. Important design details, recommended procedures and other usage constraints are not contained within the code, and therefore can be easily ignored or misrepresented as the code travels through the development process.

Clearly, then, there is gap between what is typically published about the design or evaluation of a proposed system design and the information deemed necessary for facilitating an understanding of the critical design and evaluation decisions that underlie it. In an effort to both capture the activities and results of the T-NASA program and others like it, and to provide a useable form of traceability of the system philosophy, design guidelines, and research decisions, we argue the need for knowledge capture tools that can be used during the development process.

There are few tools in existence that purport to aid in the capture of design-relevant knowledge, and what tools do exist either focus purely on communications (e.g., the electronic cocktail napkin; Gross, 1996) or are used for the purpose of enabling people outside the project group to understand, supervise, and regulate what is done by the team (e.g., Gorry et al. 1991), or to secure intellectual property generated by the design team (Shipman & McCall, 1997). Further, they do not support real-time knowledge capture. Perhaps most telling is that few design teams make use of such tools.

While not the main focus of this paper, we advocate the future development of an easy-to-use, web-based, real-time knowledge capture or "design knowledge archive" tool; one that will capture, without undue effort on the part of the design team, high-level design decisions and rational associated with the design of complex aviation systems, as they are crafted. Such a tool would provide the underlying knowledge data base to support the automatic creation of an electronic, interactive multi-media design technology transfer library. The value and potential makeup of such a resource is described in the following section.

A Design Technology Transfer Library

The true amount of "data" and documentation that describes the research and development of a complex avionics system designed for human interaction can be daunting. In our initial concept for a prototype design technology transfer library, we have employed a familiar "ladder" metaphor. As shown in Figure 2 below, the user "climbs" the ladder, ending at the top shelf of the library with a description of the final design of the T-NASA system. The left side of the ladder presents the user with information specific to the development of the system, while the right side of the ladder presents the user with various categories of more generalized knowledge transfer information.

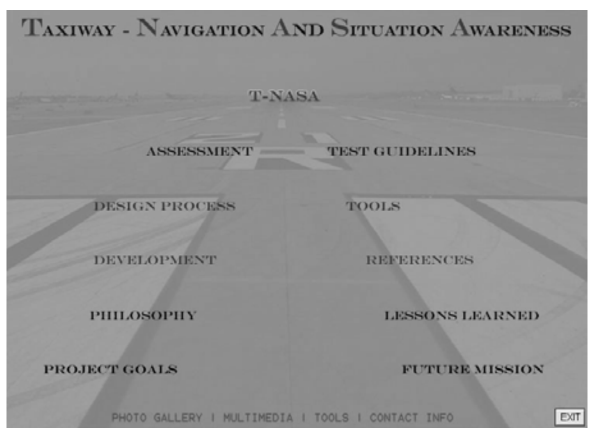

Figure 2. *Illustration of main menu category items from a prototype of the T-NASA design technology transfer library.*

The following is a brief description of the proposed purpose and content of each of these categories. The examples cited are specific to the T-NASA system and are intended only to illustrate the type of content that should be represented for any aviation system.

System Development Information

The categories of information related to system development are represented on the left side of the ladder in Figure 2.

Project Goals. To appreciate any system design one has to understand the project goals and objectives that the designers attempted to achieve. These goals and objectives may be defined by indices of safety, performance, capacity or usability, or specific use contexts, and may have derived from a government or industry program. For example, the main objective of the T-NASA system was to improve terminal area productivity in low-visibility conditions (Foyle et al., 1996). Design decisions were made based on this objective, which might have been different if, for example the goal was to improve safety in 'zero-zero' (no visibility) conditions. Specifically, for the former context we deemed augmented reality displays to be most appropriate, in which information is overlaid onto actual elements in the visual environment. In contrast, the latter context (no visibility) would require computer-generated virtual reality displays.

Clearly, then, without knowledge of the target goals and use contexts one could not understand, evaluate or appreciate the design of T-NASA. Worse still, the system could be adopted and used under circumstances for which it was never intended, creating safety hazards, or a failure to realize potential benefits.

Philosophy. Whether explicitly known to the designers or not, behind every design effort is an inherent design philosophy. This philosophy guides the design process and is the root of many design decisions. For example, a core philosophy of the T-NASA design was to support local control of the aircraft only with conformal, "head-up" information, while supporting global situation awareness with a head-down display (Foyle et al., 1996). Documenting, and communicating the design philosophy helps avoid "feature creep", and prevents future designers and developers from adding elements or modifying the design in a way that violates the original design philosophy.

Development History. Many end-users of this design transfer library may be interested in the development history of the system in question. Often, to better understand the ultimate design of a system, it is necessary to study the various incarnations it took during its development. This is a golden opportunity for the design team to explain and justify features and design elements that are NOT included in the final design. In fact, one could argue that it is often more informative to know why something was not included than to know why something was included.

For example, in the design of the T-NASA moving map, there was an active decision to NOT display taxiway centerlines in order to maximize eyes-out time and discourage the use of the map for local control purposes. Without documentation of this decision, and the rationale for it, future designers/developers could add a centerline without realizing the potential negative consequences.

In addition, systems engineers are often looking for information about a given system's hardware/software platform; information rarely specified in a human factors publication. Details regarding the assumptions that were made about data resolution, sensor reliability, and false alarm rates (as examples) are important to document. With rapid advancements in technology, it is very likely that what is considered a design constraint at the beginning of a design process is no longer a limitation by the time the system is fielded. This information would enable system engineers to differentiate between characteristics that were intended by design, or simply legacy due to (outdated) technology limitations.

Design Process. Capturing the design process and demonstrating a human-centered approach is recognized as an important element to document among the human factors community (e.g., Hooey, Foyle and Andre, 2001). Often, manufacturers or regulatory agencies are interested in the activities and process carried out to evaluate and/or validate the design. How were design requirements determined? How was the system tested? Were subject matter experts used to validate the proposed design? Was there a process to identify relevant procedural issues that might need to be addressed in order to accommodate the system? The processes that were engaged in to answer these questions can, and should be, articulated.

Evaluation/Assessment. Here, information on the assessment methods and data is found. Both quantitative and qualitative studies can be summarized, with samples of actual data, statistical analyses, etc. Documenting this information allows manufacturers, regulatory agencies, potential users, and purchasing agents to understand the extent to which the system has undergone a comprehensive evaluation process. For example, it is possible that a system demonstrates increased productivity, yet was never tested for safety impacts, or workload effects. Further, it is possible that a system was tested under nominal, or ideal operating conditions, yet was never tested under off-nominal or failure scenarios.

Without this form of documentation, it is difficult for various stake-holders to make informed decisions about adopting a system.

The System Design

In Figure 2 the final system design is represented by the T-NASA "shelf" at the top of the ladder. Here, the end-user would see the actual system design, be able to watch video of the system in action, and have access to an interactive design specification. The latter component could be presented in the form of an illustration with embedded hyperlinks that allows the user to hover over any design element and read a description and justification of that element.

In addition to design details, this category would also include information on usage assumptions, roles and responsibilities and assumed procedures. For example, information about usage assumptions can be helpful for future users of the system, those involved in developing training programs and standard operating procedures, and those responsible for integrating systems into future cockpits.

Knowledge Transfer

The categories of information related to knowledge transfer are represented on the right side of the ladder in Figure 2.

Test Guidelines. Beyond the data obtained from any given test or evaluation, it is often the case that useful methodological guidelines for testing similar systems or in similar contexts can be gleaned from the various research activities (Andre et al. 1998). As such, this section is devoted to conveying test guidelines, methods and best practices.

Tools and Techniques. Just as there are useful test guidelines to transfer, there are various tools and techniques employed by the design team over the course of the system's research and development that are useful to document. For example, a particular design technique (shadowing, perspective, transparency, etc.) or software program may have been used to render the specific look or behavior of a given interface element.

References. Most research and development efforts produce some amount of published material. Here, all references (and actual publication content) directly and indirectly related to the project are contained, ideally in an electronic form. Also this category could contain industry standards and guidelines that were used in the process.

Lessons Learned. All large-scale systems design projects are inherently educational in nature. Too often, the valuable lessons learned are not captured and transferred to future designers or engineers. This section provides an opportunity for the design team to communicate valuable information in perhaps a more personable form. Information on how system designers can best communicate design information to developers, or how to avoid feature creep are examples of useful lessons learned.

Future Mission. This section provides an opportunity for the design team to "close the loop" by indicating where the end-user might expect to see a commercial production of the system and/or future activities planned by the design team. In addition, insights into how the product may be adapted or useful for other contexts can be communicated.

Making it Interactive

Having the right information is one thing, making it easy, engaging and worthwhile to interact with is another. We advocate that the information contained in the library be presented in an interactive, multi-media format, making use of the latest software and audio-visual technologies, including images, sounds, animation and video.

Summary

Too often, successful system development projects fail to leave a legacy of design transfer information, beyond providing access to the mere physical descriptions of the system, or the software code itself. Thus, a gap exists between what is published or can be gleaned from looking at the final system design and the comprehensive library of knowledge, activities, guidelines and data often left to the memories of the design team. We argue the need for easy-to-use, real-time distributed software tools for capturing the knowledge and process behind the research and development of complex avionics systems. We advocate that the output of this tool be used as the input to an interactive, multi-media design technology transfer library, with the end-purpose of creating a detailed legacy of the philosophy, design rationale, development history and supporting data behind new aviation systems and conveying important guidelines, methodologies and "lessons learned" from the course of their research and development.

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