ENVISIONING USER REQUIREMENTS FOR FIRST-OF-A-KIND FUTURE ROTORCRAFT

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In this paper, we describe an ongoing effort to envision and articulate requirements for the United States Army's Future Vertical Lift (FVL) program, specifically related to crewing. The goal of FVL is to develop a new family of rotorcraft that will incorporate advanced technologies to support new capabilities. We will discuss the challenges associated with envisioning a future system, along with approaches to design for the envisioned world with examples. We emphasize the importance of focusing on the envisioned work domain, rather than advances in new technologies. We recommend that by articulating the future work domain, requirements for new technologies that will support human crew members can be more easily articulated. When designing for an envisioned world, it is important to incorporate relevant perspectives early and often throughout the process.

The United States Army is in the process of articulating a new family of vertical lift aircraft. The goal of the Future Vertical Lift (FVL) program is to develop a new family of rotorcraft to replace existing airframes. These aircraft will incorporate advanced automation and technologies to increase and change current Army aviation capabilities. In this paper, we describe how we are addressing the envisioned world problem in the context of a project to determine crewing recommendations for the first FVL platform – the Future Attack Reconnaissance Aircraft (FARA). Technologies are already being developed for the FARA platform; our challenge is to articulate the current constraints and predict the envisioned end state in order to guide development toward an optimal, and achievable, human-vehicle system. However, the envisioned end state will include many new capabilities that are not present in current operations, which complicates the task of analyzing the future work domain.

Defining an Envisioned World

Introducing new technology into a work domain invariably transforms the work domain, especially when new technology involves advanced automation (Bainbridge, 1983; Dekker & Woods, 2002; Woods & Dekker, 2000). Technology can change how people accomplish their work (tasks, goals), how expertise is defined, and how failures can occur (Woods & Dekker, 2000). The key challenge of designing for a future work domain is what Woods and Dekker (2000) called the *envisioned world problem* – how can studies and analyses of cognitive and cooperative activities in current practices be applied to the design of future practices when the future technologies will transform the work domain itself? Stated differently, because technology will change the cognitive and cooperative aspects of the work domain when it is implemented, current studies of cognitive and cooperative activities will not generalize completely to the future domain. If the introduction of a new technology changes the support that operators require to complete their work, then how else will the work domain need to be modified to support the operators (in terms of new work processes, different roles, additional technology, etc.)?

When envisioning a new world, stakeholders develop concepts and ideas about how the future world will operate. Woods and Dekker (2000) outlined four properties of these types of envisioned world concepts that make it challenging to develop requirements for a future system:

- Plurality – There are many different concepts that could be implemented, each with many different manners of affecting the future domain.
- Underspecification – different envisioned concepts for how the future domain will operate are simplifications, with only partial representations of all aspects of how they would function in a concrete system.
- Ungrounded – envisioned concepts are easily disconnected from the research base.
- Overconfident – advocates for envisioned concepts may become overly confident that only the predicted consequences associated with a concept will occur.

It is important to keep these four properties of envisioned world concepts in mind as we begin to articulate how the envisioned operating environment for FVL aircraft will look.

Envisioned World for Future Vertical Lift

Method. Addressing the envisioned world problem requires a clear definition of the envisioned end state – what will the FVL work domain be? This is challenging because the envisioned end state shifts based on changing priorities within the Army, along with improved understanding of the nature of the future work domain (operating environment, enemy threats, technological capabilities, etc.). We used a combination of methods to articulate the envisioned world. This included interviews with Army stakeholders to understand the vision for FVL, as well as priorities and how they have evolved over time. We reviewed doctrine for insight into current operations and conducted cognitive task analysis interviews with pilots to collect examples of challenging incidents. This combination of methods supported our focus on the work that will need to be accomplished, which will inform the development of requirements for supporting technologies.

Early in our effort, we articulated the envisioned world and core missions in which we hypothesized the crew of the FARA platform were likely to engage. We then took these to stakeholders (subject matter experts, FVL program leadership) for feedback. These documents represent the envisioned end state that our project team could focus on during the rest of our analysis activities (Militello et al., 2018).

Outcomes. The envisioned operating environment for FVL will be different from the environment that current Army aviation assets are built to support. Instead of conducting operations in the two-dimensional battlespace (the air and ground between forces), FVL aircraft will be designed to conduct operations in a more complex battlespace that includes air, ground, space, radio-frequency, and cyber (Phillips et al., 2018). FVL aircraft will likely contend with sophisticated anti-access area denial (A2AD) strategies from near-peer threats. To support Army pilots operating in this type of environment, FVL aircraft will be designed to support teaming with unmanned assets and conducting electronic warfare.

Crewing will also be different in the envisioned world. Current crew configurations employ two rated pilots – one who flies the helicopter, and one who manages non-flying tasks. The Army's vision for FVL platforms does not necessarily rely on the same configuration. The Army wants the airframes capable of flying with two pilots, one pilot, or potentially no pilots (managed by remote operators on the ground or on board other aircraft), depending on mission type. The core missions that we identified for the FARA platform are attack, air assault, reconnaissance, and support of air assault and air movement.

Approaches for Designing for the Envisioned World

Miller and Feigh (2019) described different approaches to addressing the envisioned world problem to identify requirements for a new system. They represent the envisioned world problem as a decomposition space with two axes: the work domain (x-axis) and technological capability (y-axis; see Figure 1). The lower left quadrant of the space represents the existing world. The envisioned world sits in the upper right quadrant of the space. The authors identify two possible pathways (or vectors) to reach the envisioned world: along the technological capability axis or along the work domain axis.

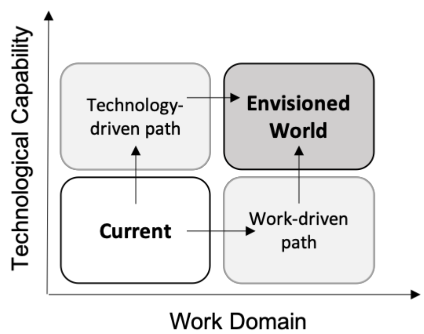

Figure 1. The envisioned world problem represented as a decomposition space (adapted from Miller & Feigh, 2019).

Technology-Driven Pathway

The pathway to the envisioned world that follows the technological capability axis is a commonly used path: new technologies are built, then they are incorporated into the work domain. Often, the new technologies initially appear to provide capabilities that align with the goals of the domain. For example, the addition of a forward-looking infrared (FLIR) sensor to the UH-60 Black Hawk helicopters flying medical evacuation missions in Afghanistan was meant to improve a pilot's ability to land in a degraded visual environment. Desert landings are often complicated by the brown-out conditions caused by dust getting caught in the Black Hawk's rotorwash, reducing visibility. The FLIR sensor provided the pilot with an infrared view of the environment that was not hindered by the flying dust and debris.

The FLIR sensor was installed on the lower side of the aircraft landing strut, which affected how pilots landed the helicopter. It was also expensive – damage to the sensor when landing was classified as a Class A (i.e., most serious) accident, requiring the pilot to report the accident up the chain of command. The FLIR was not certified for pilotage (i.e., never approved as a primary flight display); pilots could use it for situational awareness regarding the location of the ground and other obstacles, but they were not allowed to use it for landing the helicopter in brownout conditions. Many pilots chose not to fly with the FLIR sensor because of the adaptations they were required to make to their own operations to accommodate the technology. In this case, a promising new technological capability was coupled with significant barriers to use, becoming a liability rather than a support. The integration of the technology into the work domain was poor. Ultimately, the risks associated with the technology outweighed the benefits, and did not fully support the pilots as intended.

Work-Driven Pathway

Miller and Feigh (2019) endorse the work-driven pathway as a better alternative to achieving the envisioned end state than the technology-driven pathway. Following this approach, system designers focus on envisioning the future work domain first. They accomplish this by including operators in the design process early enough to generate and envision the desired end state. By engaging operators early, system designers can study the constraints of the current work domain and ground the envisioned work domain in the existing context. Miller and Feigh (2019) state that it is reasonable to assume that *certain* constraints that are present in the current environment will translate to the envisioned world (e.g., those related to physical laws, human capabilities, legal boundaries, etc.), while others will change to meet the requirements of the envisioned world. Therefore, it is important to analyze the current constraints and work with stakeholders to anticipate which will likely remain, and which will likely change in the future.

An example of the work-driven approach to introducing new technology is the modification of a software system designed to help Army commanders with pre- and post-mission flight and maintenance management. Developers approached commanders in Afghanistan with an existing product and asked how it could be improved to better support them. One suggested improvement was to support commanders as they determined how to select helicopter pilots for a mission to optimize the crew mix. There are several variables that must be taken into account when making these decisions, from flight experience level to recency in certain environmental conditions such as flights using night vision goggles. The development team listened to the operators' input and created a patch for the existing software system to provide an immediate fix. Later, the Army produced and fielded a new software program that incorporated the operators' feedback. In this case, the technology was successfully implemented to meet a critical mission need.

Future Work Domain for FVL

Method. To understand the current work doman from which the envisioned world of FVL will evolve, we conducted cognitive task analysis (CTA) interviews (Crandall, Klein, & Hoffman, 2006). CTA interviews informed a functional analysis, as well as identification of cognitive requirements. We tailored traditional critical decision method interviews by adding questions that prompted interviewees to consider potential benefits and drawbacks of envisioned technologies, and the impact of different crewing configurations. When designing for an envisioned world, determing which types of experts to interview is not straightforward. Often the roles and tasks envisioned do not currently reside in a single career field. As a result, we engaged with a variety of operators and stakeholders to understand the work domain and the types of skills anticipated to be required in the envisioned world. Specifically, we interviewed Black Hawk and Apache pilots who had relevant experience (e.g., serving as an Air Mission Commander, flying attack missions, or teaming with unmanned systems). We also interviewed operators outside of the pilot community. For example, while no one in the Army is currently conducting electronic warfare operations from a helicopter (to our knowledge), we anticipate that this will be an important function in FVL. To better understand the work domain associated with electronic warfare, we interviewed an electronic warfare specialist from the Navy.

We also conducted a series of focused sessions with an experienced pilot to support two additional research activities to understand current operations: creating an abstraction hierarchy depicting high-level goals and core functions, and to inform modeling efforts. A member of our research team created human performance models that simulated the workload associated with current and envisioned Army attack missions. To deal with the challenge of underspecification that Woods and Dekker (2000) identified as a characteristic of trying to articulate concepts for an envisioned world, we wanted to intentionally characterize the complexities associated with the current work domain that will likely continue in the future work domain. Cognitive task analysis methods allow us to identify complexities that have arisen in the past and analyze how operators adapted to them.

To extend what we learned from these retrospective interviews, we also considered empirical results from lab simulations of systems designed to allow pilots to control multiple unmanned assets simultaneously.

Outcomes. The outcomes of our analysis of the work domain include artifacts from the functional analysis – abstraction hierarchy, contextual activity templates, and interdependency analyses; IMPRINT models; and cognitive requirements. These outcomes allow us to hypothesize what the the envisioned work domain might look like, while maintaining a grounding in the current work domain. Furthermore, these analyses allowed our research team to articulate sample crewing configurations for the FARA attack mission that stakeholders and experts can react to.

Generating Requirements for FVL

Woods and Dekker (2000) recommended that addressing the envisioned world problem requires a shift from late-cycle human factors evaluations of proposed technologies to early-cycle generative activities, such as ethnographic methods and participatory design. Consistent with this recommendation, we have engaged relevant subject matter experts and FVL stakeholders in every step of our process. The final step will be to present the Army with a method to determine how to crew FVL platforms, which have not yet been built and that include technologies that have not yet been developed, for missions that are not yet clearly defined.

To this end, we have also created a framework (Sushereba, Diiulio, Militello, & Roth, 2019) to conduct an analysis of the trade-offs associated with different crewing configurations. This “tradespace framework” will serve as a mechanism for stakeholders and subject matter experts to provide input about key evaluative factors for each envisioned concept (i.e., crew configuration). The research team will use the tradespace framework during a multi-day workshop with FVL stakeholders. During the workshop, attendees will participate in activities designed to immerse them into the envisioned world for FARA and help them articulate the envisioned tasks. The anticipated outcomes of the workshop will be more specific crewing configuration recommendations, along with the associated risks and technological capabilities that will be required to support each of the configurations. From these outcomes, requirements for the FARA platform will begin to emerge.

To achieve the envisioned world for FVL, a significant shift in the work domain is needed, along with new required technologies to support the envisioned capabilities. We agree with Miller and Feigh’s (2019) work-driven approach being a better approach to developing future systems than to focus entirely on the technology and forcing the work domain to adapt. Our approach outlined in this paper combines theoretical knowledge from human factors and cognitive systems engineering with the expertise of operators and the vision of envisioners to develop intelligent requirements for FVL. Each of these perspectives offer a unique, but incomplete picture; focusing on a single perspective will inevitably lead to a less than ideal solution. We recommend incorporating each of these perspectives to create a holistic approach to articulating and designing the FVL platforms to effectively operate in the envisioned world.

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