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TECHNICAL
REPORT

A RAND Analysis Tool for Intelligence, Surveillance, and Reconnaissance

The Collections Operations Model

Lance Menthe, Jeffrey Sullivan

Prepared for the United States Air Force

Approved for public release; distribution unlimited

RAND PROJECT AIR FORCE

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Preface

Over the past several years, the RAND Corporation has invested in the development of increasingly sophisticated constructive simulations to support the analysis of command, control, communications, intelligence, surveillance, and reconnaissance (C3ISR). These models have been built cooperatively across three federally funded research and development centers at RAND: the Arroyo Center, the National Defense Research Institute (NDRI), and Project AIR FORCE (PAF). The latest and most advanced simulation produced by this ongoing line of research is the Collections Operations Model (COM).

The COM grew out of an intelligence, surveillance, and reconnaissance (ISR) tasking and employment study conducted by Project AIR FORCE in fiscal years 2005 and 2006[1] and has since been used to support several other ISR studies in PAF and NDRI that continue to drive further improvements to the model. In this report, we describe in broad terms the design, capabilities, and utility of the COM as an analysis tool.

The research reported here was sponsored by the Commander, Pacific Air Forces; the Director of Intelligence, Headquarters, Air Combat Command; and the Director of Intelligence, Surveillance, and Reconnaissance, Office of the Deputy Chief of Staff for Air, Space, and Information Operations, Headquarters United States Air Force. The work was conducted within the Force Modernization and Employment Program of RAND Project AIR FORCE.

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[1] Sherrill Lee Lingel, Carl Rhodes, Amado Cordova, Jeff Hagen, Joel S. Kvitky, and Lance Menthe, *Methodology for Improving the Planning, Execution, and Assessment of Intelligence, Surveillance, and Reconnaissance Operations*, Santa Monica, Calif.: RAND Corporation, TR-459-AF, 2007.

Contents

Preface iii
Figures and Tables vii
Summary ix
Acknowledgments xi
Abbreviations xiii

CHAPTER ONE
Background 1

CHAPTER TWO
Overview 3

CHAPTER THREE
Sensor Capabilities 9
Signals Intelligence 9
Electro-Optical, Infrared, and Synthetic Aperture Radar 9
Inverse Synthetic Aperture Radar and Maritime Moving Target Indicator 10
Ground Moving Target Indicator 10

CHAPTER FOUR
Design 13

CHAPTER FIVE
Future Work 17
Space-Based Assets 17
Fusion 17
Communications 18
Workflow Representation 18
Misinformation and Deception 18

References 19

Figures and Tables

Figures

2.1. Modular Design of the COM Within SEAS 4
2.2. Representative Screenshot of SEAS Running the COM 5
2.3. Cueing and Tasking Vignette 7
3.1. GMTI Sectorized Representation 11
4.1. Dynamic Retasking Loop 16

Tables

2.1. Sensor Representation in the COM Library 6
2.2. Commonly Used Behaviors in the COM Library 6
4.1. Excerpt from a Sensor FOR Configuration File 14
4.2. Excerpt from Sample Behaviors Assignment File 15

Summary

This report is an introduction to the Collection Operations Model (COM), a stochastic, agent-based analysis tool for C3ISR written for the System Effectiveness Analysis Simulation (SEAS) modeling environment. SEAS is a multiagent, theater-operations simulation environment sponsored by the Air Force Space Command, Space and Missile Systems Center, Directorate of Developmental Planning, SEAS Program Office (SMC/XRIM) (see pp. 13–16).

The COM grew out of ISR tasking and employment studies conducted by Project AIR FORCE in fiscal years 2005 and 2006. It has since been used to support further research, notably to investigate the utility of the Global Hawk as a maritime surveillance platform.[2] The COM is designed for the study of processes that require the real-time interaction of many players, such as ad hoc collection, dynamic retasking, and resource allocation. The COM can provide analytical support to questions regarding force mix, system effectiveness, concepts of operations, basing and logistics, and capability-based assessment.

The COM is designed to be a universal model that can be adapted to support almost any scenario. It can represent thousands of autonomous, interacting platforms on all sides of a conflict that employ a wide variety of sensor packages and communications devices and execute individual behaviors of arbitrary complexity (see pp. 3–6). The COM can explore the capabilities of a wide range of ISR assets, including manned platforms, unmanned aerial vehicles, unattended ground sensors, special operations forces, and virtually any air, land, or sea system. The model accepts as input a wide array of sensor capabilities, target properties, terrain analysis, weather effects, resource limitations, communications delays, and command and control delays. Its final output is a minute-by-minute account of each agent's changing operational picture.

As an agent-based construct, the COM supports interactive behaviors that link the actions of agents to environmental conditions, to the perceived activity of other agents, and to commanders' orders. Examples of such behaviors are maintaining a surveillance orbit around a moving ship, attempting to provoke an enemy vessel by repeatedly approaching and retreating, and reorienting sensors in response to revised tasking orders.

The COM's sensor models (see pp. 9–11), which are categorized according to the type of intelligence they collect, are its most detailed components. The signals intelligence (SIGINT) model is the COM's most sophisticated individual model. Many aspects of emitters and receivers are represented: field of regard (FOR), including main and side lobes where appropriate; scan cycle, emission interval, or emission probability; frequency bands; relative angular size of

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[2] Carl Rhodes, Jeff Hagen, and Mark Westergren, *A Strategies-to-Tasks Framework for Planning and Executing Intelligence, Surveillance, and Reconnaissance (ISR) Operations*, Santa Monica, Calif.: RAND Corporation, TR-434-AF, 2007; Lingel et al., 2007.

main and side lobes (for directional signals); and the effective radiated power of each radiative lobe. The COM's related communications intelligence exploitation model, which involves further processing, may result in target identification.

The imagery intelligence model estimates the quality of electro-optical, infrared, and synthetic aperture radar images. For each individual sensor, an empirical formula relates target range to expected image quality on the National Imagery Interpretability Rating Scale. In the maritime environment, detection and classification are performed by inverse synthetic aperture radar. Ground moving target indicator (GMTI) and maritime moving target indicator (MMTI) models are inherently complex, and currently the COM does not incorporate tracking algorithms per se for either mode. For GMTI, the COM estimates and monitors the percentage of available sensor resources required to track a given target. For MMTI, maintenance of track is approximated by repeated radar contact.

For fiscal year 2008, RAND has invested in the addition of space-based assets to the COM, including relevant space weather and atmospheric effects (see p. 17). Other planned upgrades include a more robust model of sensor data fusion, communications modules that more accurately represent the advantages of a networked force, a more realistic representation of workflow within the air operations center and the deployable ground station, the capability of sensors to generate spurious reports (i.e., false positives) on their own, and the capability of agents to deliberately induce such reports (i.e., deception) (see pp. 17–18). The larger goal of these extensions and enhancements is to create a COM that can represent the entire C3ISR process specifically and network-centric operations in general.

Acknowledgments

We would like to acknowledge the assistance and support of those who made this report possible. Endy Min and Amado Cordova worked tirelessly to add data to and build scenarios for the COM, and they also cheerfully (if unwittingly) played supporting roles as quality assurance testers. Joel Kvitky provided and articulated for us the theoretical underpinnings of many of the sensor models. Brien Alkire developed the output parser to help organize and analyze the large amount of data returned by the model. Louis Moore provided patient advice and assistance in navigating the SEAS modeling environment. Holly Johnson polished and formatted this report for publication. Last but never least we thank Sherrill Lingel and Carl Rhodes, without whose leadership the COM would still be without form, and void.

Abbreviations

AMTI	air moving target indicator
AOR	area of responsibility
ASIP	Airborne Signals Intelligence Payload
ATO	air tasking order
BASIC	Beginner's All-Purpose Symbolic Instruction Code
C2	command and control
C3ISR	command, control, communications, intelligence, surveillance, and reconnaissance
COM	Collections Operations Model
COMINT	communications intelligence
COP	common operating picture
DTED	digital terrain elevation data
EO	electro-optical
EW	early warning
FOR	field of regard
GMTI	ground moving target indicator
HMMWV	high mobility multipurpose wheeled vehicle
IMINT	imagery intelligence
IR	infrared
ISAR	inverse synthetic aperture radar
ISR	intelligence, surveillance, and reconnaissance
JSTARS	Joint Surveillance Target Attack Radar System
LOS	line of sight
MMTI	maritime moving target indicator

NDRI	National Defense Research Institute
NIIRS	National Imagery Interpretability Rating Scale
PAF	Project AIR FORCE
RCS	radar cross section
RSAM	Reconnaissance and Surveillance Allocation Model
SAM	surface-to-air missile
SAR	synthetic aperture radar
SEAS	System Effectiveness Analysis Simulation
SIGINT	signals intelligence
SITREP	situation report
SMC/XRIM	Air Force Space Command, Space and Missile Systems Center, Directorate of Developmental Planning, SEAS Program Office
SOF	special operations forces
SSM	surface-to-surface missile
TEL	transporter erector launcher
TPL	tactical programming language
UAV	unmanned aerial vehicle
UGS	unattended ground sensor

CHAPTER ONE

Background

In the late 1990s, RAND developed the Reconnaissance and Surveillance Allocation Model (RSAM) to investigate route planning and tasking in collections operations. The model was later expanded to examine the larger issues of optima and trade-offs in the mix and sizing of intelligence, surveillance, and reconnaissance (ISR) forces.[1]

RSAM is a database-driven tool written in Beginner's All-Purpose Symbolic Instruction Code (BASIC) for the Macintosh personal computer platform. The model takes as its input a "ticker tape" of targets designated for prosecution in each air tasking order (ATO) cycle, which is derived from the master attack plan; a matrix of sensor or target capabilities; and any physical or role-based partitions of the battlespace. The model returns as output detailed flight plans for all available ISR assets. Routes are calculated to visit each listed target (or as many listed targets as possible) during each ATO cycle, taking into account constraints of travel time, sensor search capabilities, collection time, platform range and endurance, geographic line of sight (LOS) as derived from digital terrain elevation data (DTED), and defined exclusion zones.[2]

Although it is a rich and detailed calculational tool, RSAM uses a static, equation-based modeling approach best suited to the analysis of collection operations that can be planned well in advance. Given the increasing importance of time-sensitive targeting and network-centric operations, RAND decided in 2005 to develop a dynamic, agent-based model for the study of collection operations that evolve with time and respond to changing conditions.

RAND chose the System Effectiveness Analysis Simulation (SEAS) as the modeling environment for the COM for several reasons. SEAS—a non-proprietary, government-owned product—is the Air Force's premier, multiagent-based theater operations simulation, and RAND has strong prior experience using SEAS to support research in its federally funded research and development centers.[3] RAND analysts also have productive, ongoing relationships with the

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[1] See Joel Kvitky, Mark Gabriele, Keith Henry, George S. Park, and David Vaughan, *Description of RAND's Reconnaissance and Surveillance Allocation Model (RSAM): Application to ISR Requirements Analysis*, unpublished RAND Corporation research, 1996; David Vaughan, Joel S. Kvitky, Keith H. Henry, Mark David Gabriele, George S. Park, Gail Halverson, and Bernard P. Schweitzer, *Capturing the Essential Factors in Reconnaissance and Surveillance Force Sizing and Mix*, Santa Monica, Calif.: RAND Corporation, DB-199-AF, 1998.

[2] Routes are computed by a nearest-neighbor algorithm to satisfy all requirements. Solutions are efficient but not optimal.

[3] The General C4ISR Assessment Model was developed and has been used by the Arroyo Center and NDRI for several years. See Daniel R. Gonzales, Louis R. Moore, Christopher G. Pernin, David M. Matonick, and Paul Dreyer, *Assessing the Value of Information Superiority for Ground Forces: Proof of Concept*, Santa Monica, Calif.: RAND Corporation, DB-339-OSD, 2001; Daniel Gonzales, Louis R. Moore, Lance Menthe, Paul Elrick, Christopher Horn, Michael S. Tseng, and Ari Houser, *Applying New Analysis Methods to Army Future Force C3-ISR Issues: Focus on Future Combat System (FCS) Milestone B*, unpublished RAND Corporation research, 2004; Daniel Gonzales, Angel Martinez, Louis R. Moore, Timothy Bonds,

developer of SEAS and with the SEAS Program Office.[4] Leveraging these resources, RAND Project AIR FORCE (PAF) has developed the Collections Operations Model (COM).

The COM was initially developed as part of an ISR tasking and employment study, "Tasking and Employing USAF Intelligence, Surveillance, and Reconnaissance Assets to Support Effects-Based Operations," conducted by PAF in fiscal years 2005 and 2006. The COM has since been used to support further research, notably to investigate the utility of the Global Hawk as a maritime surveillance platform.[5] Since 2005, the COM has been used to model a range of scenarios—including counterinsurgency, counterpiracy, and maritime surveillance—and two major combat operations. It has also been used to study processes that require the real-time interaction of many players, such as ad hoc collections, sensor cueing, dynamic retasking, and resource allocation.

In the following chapters, we describe the design of the COM and its extensive ability to model platforms, sensors, and processes. We also discuss how the COM can be customized and expanded, and the ways in which analysts can use the COM to construct complex scenarios. Finally, we discuss the continuing development of and planned upgrades to the model.

Christopher Horn, John DeRiggi, Ricky Radaelli-Sanchez, and David Nealy, *Estimating Theater Level Situation Awareness for Campaign Level Force Analysis*, unpublished RAND Corporation research, 2007.

[4] SEAS was developed in the 1990s at Synectics and Aerospace Corporation for the Air Force Materiel Command Rome Laboratory. It is now maintained and developed by Sparta, Incorporated, in Los Angeles, California. For more background on SEAS, see Gonzales et al., 2001; Andrew W. Zinn, *The Use of Integrated Architectures to Support Agent Based Simulation: An Initial Investigation*, Air Force Institute of Technology, AFIT/GSE/ENY/04-M01, 2004. The SEAS program office is USAF Space Command, Space and Missile Systems Center, Directorate of Developmental Planning, SEAS Program Office (SMC/XRIM), at the Los Angeles Air Force Base.

[5] See Carl Rhodes, Jeff Hagen, and Mark Westergren, *A Strategies-to-Tasks Framework for Planning and Executing Intelligence, Surveillance, and Reconnaissance (ISR) Operations*, Santa Monica, Calif.: RAND Corporation, TR-434-AF, 2007; Sherrill Lee Lingel, Carl Rhodes, Amado Cordova, Jeff Hagen, Joel S. Kvitky, and Lance Menthe, *Methodology for Improving the Planning, Execution, and Assessment of Intelligence, Surveillance, and Reconnaissance Operations*, Santa Monica, Calif.: RAND Corporation, TR-459-AF, 2007.

CHAPTER TWO

Overview

The COM is a stochastic, agent-based simulation of command, control, communications, intelligence, surveillance, and reconnaissance (C3ISR) operations that is written in the SEAS modeling environment.[1] By virtue of its particular modular construction, which is unique within the SEAS community, the COM constitutes a nearly universal model that can be adapted to a broad array of military scenarios. It can represent thousands of autonomous, interacting platforms on all sides of a conflict that employ a wide variety of sensor packages and communications devices and execute behaviors of arbitrary complexity.[2] At the tactical level, this flexibility enables the COM to explore the ISR capabilities of a broad range of assets, including manned platforms, unmanned aerial vehicles (UAVs), unattended ground sensors (UGSs), dismounted special operations forces (SOFs), and virtually any other air, land, or sea system. At the operational level, the COM can model complex, multiagent C3ISR processes, including ground and maritime tracking, sensor cueing and dynamic retasking, coordination of unmanned ground and air systems, and communications network delays.[3]

The COM is not a single, fixed model per se but is rather a suite of modules and libraries designed to work together. This suite is managed by a compact core of code (see Figure 2.1) that an analyst can configure to modify or generate scenario models. The COM is configured by a comparatively user-friendly “shell” of standardized, text-based input tables that shield the analyst from the minutiae of the underlying tactical programming language (TPL) (see Chapter Four, “Design”). This allows programmers and nonprogrammers to collaborate directly in scenario development.

A similar approach to output gives the analyst multiple, adjustable perspectives from which to measure outcomes. Operating on the “more is better” principle, the COM implements custom routines to generate a large amount of data for each agent involved in the simulation. The primary output is a minute-by-minute account of each agent’s changing operational picture.[4] Most commonly, this logging is used to analyze the performance of a small number of platforms and their associated sensors. In addition to various platform-state data, the COM

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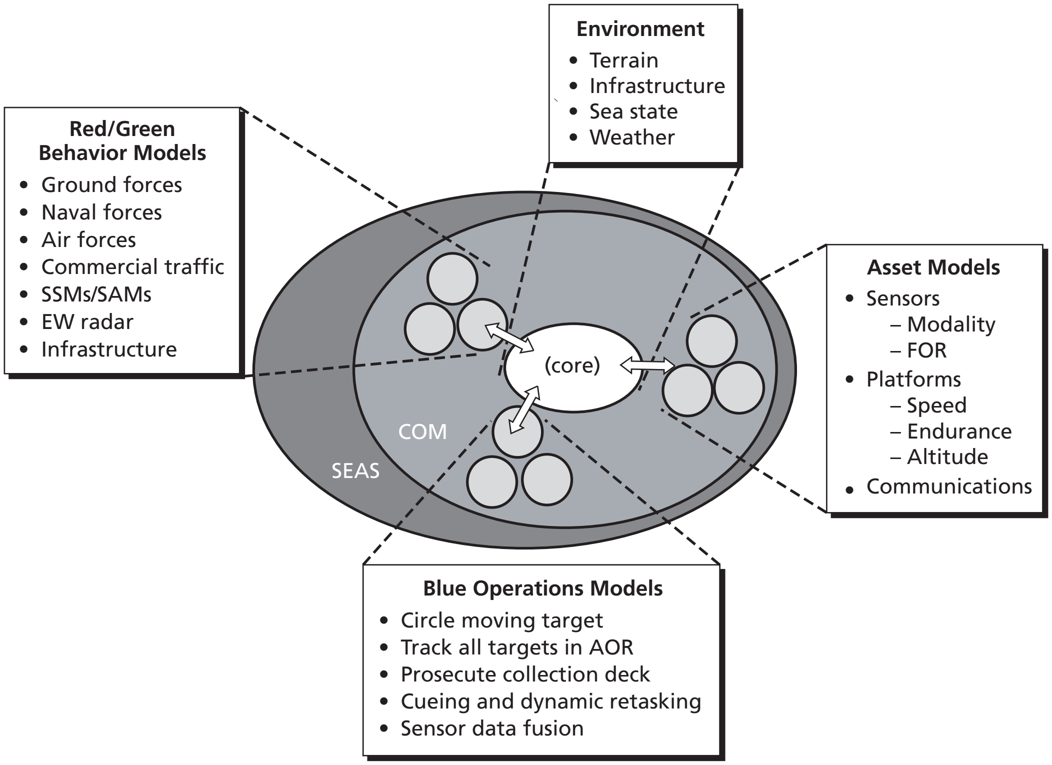
[1] Without wading into the debate over the best definition of an agent, for the present purpose we define an agent as a construct that makes its own choices based on its own perceptions. An agent has autonomy.

[2] In this report, “behaviors” are individual scripts, programs, instructions, or decision rules that describe what actions an *individual* agent may take under specified conditions. These are distinguished from more-generic “processes,” which comprise the actions and individual behaviors of *multiple* agents.

[3] Lockheed Martin recently demonstrated a single controller for multiple UAVs and UGSs. See “Lockheed Martin Completes UAV Tests,” *Avionics Magazine*, February 27, 2007.

[4] The default time step is one minute, but the duration can be set by the analyst. The output, like the input, takes the form of a series of text files.

Figure 2.1
Modular Design of the COM Within SEAS



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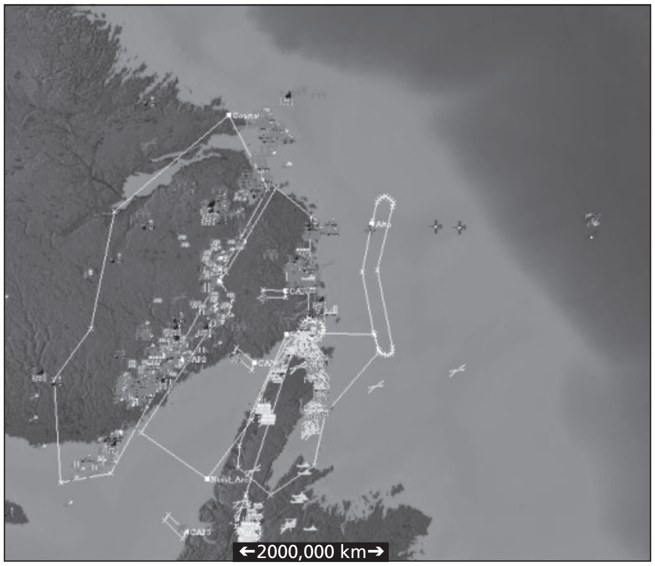
records information about each potential sensor contact, the result of that sensor contact, and the sensor performance data that led to that result. For instance, an emitter may technically be within field of view of a receiver, but the contact could be excluded because of lack of LOS, electromagnetic interference, or insufficient receiver sensitivity in the relevant bandwidth. This information is crucial to determining the drivers of sensor performance, and it allows analysts to make more-informed decisions. In addition to the output files produced by the COM, the SEAS environment provides graphical output during runtime so the analyst can watch the scenario unfold. A representative screenshot is shown in Figure 2.2.

Within the COM framework, platforms are characterized by their operational capabilities (e.g., speed, endurance, and altitude), by the capabilities and resources of the sensors they own (see Chapter 3, "Sensor Capabilities"), and by their properties as targets (e.g., size, visibility, and emission frequency).[5] Several environmental effects are also represented in the COM, including terrain LOS, sea state, and wind direction. Roads and other infrastructure can be represented to refine maneuver, LOS, and sensor performance in urban operations. The COM offers growing libraries of platforms and sensors with different capabilities and characteristics; all are able to operate in the model's different environments.

---

[5] As platform-specific data are often classified, the COM is typically run in a classified environment. However, the COM can be run in an open environment with reduced libraries.

Figure 2.2
Representative Screenshot of SEAS Running the COM



RAND *TR557-2.2*

The model often incorporates several variants (or blocks) of each platform. The following platforms have been most extensively represented in the COM library to date:

- Assets—EP-3, Global Hawk, Joint Surveillance Target Attack Radar System (JSTARS), Predator, RC-135, SOF, and U2
- Targets—*dhow* (a fishing boat); various types of early warning (EW) radar; ground vehicles (e.g., the high mobility multipurpose wheeled vehicle [HMMWV]); various types of infrastructure; large or small merchant vessels; various types of maritime patrol craft; Surface-to-Surface Missile, Surface-to-Air Missile, and Coastal Defense Cruise Missile Transporter Erector launchers; submarines; and supertankers.

The sensor library incorporates many different sensor modalities, including electro-optical (EO), infrared (IR), synthetic aperture radar (SAR), inverse synthetic aperture radar (ISAR), ground moving target indicator (GMTI), maritime moving target indicator (MMTI), and signals intelligence (SIGINT) receivers. Each modality has its own functional model within COM.[6] Sensor "packages" are also available to model platforms that bear complex payloads (i.e., suites of sensors with shared resource limits). Table 2.1 lists specific sensors and sensor packages that are represented in the COM library. Generic sensors are also available to represent visual contact.

The true strength of the COM as an analysis tool, however, lies not in its existing libraries of platforms or sensors but in its ability to model *behaviors*. The COM has a library of individual agent behaviors that govern everything from operational maneuvers to tasking, processing, exploitation, and dissemination, and each agent can run multiple behaviors simultaneously.

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[6] There is currently no air moving target indicator model (AMTI) in the COM.

Behaviors are assigned to agents through the same shell used to configure other aspects of the COM. Table 2.2 lists and describes commonly used behaviors in the behavior library.

As an agent-based construct, the COM can model interactive behaviors that link the actions of agents to environmental conditions, the perceived activity of other agents, and commanders' orders. Examples of such behaviors that are already available in the behavior library are maintaining a surveillance orbit around a moving ship, attempting to provoke an enemy vessel by repeatedly approaching and retreating, and reorienting sensors in response to revised

Table 2.1
Sensor Representation in the COM Library

Sensor or Package	Modalities
Active Electronically Scanned Array[a]	ISAR/SAR/GMTI/MMTI
Enhanced Integrated Sensor Suite[a]	EO/IR/SAR/ISAR/GMTI/MMTI
Integrated Sensor Suite[a]	EO/IR/SAR/ISAR/GMTI/MMTI
Multi-Platform Radar Technology Insertion Program[a]	SAR/ISAR/GMTI/MMTI
LR-100	SIGINT
Airborne Signals Intelligence Payload	SIGINT
Military Very High Frequency	SIGINT
U2 Sensor Suite	EO/IR/SAR

[a] Representation also includes potential maritime modes (ISAR, MMTI) as shown.

Table 2.2
Commonly Used Behaviors in the COM Library

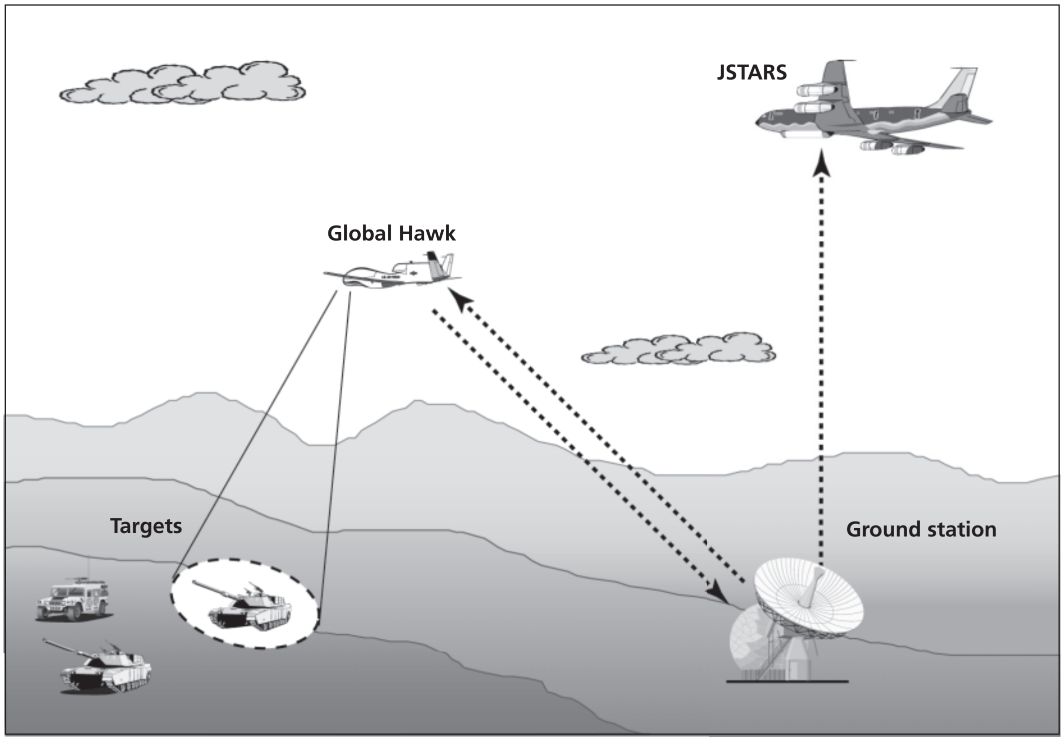
Behavior	Description
Banked orbit	Fly a specified path, banking in turns
Brownian	Move on a random path within allowed areas only
Circle	Fly a shifting orbit to track a moving target
Collection deck	Prosecute a preplanned collection deck
Collection heap	Prosecute a heap of targets, visiting the nearest first
Exciter ops	Provoke an enemy by alternately approaching and retreating
EW cycle	Conduct EW radar installation sweeps according to a pattern
IMINT	Estimate NIIRS values of imagery
LOS filter	Determine target LOS and filter targets accordingly
Sail	Sail an approximate sea path, avoiding islands
SIGINT	Evaluate emitter-receiver pair for detection
SITREP	Report sightings to ground station
SSM TEL cycle	Move, hold, and hide in a set pattern
Stack	Prosecute targets in an ad hoc stack, visiting the newest first
Tasking	Add targets to the ad hoc stack of an available ISR asset

tasking orders. Support for complex behaviors is essential to modeling C3ISR processes that involve multiple agents.

To understand how an analyst might use the COM to examine a C3ISR process, consider the following notional vignette: A Global Hawk flies a scheduled ISR orbit as part of a major combat operation, while a JSTARS platform waits ready at base (see Figure 2.3). The analyst first draws upon the existing libraries of platforms and sensors to populate the scenario with a Global Hawk, JSTARS, ground station, and selected enemy targets. These agents are deployed to the appropriate initial locations in accordance with the scenario. Next, the analyst assigns behaviors to each agent: The Global Hawk is assigned an orbit, a preplanned collection deck, a stack for ad hoc collections, and instructions to send sightings to the ground station. The ground station is assigned behaviors to receive and process the sightings from the Global Hawk, instructions to watch for specified high-value targets, and protocols to add these targets to the Global Hawk's ad hoc collection stack. Selected enemy targets are assigned behaviors specific to their class; for example, transporter erector launchers are told to occasionally move and hide, and maritime patrol craft are instructed to commence mine-laying operations. Finally, the analyst establishes the environmental conditions and runs SEAS to set the entire scenario in motion.

Although it involves relatively few players, this vignette requires coordination and decisionmaking based on the flow of information among several interacting players. The UAV sends its imagery to the ground control station, where the data are processed and a number of potentially high-priority targets are flagged as requiring further identification. The operator cues the Global Hawk to revisit several of the targets, but he must be selective about these

Figure 2.3
Cueing and Tasking Vignette



RAND *TR557-2.3*

new visits because (1) there are limited ad hoc collection slots available to revisit each target and (2) some targets may require sensor modalities for identification that are not available on the Global Hawk platform. Therefore, the operator passes this information to the commander, who may decide to task JSTARS to prosecute the remaining targets.

It is difficult to imagine how an equation-based simulation could provide insights into such collection operations. With an agent-based simulation, however, in which each agent makes choices based on available information, we can investigate many aspects of collection operations, including the quality, currency, and completeness of both local situational awareness and the emerging common operating picture (COP);[7] the strategic trade-off between maximizing planned collections and reserving space for ad hoc collections; the relative merits of centralized versus decentralized data fusion locations; and the effects of communications and processing delays on the ability of a networked force to prosecute time-sensitive targets.

As collection operations become increasingly network-centric, it will be necessary to incorporate more-sophisticated behaviors into the model. As the COM is extended and enhanced (see Chapter Five, "Future Work"), it will better represent the entire C3ISR process specifically and network-centric operations in general.

---

[7] In this context, "quality" measures how well the target was recognized: Was it specifically identified, classified only by type, or simply detected? "Completeness" measures how many targets were detected as a percentage of those actually present. "Currency" measures how recently the sightings on the COP have been updated. The COP supports additional similar measurements.

CHAPTER THREE

Sensor Capabilities

Signals Intelligence

SIGINT is the COM's most sophisticated individual sensor model.[1] Many aspects of emitters and receivers are represented: field of regard (FOR), including main and side lobes where appropriate; scan cycle, emission interval, or emission probability; frequency bands; relative angular size of main and side lobes (for directional signals); and the effective radiated power of each radiative lobe.

With these parameters and the specific sensor-target geometry, the model calculates the probability of detection for each per scan cycle. Depending on the sensor-target pair, the result can be interpreted as either a detection or classification. DTED data for LOS visibility is also used here where appropriate. The COM's related communications intelligence (COMINT) exploitation model, which involves further processing, may result in target identification.[2]

Electro-Optical, Infrared, and Synthetic Aperture Radar

EO, IR, and SAR sensors are modeled using the National Imagery Interpretability Rating Scale (NIIRS).[3] For each specific sensor an empirical formula yields an estimated NIIRS value that is based on distance and calculated in accordance with appropriate cutoffs for grazing angles. (The model currently supports quadratic and logarithmic expressions. When available, system NIIRS-versus-range curves are preferred. Civilian and military tables give threshold NIIRS requirements for detection, classification, and identification for a wide variety of fixed and mobile targets; the COM allows the analyst to map these target types to enemy assets with equivalent characteristics.

DTED data are also used to determine if LOS exists between the sensor and the target; if it does not, the sighting is discarded accordingly. Night, day, and cloud cover conditions can be specified. Platforms may also hide to avoid EO or IR detection, and platforms with greater than a certain minimum velocity cannot be detected by SAR.

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[1] ISAR and MMTI calculations are also complicated, but because they require numerical integration, they are compiled outside of the SEAS modeling environment.

[2] COMINT modeling details are classified.

[3] See L. A. Maver, C. D. Erdman, and K. Riehl, "Imagery Interpretability Rating Scales," *Society for Information Displays 95 Digest*, 1995, pp. 117–220.

Inverse Synthetic Aperture Radar and Maritime Moving Target Indicator

ISAR, a maritime radar mode, performs classification of large ships on the ocean surface. The ability to detect objects on the ocean is a function of wind direction, sea state, and radar performance parameters (e.g., the power aperture product). These variables determine a minimum radar cross section (RCS) that the radar can detect or classify or both. Potential targets are rated by RCS, and ISAR sensors are parameterized by both the minimum RCS required for detection and certain forms of classification (e.g., ship length, whether the vessel is military or civilian). MMTI tracking is maintained through repeated radar contact. This is an acceptable approximation in environments of low traffic density or of higher but more ordered traffic density (such as in shipping lanes), where the risk of confusion among vessels is minimal.

Ground Moving Target Indicator

GMTI models are inherently complex. The COM's current GMTI model does not incorporate a tracking algorithm per se, but instead uses resource allocation estimates to identify the percentage of available sensor resources required to track a given target.[4] This process resembles the way that GMTI platforms (such as JSTARS) manage their sensor resources. Required resources are determined by the required revisit rate, which is a function of the size of the target, weather conditions, and local traffic or "clutter." Platforms with less than a certain minimum velocity cannot be tracked. The model assumes that the GMTI sensor will maintain track on as many targets as possible, applying a limit that is based on prioritized intelligence requirements only when resources would be exceeded. Sector-by-sector accounting of sensor resource allocation (see Figure 3.1) allows the COM to adjust required GMTI revisit rates according to local traffic conditions.

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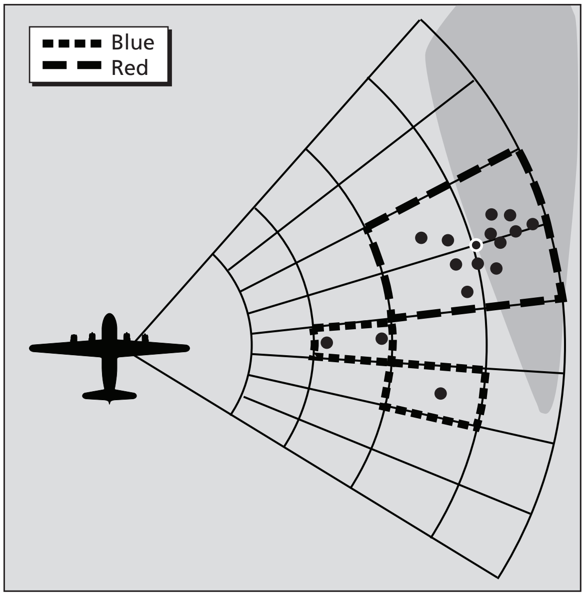
[4] Tracking is accomplished via offboard processing of GMTI sensor data, not by the GMTI sensors themselves

Figure 3.1
GMTI Sectorized Representation



RAND *TR557-3.1*

CHAPTER FOUR

Design

The COM is written in TPL for version 3.7 of the SEAS modeling environment. SEAS is a multiagent, theater operations simulation environment sponsored by the Air Force Space Command, Space and Missile Systems Center, Directorate of Developmental Planning. SEAS has matured for over a decade and is now part of the Air Force Standard Analysis Toolkit and the Air Force Space Command Modeling and Simulation Toolkit.

One feature that makes SEAS such a strong modeling environment is flexibility. The analyst, starting with a nearly blank page, can design agents with almost any parameters (e.g., maximum speed, fuel capacity), as well as any desired sensors, communications devices, and weapons.[1] SEAS also offers useful built-in functionality: The code natively handles Earth's spherical geometry, thereby simplifying a number of remote-sensing calculations. Earth's rough geography is also preloaded into the model.[2] One limitation of SEAS is that it runs in fixed time steps; another is that can run only on the Microsoft Windows operating system.[3]

In several ways, the COM represents a significant advance in the use of agent-based technologies in closed-loop military simulations. First, the COM uses simple, text-based tables to provide all scenario-specific data. Because most sensor and platform properties are no longer preprogrammed or hidden under layers of code, their effective ranges (minimum and maximum), multiple FOR sectors, spot mode field-of-view properties, minimum grazing angles, and new modality-specific properties (i.e., NIIRS curves for EO, IR, and SAR sensors, RCS curves for ISAR and MMTI sensors, etc.) are all freely configurable and clearly visible to the analyst. Moreover, isolating the data from the code in this manner means that the majority of the model can be tested and developed in an unclassified computing environment.[4] An excerpt from a sample sensor property configuration input file is shown in Table 4.1.

The second advance is that the COM's core code treats all agents equally, regardless of alignment (i.e., to Red or Blue forces), size, or echelon, and uses a comprehensive shell of text-based input tables to manage all behaviors interchangeably. To build a scenario, the analyst first selects required platforms, sensors, and communications devices from their respective

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[1] The COM does not currently represent weapons.

[2] The analyst must provide the terrain features. The COM contains routines that incorporate the results of DTED analysis.

[3] The next generation of SEAS, version 4.0, may be rewritten in a cross-platform language (e.g., Java). RAND is also developing the hardware and software capability to parallelize SEAS across a dedicated computing cluster (see Gonzales et al., 2007).

[4] Only when the model's algorithms themselves are classified must the modules be developed on classified systems.

Table 4.1
Excerpt from a Sensor FOR Configuration File

Sensor Name	Elevation Angle Minimum (degrees)	Elevation Angle Maximum (degrees)	Azimuth Angle Minimum (degrees)	Azimuth Angle Maximum (degrees)
'GlobalHawk_EO'	-90	0	30	150
'GlobalHawk_EO'	-90	0	210	330
'GlobalHawk_IR'	-85	5	30	150
'GlobalHawk_IR'	-85	5	210	330
'GlobalHawk_ASIP'	-30	-10	0	360

NOTES: Multiple entries define disjointed sectors of the FOR of the same sensor. Figures are notional only. In actual input text files, fields are tab delimited.

libraries.[5] These are arranged to form the basic hierarchy of agents (and other devices) available to each force.[6] After this skeleton is complete, the analyst uses the shell to define everything else: the allocation of resources, the environmental factors that affect area-based effects, and the behaviors of agents. This allows the user to endow any agent with any set of capabilities, and to assign multiple simultaneous behaviors as needed to any number of agents. In this way, the same core code may be used to generate vastly different scenarios or vignettes in a straightforward manner.

An sample behavior assignment file is shown in Table 4.2. The associated parameter files (presented in the third column) typically consist of a list of numbers, key words, location names, or geographic coordinates. The COM is intended to establish the larger framework quickly, allowing the analyst to concentrate on fine-tuning these parameter files for each instantiation. This multitiered, modular approach to scenario modeling is unique in the SEAS community.

The third is advance is that the behaviors defined in the COM are modular and prioritized, and the core code acts as a wrapper and intermediary that exchanges data as needed between different modules. Using existing behaviors as a template, a competent but nonexpert programmer with only a working knowledge of TPL can now design new and complex behaviors—even interactive behaviors—for an agent without fear of generating an internal programming conflict. Furthermore, once added to the library, the behavior will automatically be available for assignment to any agent in any scenario.

Finally, the COM does not rely on preexisting output routines or proprietary file formats, but rather uses configurable text output. Depending on user choices, a single "run" of a scenario may generate gigabytes of text describing the activity and situational awareness of every agent. An accompanying Visual Basic script written for Microsoft Excel parses the output data to generate graphs, tables, and other statistics as desired.

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[5] In practice, the analyst often adds new platforms or sensors to the library as well. Unlike other SEAS models, however, the COM captures and saves these additions; this is how its library grows.

[6] At present this occurs manually: Small blocks of text are copied and pasted to build up the skeletal files. Although automating this process (through a Perl script, for example) would not be especially difficult, the process is simple enough that automation has been considered unnecessary. The shell has been designed to mediate more-complex user input to the COM.

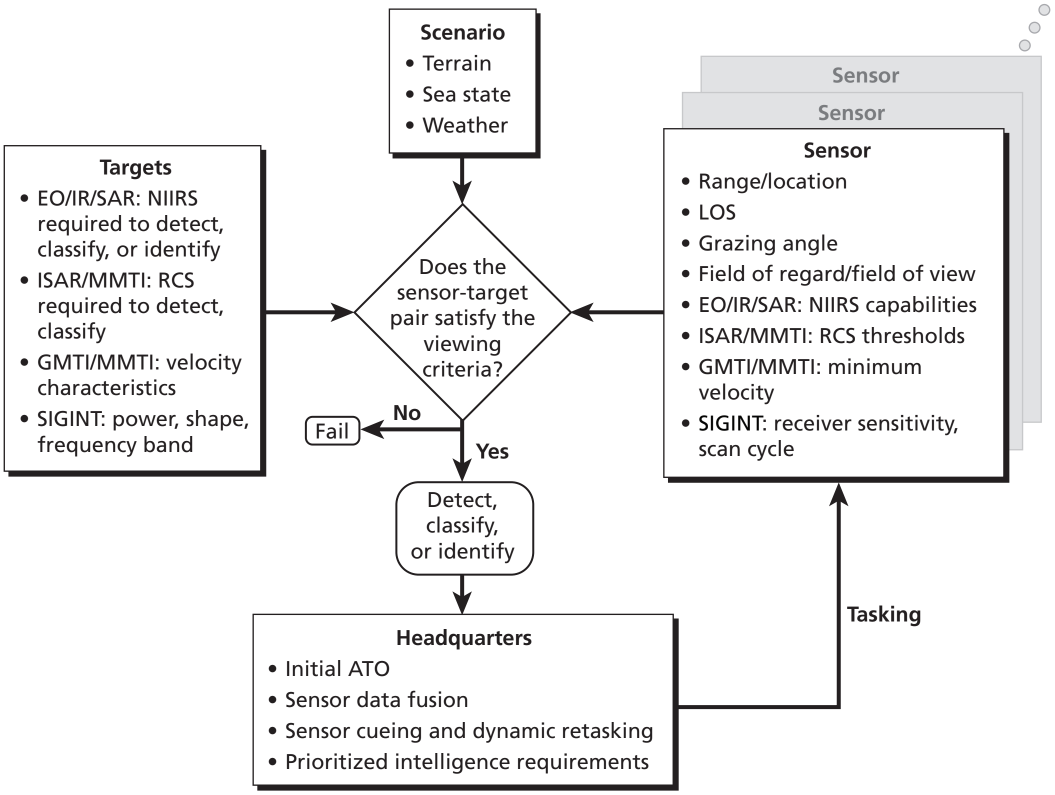
Table 4.2
Excerpt from Sample Behaviors Assignment File

Platform Name	Behavior	Parameter File	Start	Duration	Priority
'Blue.AF.GlobalHawk#1'	'orbit'	'tango.txt'	30	320	1
'Blue.AF.GlobalHawk#1'	'sitrep'	'to_dcgs.txt'	30	320	3
'Blue.AF.GlobalHawk#1'	'imint'	0	30	320	2
'Blue.AF.GlobalHawk#2'	'orbit'	'tangoNW.txt'	60	665	1
'Blue.AF.GlobalHawk#2'	'sigint'	0	60	665	2
'Blue.AF.GlobalHawk#2'	'sitrep'	'to_dcgs.txt'	60	665	3
'Blue.Navy.Fleet#1'	'patrol'	'guam3.txt'	5	1220	1
'Red.Navy.Ship#1'	'mine'	'routeXN.txt'	5	1440	1
'Red.Navy.Ship#2'	'travel'	'routeXN.txt'	5	1445	1

NOTE: In actual input text files, fields are tab-delimited.

The COM is designed to structure and facilitate the process of scenario modeling within the SEAS environment to enable the analyst to tackle more-complex modeling problems in a systematic way. For instance, the COM can represent agent-to-agent interactions that lead to feedback loops; these loops can generate nonlinear outcomes—which the model can accommodate—for C3ISR processes. One such feedback loop currently represented in the COM is dynamic retasking. As depicted in Figure 4.1, a sensor-target pair is evaluated within the context of the scenario to determine whether, if the target is sighted, the contact is sufficient to detect, classify, or identify the target. Based on the result, the commander consults a (user-provided) table of prioritized intelligence requirements and retasks available assets as appropriate. Onboard sensors can also be programmed to self-cue.

Figure 4.1
Dynamic Retasking Loop



RAND *TR557-4.1*

CHAPTER FIVE

Future Work

Several new additions and improvements to the COM are under way. The area-based effects modules have been enhanced to give scenario builders more options for incorporating terrain effects. The collection, processing, and dissemination functions are being separated more clearly to make it easier to add new sensor modalities (e.g., an AMTI). In addition to these important structural improvements, five major new capabilities are under development.

Space-Based Assets

For fiscal year 2008, RAND has invested in the extension of the COM to include space-based asset capabilities. All sensor modalities represented thus far in the COM will be represented for notional space-based assets. Representations of onboard processes for satellites will also be added, as well as anticipated interactions with ground stations. Finally, atmospheric and space weather effects will be incorporated into the sensor models as required.

Fusion

The relative value of collection strategies may, in many cases, depend on available fusion capabilities and concepts of operations. For lower levels of fusion that involve the statistical association and correlation of observations, we plan to adapt an earlier RAND implementation of a highly simplified Kalman filter in the SEAS modeling environment.[1]

Higher levels of fusion require recognition of larger formations, estimation of enemy activity and intent, and the fusion of multiple sources of intelligence; there is currently no consensus in the defense community regarding how—or even if—these processes can be automated. Instead of modeling higher fusion cases directly, we plan instead to simulate the *effects* or *utility* of sensor data fusion of specified quality at specified levels. Estimating the utility of possessing fusion capabilities is a more tractable problem, and RAND has investigated this approach to modeling higher-level fusion in general terms and through implementation in the SEAS modeling environment.[2] We will leverage these previous efforts.

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[1] These fusion algorithms (see R. E. Kalman, "A New Approach to Linear Filtering and Prediction Problems," *Transaction of ASME—Journal of Basic Engineering*, 1960, pp. 35–45) have been adapted for SEAS in an allied model. Information about this allied model is classified.

[2] The existing implementation involves "knowledge matrices." A general discussion of this approach can be found in Christopher G. Pernin, Louis Moore, and Katherine Comanor, *The Knowledge Matrix Approach to Intelligence Fusion*, unpublished RAND Corporation research, 2005.

Communications

We are currently upgrading the COM's communications modules to represent more accurately the advantages of a networked force. Averages of communications delays will be replaced with sampled distributions, which often have short medians but long tails. Bandwidth constraints will be applied to all aspects of explicit and implicit communications processes, thus allowing the analyst to consider less-obvious trade-offs (such as the possibility that overabundant streaming video imagery from one asset may inhibit the ability of a remote operator to rapidly retask another asset). Finally, indirect message routing will be implemented to allow analysts to consider the effects of jamming and loss-of-node on the communications network.

Workflow Representation

Command and control processes take time. By disaggregating the command centers within the model, we will extend the COM to include a realistic representation of workflow within the air operations center and the deployable ground station. This will enable the COM to model other C3ISR processes and to more accurately model processes that involve many intelligence analysts (such as sensor data fusion and COMINT). It will also enable the COM to incorporate the effects of tasking, exploitation, and processing delays in a more thorough manner.

Misinformation and Deception

Misinformation and deception will not be incorporated into a single module, but rather will constitute an additional dimension that will be added to many parts of the COM. Currently, the COM can model poor or missing information: Sensors can offer degraded reports or fail to detect a target entirely, and an enemy can hide to avoid detection. However, we plan to make the model capable of allowing (1) sensors to generate spurious reports (i.e., false positives) on their own and (2) agents to deliberately induce such reports (i.e., deception).[3]

The ability to represent bad information is critical to simulating adaptive enemies, modeling sensor data fusion processes, and measuring the quality of the COP. In a larger, linked simulation, the effects of such misinformation can also snowball. For example, a platform tasked to prosecute a phantom target may, as an opportunity cost, deprive the commander of crucial information on real targets. Adding this capability opens up another realm of modeling possibilities.

With these forthcoming additions, the COM will be able to model increasingly sophisticated C3ISR processes that span all three intelligence domains: physical, information, and cognitive. Each addition is another step on the path toward the ultimate goal of creating a modeling framework that can represent the entire C3ISR process specifically and network-centric operations in general.

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[3] These are just two of many possible deception processes. Many more are described in a healthy body of literature. For example, see Scott Gerwehr and Russell W. Glenn, *Unweaving the Web: Deception and Adaptation in Future Urban Operations*, Santa Monica, Calif.: RAND Corporation, MR-1495-A, 2002.

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