Acquisition Directorate
Research & Development Center

Report No: CG-D-04-12

Human Performance Modeling: Improving M&S for CG Acquisitions and Operations

Representing the Total System Reduces Acquisition Risk

Distribution Statement A: Approved for public release; distribution is unlimited.

November 2011

Homeland Security

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **NOV 2011**	2. REPORT TYPE	3. DATES COVERED **00-00-2011 to 00-00-2011**

4. TITLE AND SUBTITLE **Human Performance Modeling: Improving M&S For CG Acquisitions And Operations**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **United States Coast Guard,Research & Development Center,1 Chelsea Street,New London,CT,06320**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**9**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

N O T I C E

This document is disseminated under the sponsorship of the Department of Homeland Security in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

This report does not constitute a standard, specification, or regulation.

Timothy P. Hughes
Acquisition Support & Analysis Branch Chief
United States Coast Guard
Research & Development Center
1 Chelsea Street
New London, CT 06320

1 INTRODUCTION

United States Coast Guard (USCG) mission responsibilities have grown significantly over the past decade. Mission growth is accompanied by a commensurate growth in system and tactical complexity. Both types of growth are influenced by changes in threat behaviors, requirements for internal and interagency coordination, and changes to doctrine and tactics. USCG platforms and systems must become increasingly sophisticated and complex to meet these demands.

Generally speaking, acquisition risk increases with system complexity. One major risk involves basing acquisition decisions on potentially erroneous estimates of mission performance – generally overestimates due to engineering optimism. In complex systems, performance overestimation often occurs due to difficulties in understanding how system components and the mission environment interact with each other and how these interactions influence mission performance. Development of more accurate mission performance estimates can help prevent unanticipated performance decrements during testing and fielding, and thus save program costs and prevent the schedule delays associated with late-stage corrective actions.

Savvy acquisition Program Managers (PMs) who want to mitigate these risks will take every reasonable action to develop high-quality information about their systems. Human performance modeling can be a key component in these efforts, especially when coupled with other, more-traditional modeling, simulation, and analysis approaches available to the PM.

2 MODELING AND SIMULATION: AN INFORMATION SOURCE FOR THE ACQUISITION PM

Modeling and simulation (M&S) provides a cost-effective means for developing information and knowledge about system concepts and estimating their mission performance potential. M&S-based analysis can be applied to inform nearly every step in the acquisition process: from pre-acquisition mission analysis; to analysis of as-built systems; to supporting the development of Tactics, Techniques, and Procedures (TTP). M&S techniques are particularly well-suited for developing and exploring system trade-offs and requirement specifications, using approaches similar to that depicted in Figure 1. First, alternative system concepts are proposed in terms of functionality and the capability levels of subsystems and components (Fig. 1, top left). The system concepts are then captured in a constructive simulation of a representative mission in the context of a real-world scenario (Fig. 1, bottom left). The mission simulation environment facilitates analyses influenced by the same dynamic demands that the system must serve in the real world. This includes key factors relating to demand types, frequencies, and magnitudes that are difficult to account for in isolated analyses of individual components. Scenario outcomes are measured objectively in terms of predicted mission performance along with other supporting metrics (Fig. 1, top right). Component performance levels linked to objective, quantified overall system performance goals then become the basis of system requirement specifications (Fig. 1, bottom right).

Alternative Unmanned Air Vehicle (UAV) Capabilities		
Capability	Alternative 1	Alternative 2
Endurance	24 hrs	36 hrs
Cruise Speed	120 kts	100 kts
Radar Range	40 NM	35 NM

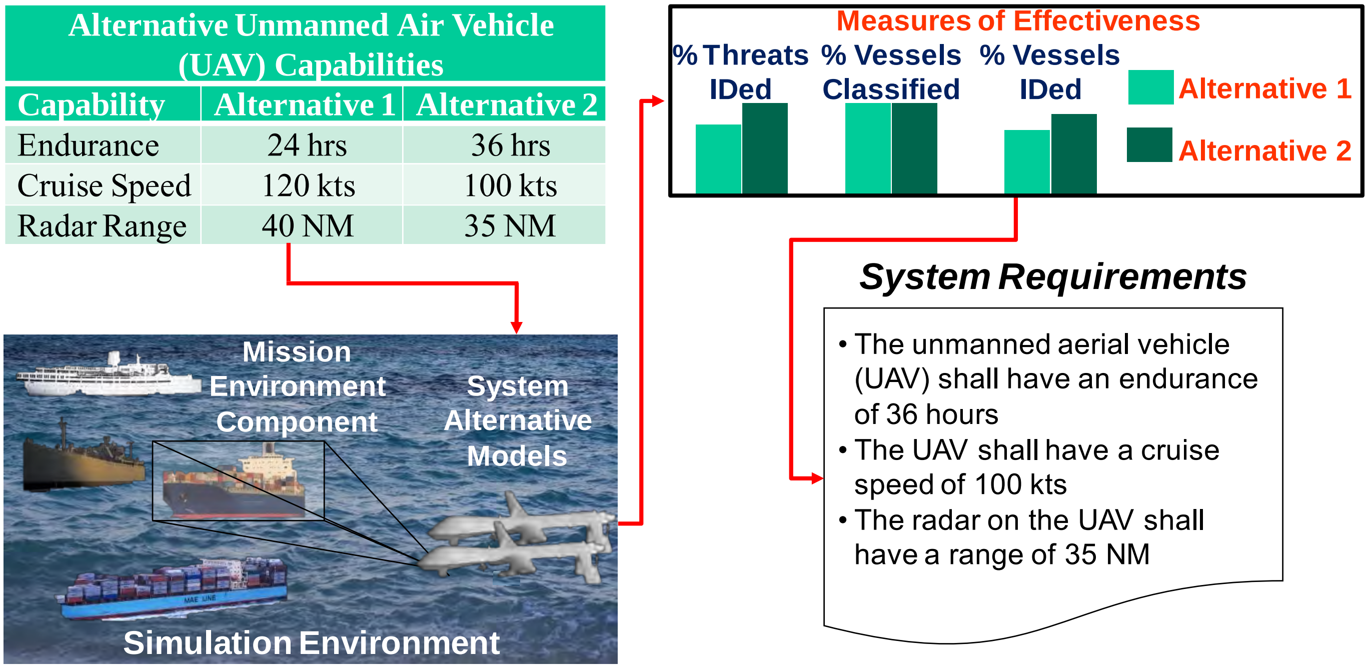

Figure 1. An illustration of how M&S is used to develop system requirements.

In practice, numerous alternatives are proposed and evaluated using this process. When compared to development and testing of physical prototypes, *M&S-based alternatives analyses are accomplished more quickly, executed at far less cost, and remain more flexible*. This translates to an ability to examine and refine many variations in types and levels of system capabilities under a range of missions and conditions. Furthermore, M&S-based analysis can include *tactical situations from the riskiest part of the operational spectrum* without risking the lives and health of personnel. Such analysis is often necessary to develop a proper understanding of system performance and limitations in extreme conditions. Finally, and perhaps most importantly, some of the system concepts formulated and tested using the M&S process may fail to deliver the required levels of mission performance. *Such failures in early analysis activities are okay* – especially when they are discovered before sunk costs begin to accumulate. Knowing both what works and what does not work in a system concept helps to define the capability boundaries of an effective solution.

In many ways the process of proposing, testing, and refining alternative system concepts is as important as selecting the one to implement. Taken together across the complete set of system alternatives, the PM benefits from an extensive, objective knowledge-base and can therefore make well-informed decisions.

Like any analytic method, the quality and accuracy of the results obtained with M&S and the success of the decision-making it supports are dependent upon the quality and accuracy of the implemented system models and mission environment representations. *It is critical that the system model represent all of the system components and elements that contribute to mission performance* and further capture the salient aspects of all of the entities, factors, and attributes that stress and drive the system. Simulations that fail to do this can result in inaccurate predictions of a system's performance, opening the door to poor acquisition decisions.

3 HUMAN PERFORMANCE MODELS ENABLE TOTAL SYSTEM ANALYSIS

Recent research conducted by the USCG Research & Development Center (RDC) has shown that incorporation of detailed representations of personnel roles and actions within system models can greatly improve the quality and accuracy of system performance estimates. This finding is important because nearly all of the constructive simulations used to develop system requirements include only highly-aggregated (i.e., summary-level) representations of personnel performance. Personnel are a critical component of most systems; they make the most difficult and significant decisions and they perform activities too complex to automate. In short, personnel are primary contributors to the mission and, therefore, need to be represented in any simulation that estimates total system performance.

There is a capability for incorporating portrayals of personnel into current models and simulations used to represent and test systems. It is called *human performance modeling* (HPM). RDC research has demonstrated how HPM can be integrated with simulations used to test system concepts. Figure 2 illustrates the conceptual architecture employed and shows how operator-focused system requirements can be generated along with requirements for the physical system.

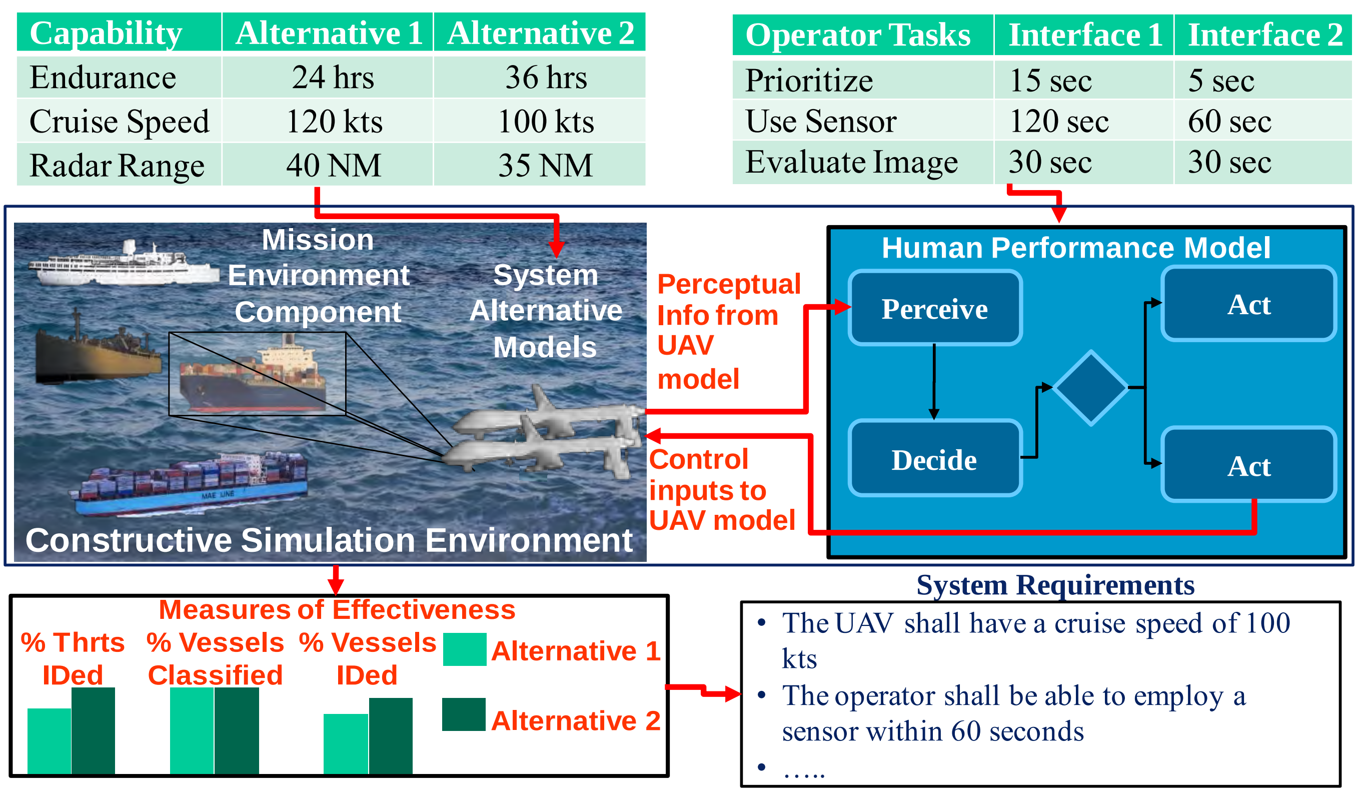

Figure 2. Illustration of how HPMs can be integrated with current acquisition simulations.

Essentially, HPMs provide computational representations of how people perform work and other activities. The models represent human tasks, processes, information-processing, decision-making, control actions, communications, and other required behaviors in terms of human abilities such as perception, cognition, and psychomotor actions. Just as models can be adapted to represent the functionality and capability of physical components associated with a system concept, an HPM can be shaped to represent how an operator would perform within a system concept based on anticipated roles and system interfaces. Individual or collective HPM elements can be adapted to exchange data and commands with constructive simulation model elements to create an integrated simulation representation. As shown in Figure 2, the constructive model passes perceptual information (such as the data on a cockpit display) to the HPM, where it is "perceived" by the simulated operator. The HPM "decides" what action to take and sends data back to the system model to implement the action. The result is an integrated, dynamic representation of the total system – the hardware, software, mission environment, and people.

4 USE OF HPM CAN IMPROVE SYSTEM PERFORMANCE ESTIMATES

RDC researchers were interested in knowing whether integrated HPM-constructive simulation environments would produce mission performance results that are different from those produced by traditional, "stand-alone" constructive simulations. The accredited *Coast Guard Tactical Modeling Environment (CGTME)* was used to construct a simulation of an unmanned aerial vehicle (UAV) executing a surveillance mission in the Florida Straits. In this mission, the UAV is searching for two types of threat vessels – small, high-speed boats ("Go-Fasts") and even smaller, slower-moving vessels ("Chug-Chugs") – carrying illegal drugs and/or migrants. Legitimate vessel traffic typical of the Florida Straits environment was modeled as well, and included freighters, tankers, cruise ships, commercial fishing boats, and recreational motor vessels. The density of legitimate traffic was varied to represent typical and high traffic densities (150 and 250 vessels, respectively). The threat density was held constant at three Go-Fasts plus three Chug-Chugs.

The scenario's UAV is controlled remotely from a ground station by a crew consisting of a pilot and a sensor system operator (SSO). The mission profile required the UAV to fly a pre-determined flight path. Consequently, the pilot had a minimal role. The SSO was the key player, using the UAV's sensors to search for threats (primary mission) while attempting to detect, classify, and identify all other traffic (secondary mission). The UAV was equipped with multi-mode radar capable of both vessel detection and classification; an electro-optical (EO) sensor that supported vessel identification; and an Automatic Identification System (AIS) receiver, which could detect and track all traffic with AIS transceivers. The CGTME constructive model used simple modeling algorithms for performing detections, classifications, and identifications, using time delays to represent aggregated SSO actions. These time delays were established based on subject matter expert (SME) estimates of the overall time required to accomplish an *aggregated* process (e.g., the total amount of time it takes to classify a vessel).

To create the integrated simulation, a HPM was developed – using the IMproved Performance Research INtegration Tool (IMPRINT) – that implemented the details of the full range of actions that an SSO would perform. The HPM was developed using inputs from USCG sensor and surveillance mission SMEs – but in this case, the SMEs were asked to examine *each individual task element* within the overall process. The HPM was connected to the CGTME through a custom software link. In this integrated mode, the constructive model's detection, classification, and identification algorithms were disabled. Instead, the IMPRINT SSO model received data from the CGTME UAV model that represented the information a real operator would receive from the sensor system interfaces. The SSO model processed this information to make decisions about which vessel to look at next, what sensor to use and how to use it, and the status and classification of the vessel currently being presented on a sensor display. The SSO model then passed data back to the CGTME UAV model as required to implement SSO model decisions (e.g., select and point a sensor, record an identified target, etc.) and to score the results.

Ten data collection runs were conducted for both the stand-alone and integrated simulations at both traffic density levels (scenario sizes). Two key bottom-line metrics were evaluated: (1) threat identification percentage, and (2) non-threat classification percentage. The results are summarized in Table 1.

As noted earlier, there were six threat (smuggling) vessels in each scenario. The results show that the stand-alone CGTME model always identified all six of the threat vessels but the integrated HPM-CGTME model found only four or five of these threats (67% - 80% in Table 1). It is also important to note that the percentage of threats found by the HPM-CGTME model decreased as overall traffic density increased.

From a mission performance standpoint, the stand-alone CGTME and the integrated HPM-CGTME made significantly different predictions of system performance.

Table 1. Experiment results summary.

Simulation Mode	Performance Metrics			
	Percentage of Threats Identified (of 6)		Percentage of Non-Threat Vessels Classified	
Scenario Size:	150 Vessels	250 Vessels	150 Vessels	250 Vessels
Stand-alone CGTME	100%	100%	62%	62%
Integrated HPM-CGTME	80%	67%	28%	14%

For the secondary mission objective (classification of legitimate traffic), the differences in the results are even more dramatic. In the stand-alone CGTME simulation, almost two-thirds of the non-threat vessels were identified; this was true for both levels of traffic density (scenario size). But in the integrated HPM-CGTME simulation, *the results vary with traffic density*: only 28 percent of vessels were classified in the 150-vessel condition, and that decreased to 14 percent in the high-density (250-vessel) condition. The HPM-CGTME results are consistent with human factors research, which shows that as the number of targets and amount of workload increase, human vigilance and performance decrease.

Why do we get such remarkable differences between two methods of simulating the same system? The answer lies primarily in the different levels of detail at which the detection, classification, and identification events are represented. In the stand-alone CGTME simulation, these events are each single-step processes. For example, once a target vessel is selected for classification and comes within classification range, classification success is assured, and incurs only a time delay to be completed (approximately 60 seconds). In the integrated simulation, the HPM is responsible for classification – a process that is represented as a multi-step sequence of tasks (e.g., enter radar coordinates, slew EO, step through magnification levels until vessel features are visible, etc.) that varies based on target range and vessel type. This more-realistic process, as represented in the HPM, can take from one to several minutes. Because, on average, the HPM-based simulation of operator tasks takes more time to evaluate each vessel than does stand-alone CGTME, it (and, presumably, a real operator) simply cannot process as many vessels during the scenario.

5 CONCLUSIONS

Imagine you are a PM responsible for procuring a UAV like the one described earlier. You are presented with two alternatives for assessing the UAV concept.

- The first alternative is to use a stand-alone constructive model to predict threat identification performance. Based on its (overly-optimistic) prediction that the system will identify 100% of threats, you make a significant investment to acquire an initial UAV prototype for testing. Then during testing, you discover the bitter truth: human operators cannot perform their tasks fast enough to support the promised level of performance. Your time, money, and energies are now likely to be consumed in attempting to mitigate this shortfall.

- Your other (preferred) alternative is to take the extra step early in the process to incorporate HPM and integrated simulations in your analysis work. You set more realistic goals and expectations for your program, or seek out technology solutions that can lead to better overall performance.

Bottom Line: When using M&S to assess total system performance, it is important to incorporate operator representations into models of the physical system. This helps ensure proper representation of all system components that drive mission performance, resulting in more accurate and reliable predictions of total system performance.

6 ADDITIONAL NOTES

The authors wish to point out that there are a number of different types of simulations that can be used in the acquisition process for a wide range of analyses. The focus of this paper is solely on constructive simulations that are used to predict total system performance. CGTME is an excellent M&S tool, and can be employed in stand-alone mode to serve a wide variety of analyses. Key examples include analysis aimed at assessing alternative physical system configurations, especially those where the competing alternatives imply similar duties for system operators. We do not mean to imply that HPM must be incorporated into all CGTME-based tests or with other USCG simulations. HPM is just one tool in the M&S practitioner's toolkit. As with any tool, it must be used appropriately to obtain cost-effective analysis results.

7 FOR MORE INFORMATION

Readers interested in learning more about the experiment, the related models and simulations, or how to incorporate integrated modeling into their own projects are urged to contact the RDC.

Dr. Anita Rothblum (860-271-2847, Anita.M.Rothblum@uscg.mil) leads human factors and HPM work at the RDC and was the CG project manager on this effort.

Mr. Kevin Downer (860-271-2654, Kevin.F.Downer@uscg.mil) is a senior operations research analyst at the RDC and is familiar with a range of M&S tools.