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Autonomous Systems Modeling During Early Architecture Development

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Abstract

Autonomous systems are a complex integration of human intelligence and machine automation capable of adapting to unforeseen events. Proliferation of these systems has accelerated, in part, to meet the ever-increasing demand to develop and use unmanned vehicles to conduct surveillance and reconnaissance missions. During system development, an understanding of the complex relationship between system autonomy, human interaction and machine automation is critical to support early trade studies that address architectural comparisons, scenario concepts of operations, life cycle logistic needs, and total life cycle costs. This paper develops a two dimensional algorithmic methodology and framework tools for contributing to trade space assessments during the early design phases with the intent of supporting design optimization.

Keywords: Systems Engineering; Autonomous Systems; Requirements Engineering; System of Systems

1. Introduction

Unmanned intelligence, surveillance and reconnaissance (ISR) systems are a key component of the United States Navy (USN) defense transformation [1]. Assessing ISR data to developing actionable security operations will continue to be a national priority [2]. The US Navy has defined that autonomous systems are a complex integration of human intelligence and machine automation [3]. Sheridan proposed a Model for Types and Levels of Human Interaction [4], Table 1. Level 1 defines tele-operated systems that require the most human interaction. Android like behavior, level 10, requires the least human interaction. This ten level chart is the basis for current models like the Autonomy Levels for Unmanned Systems (ALFUS) [5] that is now part of the SAE AS-4D standards. Although a significant body of work has been done to assess autonomy, an algorithmic model does not exist. These tools are needed to assess candidate architecture during tradeoffs studies in define requirements in the very early phases of development [6, 7].

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Table 1: Sheridan Autonomy Scale

High	10	The computer decides everything, acts autonomously, ignors the human
	9	Informs the human only if it, the computer, decides to
	8	Informs the human only if asked, or
	7	executes automatically, then necessarily informs the human, and
	6	allows the human a restricted time to vetoe before automatic execution, or
	5	executes that suggestion if the human approves, or
	4	suggests one alternative
	3	narrows the selection down to a few, or
	2	The computer offers a complete set of decision/action alternatives, or
Low	1	The computer offers no assistance, human must take all decisions and actions.

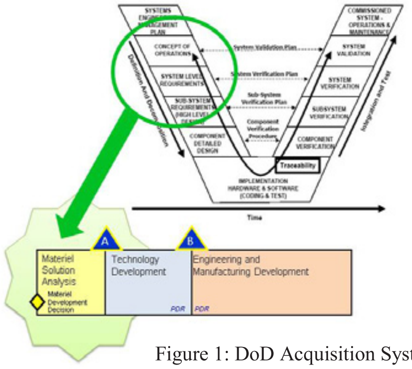

Figure 1: DoD Acquisition System

2. System Autonomy Assessment

Future ISR missions would be conducted using multiple unmanned systems (UMS) of various technologies and autonomy levels [8]. Current methods and approaches quantify autonomous capabilities of developed system but do not adequately support the pre-Milestone A trade-off studies Figure 1 [9, 10].

Figure 2: RQ11 Raven (courtesy Aerovironment)

Figure 3: NASA Mars Curiosity Control Room (courtesy NASA)

As these system architectures expand into complex system of systems (SoS), the need for interoperability between those systems and their human supervisors increase. Unmanned Air Vehicles (UAV) range in sophistication and may need one or more human supervisors to successful carry out a surveillance mission. An example of this can be a simple radio controlled hand held UAV depicted in Figure 2 and used by the US Army is operated by a single user. A methodology to investigate parametric sensitivities is needed to define the requirements of Autonomous System architectures. “Conventional methods are extremely complex, hard to understand in detail and are difficult, even impossible, to test adequately using traditional methods” [11]. A workable and measurable definition of system autonomy (SA) would establish a functional relationship between the degree of human interaction (HI) and the degree of machine automation (MA) shown as:

$$F[SA] = F[MA] + F[HI] \quad (1)$$