MANAGING THE DEVELOPMENT AND INTEGRATION OF AI-BASED MISSION AUTONOMY IN UNMANNED SYSTEMS: A PROGRAMMATIC AND SYSTEMS ENGINEERING APPROACH.

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Abstract

The Department of War is aggressively integrating AI into unmanned systems across all domains. However, as autonomy increases, program managers and system engineers face new challenges in verification and trust assurance. The lack of standardized processes for validating AI behaviors within legacy command-and-control architectures complicates risk management and compliance. This project seeks to define a structured framework that enables effective planning, testing, and deployment of AI-enabled autonomy while maintaining system reliability and operator confidence. Traditional requirement frameworks rely heavily on positive requirements that define what the system must do. However, AI-based mission autonomy introduces behaviors that may be emergent, probabilistic, or non-deterministic, requiring a complementary emphasis on negative requirements that define what the system must not do under any conditions. DoW acquisition and verification processes do not yet provide structured methods for developing, managing, and testing these behavior constraints. This gap inhibits safety certification, complicates mission risk assessments, and limits operator trust in autonomous systems.

Methods

- Used a qualitative defense-focused research design to assess the development and integration of AI-based mission autonomy in unmanned undersea vehicle programs.
- Analyzed government reports, acquisition guidance, technical studies, Naval Postgraduate School research, and peer-reviewed literature.
- Coded and evaluated findings using five analytical lenses: program management, systems engineering, autonomy requirements, verification and validation, and lifecycle risk management.
- Compared autonomy integration challenges across acquisition policy, systems engineering practices, and modular open systems architectures.
- Synthesized recurring themes, gaps, and best practices into a risk-informed framework for managing AI-enabled mission autonomy.

Results & Impact

- Developed a risk-informed framework for managing AI-based mission autonomy within DoD acquisition programs.
- Established a structured approach for developing, tracing, and validating positive and negative autonomy requirements.
- Improved alignment between program management, systems engineering, verification activities, and responsible AI governance.

Future Research

- Validate the framework through application to active defense autonomy programs.
- Develop quantitative metrics for assessing autonomy risk and negative requirement effectiveness.
- Evaluate framework applicability across unmanned surface, air, space, and joint autonomous systems.

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