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A METHOD TO DERIVE HUMAN INTEGRATION REQUIREMENTS FOR COMPLEX SYSTEMS THROUGH STOCHASTIC MODELING

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ABSTRACT

As the complexity of flight deck automation has grown over the past several decades, so too has the potential for operator confusion and decision-making errors in complex failure scenarios, a problem that is only expected to increase dramatically with the development of new forms of Advanced Air Mobility (AAM). These errors often stem from design gaps in the Human Machine Interface (HMI) in the face of unexpected emergent properties of the human-machine system. This research seeks to enhance system designers' ability to cut through this complexity by proposing a new stochastic modeling and simulation method that models HMI design elements and human task analysis over a range of scenarios. Through this method, potential for latent errors can be identified early in the design process. The viability of the method is demonstrated through a proof-of-concept Simulink model, though further work is needed to validate predictions against real world data.

1 INTRODUCTION

Advances in flight deck automation, while safety enhancing, have also been known to lead to operator confusion in complex failure scenarios. Pilot decision-making errors in these scenarios are not easily anticipated and are often only discovered in the wild as a combination of multiple intrinsic and extrinsic factors, such as variability in human information processing or timing with respect to other events (Dismukas 2001). These decision failures can almost always be attributed (at least in part) to a design gap in the Human Machine Interface (HMI) in which either the information or affordances available at the time are insufficient to address the unanticipated condition. Trends over the past several decades to spread information across multiple pages in a glass cockpit design only exacerbate this challenge.

To contend with this potential for "unknown unknowns", designers have historically relied on expert pilot opinion to identify essential HMI elements (Konrad et al. 2022). However, with the rise of new forms of automation found in advanced air mobility systems, pilot opinion is increasingly challenged to keep up with the growing complexity. Furthermore, traditional backstops such as reversion to manual modes of control are incompatible with the complexity found in highly automated or remotely managed systems. The purpose of this research is to improve the ability for system developers to understand this complexity through modeling and simulation and thus allow the HMI designer to better predict usability of the design before it's built, catch the potential for design induced errors, and support design trades between HMI and automation complexity.

2 METHOD

The modeling methodology (Figure 1) centers on the creation of three distinct but tightly coupled model elements: (1) A representation of the human-machine interface capturing the information hierarchy and dynamic aspects of the design, (2) A comprehensive task analysis capturing the full range of monitoring and decision-making tasks that flow from the design, and (3) A representative set of nominal and off-nominal scenarios from which to drive stochastic simulations that instantiate various combinations of tasks over time. Tasks are linked to HMI elements, and scenario events are linked to tasks. With this model in place a stochastic simulation is then run to produce data on the expected utilization of various HMI design elements over time, including: the identification of which elements are under-utilized, inefficiencies in scan patterns, identification of which elements are likely to be used concurrently, and (crucially) which conditions result in resource contention in which the required resources at a given moment are not concurrently available. These data are then used to inform future iterations of the design cycle

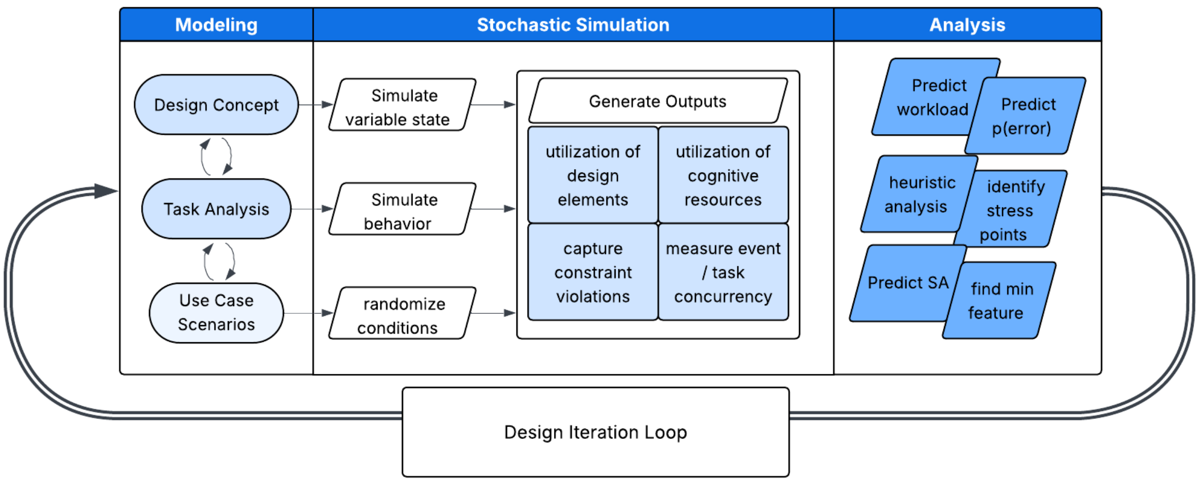

Figure 1: Simulation-based design iteration cycle.

To illustrate the application of this method, a simple proof of concept model was created in Simulink to represent a notional HMI for an uncrewed aircraft system. Scenarios included random injection of traffic conflicts and system faults into an otherwise quiescent enroute transit phase of flight.

3 RESULTS AND LIMITATIONS

Running the simulations in Simulink uncovered multiple instances in which the cognitive requirements for a task were violated, each of which could represent a potential for a decision-making error in the real world. The design was then modified to correct for these errors, and in subsequent iterations of the simulation, the errors did not recur. While this result is promising, further work is needed to extend this model across a wider range of scenarios to ensure completeness. The simulation was also able to identify peak periods of cognitive resource utilization, which is predictive of relatively high mental workload within the scenario. Future work is needed though to understand the relationship between these relative predictions and absolute measures of mental workload (such as Bedford or NASA-TLX). Finally, while the method has demonstrated the ability to highlight potential gaps in an HMI design, further work is needed to be able to positively demonstrate an acceptable level completeness of the model.

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