2006-06

Model-Based Organization Analysis and Design for an ESG Organization

Candra Meirina

Model-Based Organization Analysis and Design for an ESG Organization

Student Submission

(Modeling and Simulation)

Candra Meirina[1,*]
E-mail: meirina@engr.uconn.edu
Feili Yu[1,*]
E-mail: yu02001@engr.uconn.edu

Krishna R. Pattipati[1, 2]
[1]University of Connecticut, Dept. of Electrical and Computer Engineering
371 Fairfield Road, Unit 1157
Storrs, CT 06269-1157
Fax: 860-486-5585
Phone: 860-486-2890
E-mail: krishna@engr.uconn.edu

David L. Kleinman
C4I Academic Group
Naval Post-graduate School
589 Dyer Road, Monterey, CA 93943
Fax: 831-656-3679
Phone: 831-656-4148
E-mail: dlkleinm@nps.navy.mil

[1]This work has been supported by the Office of Naval Research under Contract N00014-00-1-010

[2]Correspondence: krishna@engr.uconn.edu
*Student

Model-Based Organization Analysis and Design for an ESG Organization

Candra Meirina, Feili Yu, Krishna R. Pattipati, and David L. Kleinman

A. Introduction

A.1. Problem Domain and Proposed Methodology

The concept of Expeditionary Strike Groups (ESGs) arose to satisfy the requirements of global war on terrorism (GWOT), when it was realized that surface warfare capabilities were needed to complement the capability of the Amphibious Ready Groups (ARGs) [Levchuk et al., 2003]. The addition of cruiser (CG), destroyer (DDG), frigate (FFG), and submarine (SSN) assets to those of an ARG, which include an amphibious assault ship (LHA or LHD) with a Marine expeditionary unit (MEU), a dock landing ship (LSD) and an amphibious transport dock ship (LPD) provide the ESG with a highly mobile, self-sustaining force, capable of conducting expeditionary warfare operations to support a full range of theater contingencies from humanitarian and disaster relief to combat operations. This addition also provides the capability for an ESG to deploy independently, as well as a part of a larger joint force. See Fig. 1 for a typical command and control (C^2) structure of an ESG.

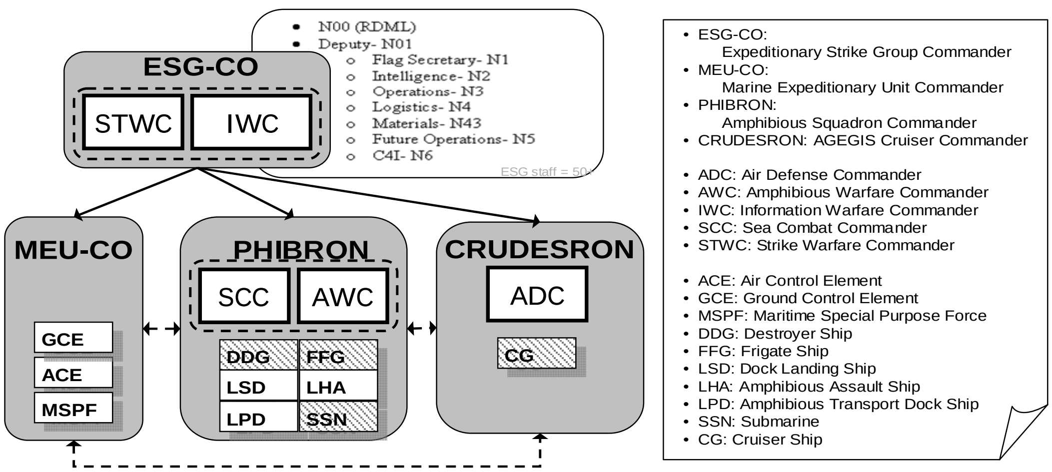


Fig. 1: Command and Control Structure of an ESG

The primary goal for the introduction of ESG organizational concept is to find suitable ways to integrate the Navy and Marine forces. These include exploring evolving non-traditional C^2 structures, and developing the corresponding new capabilities (including introduction of new offensive and defensive weaponry). The merger between the two forces and the resulting C^2 philosophy has to take into account various operational and cultural issues. Some representative examples include: deciding on how to blend ARG/MEU and Composite Warfare Commander (CWC) organizations in a way that enhances combat capabilities, but leaves the ARG/MEU relationship intact; determining the degree of dependency between ARG/MEU and Amphibious Squadron; establishing when and how they depend on each other, as well as how they collaborate and resolve conflicts; to name a few.

In this paper, we propose systematic, but somewhat simplified, analysis of an ESG organization that allows us to abstract the mission environment, and to glean various organizational issues of interest via a model-based organizational analysis framework. The heart of the proposed framework is the utilization of an agent-based simulation to capture key organizational processes, and identify strengths and potential limitations of an organization. Based on the assessment, a set of recommendations are put forth to mitigate the potential limitations. This approach is an extension of our model-based organizational design and analysis framework, wherein an organization and its mission environment are abstracted in terms of three modeling components: decision-makers (DMs – C^2 nodes), assets, and tasks [Levchuk et. al., 2002a-b and 2004]. The proposed method introduces several novel ideas, which include: 1) a means to realistically represent the diversity of threats and operating environments via an extended Distributed

Dynamic Decision-making (DDD) simulator [Kleinman et al., 1996]; 2) incorporation of a rich model of DMs' local authority, responsibility, and priorities, as well as patterns of the DM-DM interactions via an agent framework to account for uncertainty in the organizational processes; 3) modeling a task as a sequence of probabilistic activities, which depend not only on the dynamics of the environment, but also on actions taken by the organization to further account for the uncertainty in the mission environment and organizational processes; and 4) performance measures to assess the agility of our organizational design, and to suggest improvements by manipulating various aspects of the environment as well as coordination processes.

The ESG performance measures include *effectiveness* and *accuracy* (e.g., mission completion time, task completion percentage, and balance of workload and coordination load), and *efficiency* (e.g., task processing throughput and average task latency). A series of sensitivity analyses are then conducted with respect to C^2 factors (e.g., local authority, responsibilities, and priorities); availability, allocation, and utilization of assets; level of load, level of difficulty, area of coverage, and spectrum of missions; and coordination (e.g., supporting-supported relationships between Navy and Marines).

A.2. ESG Structure

An ESG organization, which satisfies the first goal of suitably blending the ARG/MEU (Amphibious doctrine) and Amphibious Squadron (CWC doctrine), places the Amphibious Squadron Commander (PHIBRON) – the first C^2 node – to fill the dual roles of an Amphibious Warfare Commander (AWC) and a Sea Combat Commander (SCC) (see Fig. 1). This structure puts the Commander of the AEGIS Cruiser (CG-CO/CRUDESRON) – the second C^2 node – to assume his traditional role as an Air Defense Commander (ADC), and the MEU commander (MEU-CO) – the third C^2 node – to assume the role of a Principal Warfare Commander.

How does one resolve resource and task assignment conflicts in this structure? There exist two distinct options to direct the coordination relationships among the C^2 nodes: the East Coast and West Coast models [Pierce, 2004]. The former places the command in the hands of a Navy captain, who is in a coequal supporting/supported (S-S) relationship with his MEU counterpart – a colonel. The latter introduces a separate ESG Commander (ESG-CO) node under a rear admiral. An obvious shortfall of the East Coast model is its inability to become a Joint Task Force (JTF), since the O-6 (captain/colonel) S-S relationship lacks the means to adequately resolve conflicts between the coequal commanders. A case in point is when the conflict arises over the deployment of scarce resources critically needed by both parties. This type of situation necessitates a single on-scene commander, who can make the decision for them; i.e., a Navy flag or a Marine general officer, who can command a JTF or be a JTF enabler. This leads to the introduction of an ESG-CO node with the authority to direct coordination relationships among the aforementioned C^2 nodes when necessary, while still facilitating the S-S relationships at the lower level of the hierarchy.

The ESG-CO defines mission priorities and controls unique resources that are needed to support common operations among the various command elements. Consequently, the ESG-CO needs information from the subordinate commanders to be able to plan in advance, to reserve resources, and to align the overall objectives of the mission with those of the subordinates. In addition, the ESG-CO assumes the dual roles of the Strike Warfare Commander (STWC) and Information Warfare Commander (IWC). See Fig. 1. It should be noted here that each of the decision-making nodes represents not only the commander, but also the supporting staff.

In order to successfully execute a wide range of missions, the ESG C^2 structure assumes a hybrid (adaptable and heterarchical) form. The fixed and dynamic (changing) C^2 relationships are denoted as the straight and dashed lines in Fig. 1, respectively. The dynamic C^2 relationships stem from the S-S structure within the ESG, wherein the commanding C^2 nodes (supported) and the supporting (commanded) roles are interchangeable, and are typically task-dependent. By having this flexible form, the ESG can adapt to various mission environments, and achieve the benefits of both a hierarchy and a heterarchy. That is, like a hierarchy, the hybrid structure has the benefits of reduced complexity and control; and similar to a heterarchy, it is more flexible, fault-tolerant, and allows the C^2 nodes to have a greater degree of autonomy in their operations.

A.3. ESG Analysis

How does the ESG structure perform in a variety of missions? In our model-based organization framework, we assess the advantages and shortcomings of the ESG structure in an agent-based simulation. The organizational analyses are conducted based on a set of potential issues identified by the subject matter experts (SME, e.g., key ESG personnel), observations during ESG training, review of available briefings, CWC and Amphibious doctrines and study reports, extensive collections of open source ESG information (e.g., various ESG web sites) [Kemple et al., 2005].

The following are highlights of areas of concern identified. One area of concern is the Amphibious Squadron Commander (PHIBRON). The potential issues here include high expected workload on the C^2 node, especially in Maritime Interdiction or Maritime Security Operations (MIO/MSO), the presence of dual doctrines (Amphibious and CWC), and the high expected external coordination with other C^2 nodes. The second area of concern is the hybrid Supporting-Supported (S-S) structure and internal control. The S-S relationship is somewhat vague, but provides a very flexible command structure, that allows dynamic collaboration among C^2 nodes. The potential issues include when to adopt S-S relationships, how to determine these relationships (static or dynamic), how to handle conflicts (e.g., supporting multiple concurrent missions), and determining when such relationship break down (e.g., under high workload and dispersed forces).

A.4. Organization of the paper

This paper is organized as follows. First, we present the problem domain, the organizational structure, and the methodology to conduct the organizational analysis. The latter includes the normative models of mission, organization, and teamwork that form the basis of our computational multi-agent framework. Next, we present details of the simulation scenarios, and discuss the performance measures utilized to assess the organization. Finally, we present the results of the simulations and discuss the findings. The paper concludes with a summary of results and future directions for research.

B. Model-Based Organizational Analysis and Design

B.1. System Overview

The model-based organizational design and analysis framework combines the normative design approach with an agent-based simulation and analysis; see Fig. 2. This combined method provides a realistic framework to discern the strong functional dependencies between the mission environment and the organization, and evaluate organizational agility.

Different from our previous model-based organizational studies [Levchuk et. al., 2002a-b and 2004], we propose a method to analyze and suggest modifications to a functioning organization via an agent-based simulation framework. Simulation-based experimentation has a vital role in organizational assessment and adaptation, by providing an opportunity to explore new C^2 structures and C^2 processes.

Inherent in our proposed approach is a means to represent a non-discretized non-prescriptive organizational adaptation that accounts for a greater spectrum of environmental uncertainty and organizational responses. The agent-based framework facilitates the representation of various organizational structures from full hierarchies to networks (heterarchies). By the same token, the framework allows for a variety of interaction patterns among the decision-makers from a completely centralized to a fully distributed control.

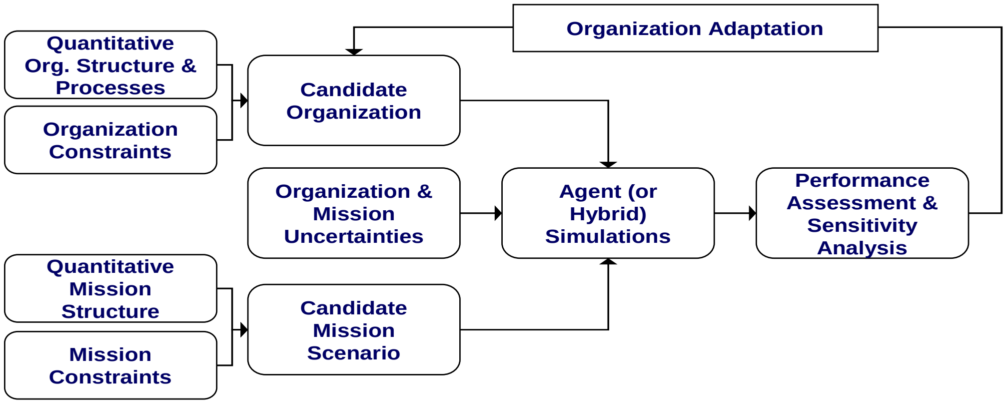


Fig. 2: Model-Based Organization Analysis and Design

B.2. Organizational Modeling

Organization and mission environment are abstracted in terms of assets, decision-makers (C^2 nodes), and tasks: organizational assets represent physical resources; C^2 nodes represent human components (commanders, operators); and tasks constitute the mission elements to be executed by C^2 nodes using organizational assets [Levchuk et al, 2002a-b]. The C^2 organization is characterized as a collection of C^2 nodes and assets connected via command, control, communication, and task-asset-DM structure; e.g., Fig. 1. C^2 nodes are entities with information-processing, decision-making, and operational capabilities that can control the necessary assets (with resource capabilities) to execute mission tasks, provided that such an execution does not violate their capability thresholds. C^2 node can represent a single commander, liaison officer, system operator, or a command cell with its staff. Assets are controllable and/or movable units/resources of the organization, which can represent individual weapons or weapon systems (e.g., planes, helicopters, tanks, mortars, etc.), sensors (e.g., radars), human teams at any granularity level (team, squad, platoon, etc.), etc. Attributes defining the assets include resource capability, velocity, maneuver constraints, attack range, identification range, kill range, etc. Assets provide a means for the organization to process (execute) tasks by matching their resource capabilities with the tasks' resource requirements. The roles and responsibilities of the C^2 nodes and the resource capabilities characterize possible operational and tactical policies of the organization: decisions they can make and actions they can perform.

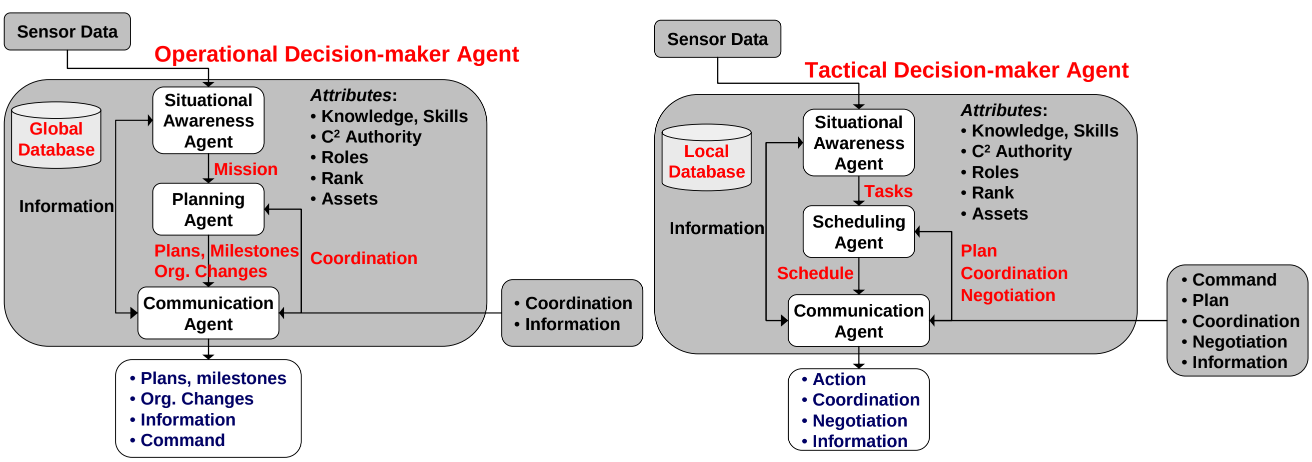


Fig. 3.a: Distributed Dynamic Agents (DDA) Architecture

Command structure, represented as a network with directed links, defines superior-subordinate relationships among C^2 nodes of the organization, thus specifying who can send commands to whom. See

Fig. 1 for an example. Communication structure is a network among the decision makers of the organization, that defines "who can talk to whom", the information flow in the C^2 organization, the communication resources that the decision-makers can use (communication channels), as well as the security of communications among the C^2 nodes. In the proposed ESG structure, each C^2 node can communicate with every other node. A control structure is an assignment of resources to C^2 nodes, and specifies which commanders can send tasking orders to which assets. See Fig. 1 for an illustration. The task-asset-DM structure is a network of assets and DMs, where each link corresponds to operations (tasks) jointly executed by the assets controlled by the concomitant DMs. The task-asset-DM structure defines the organizational plan; however, the actual evolution of this structure is typically dynamic due to changing coordination patterns and mission demands. An illustrative example of an instance within the task-asset-DM structure can be found in Fig. 7.

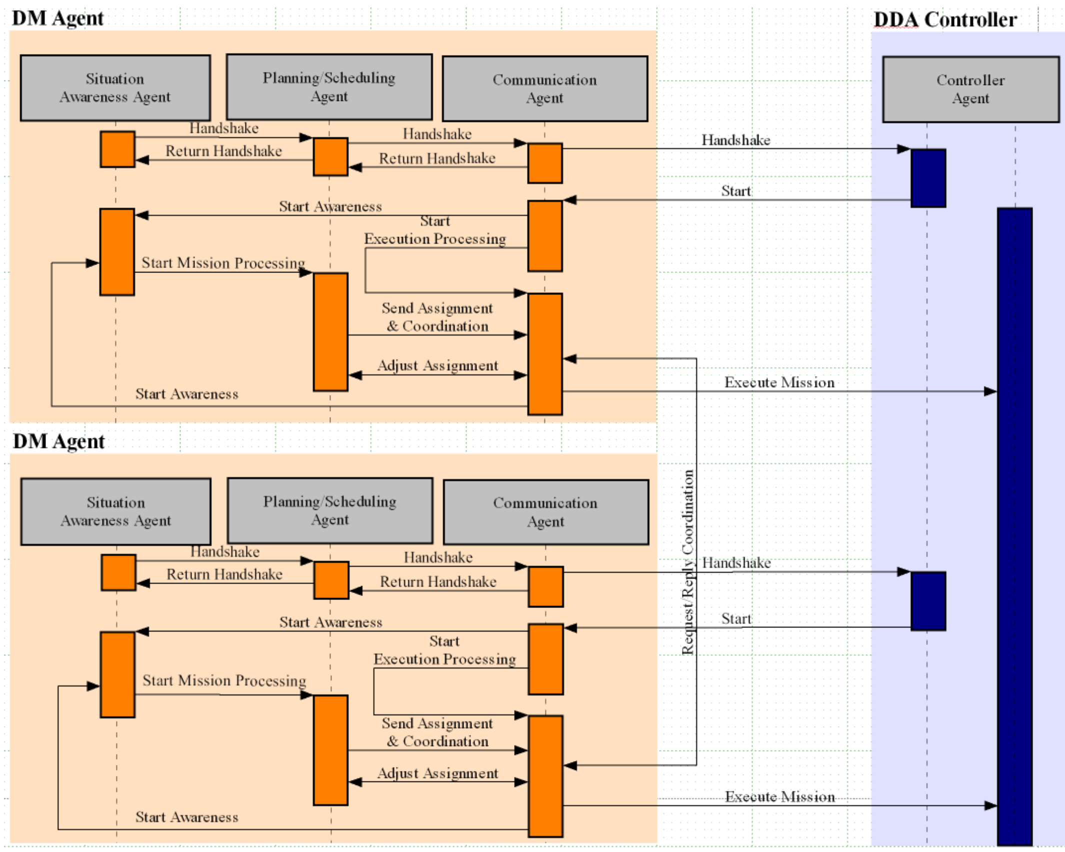


Fig. 3.b: Interaction Diagram of DDA Agents

The distributed decision-making agent (DDA) architecture adopts the hybrid agent model [Meirina et al., 2006], which combines the fast-paced reactive and the deliberative planning/adaptation elements. In particular, the DDA embraces the stimulus-hypothesis-option-response (SHOR) model [Wohl, 1981], which resembles very closely the well known belief-desire-intention (BDI) model [Bratman et al., 1988]. The reactive element of the DDA agent deals with mission processing, whereas the deliberative element handles the organizational redesign/adaptation. This framework is designed to fully realize the flexible command and control principles described earlier.

The DDA implementation utilizes the JADE agent platform [Chmiel et al., 2004]. Based on its C^2 role, the DDA considers two types of decision-maker (DM) agents: operational and tactical. The DDA represents each agent type by three sub-agents (modules); namely, (i) situation awareness (SA), (ii) planning (for an operational DM agent) or scheduling (for a tactical DM agent), and (iii) communication agents; see Fig. 3.a.

These three modules allow flexibility in the definition of roles, responsibilities, and relationships among C^2 nodes. The interconnection between the C^2 organization, the tasks, and the mission environment yield the simulated organizational activities. The functioning of each sub-agent is consistent with the SHOR-BDI models. The SA agent is responsible for managing the stimulus-hypothesis elements – the identification phase of task processing. The planning/scheduling agent handles the option element – the allocation phase. To do so, it incorporates knowledge, skills, abilities and other characteristics (KSAOs) of the C^2 node it represents. The communication agent manages the response – the prosecution and execution phases of task processing. The communication agent also facilitates coordination and control. The interactions among the sub-agent modules within a DM agent and between DM agents are shown in Fig. 3.b.

In order to represent the ESG organization of Fig. 1, the DDA agent framework utilizes an operational DM agent to represent the ESG-CO, and three instances of tactical DM agents to represent the subordinate C^2 nodes: PHIBRON, CRUDESRON, and MEU-CO. As noted above, each DM agent comprises of three sub-agents. The directed links, defining superior–subordinate relationships among C^2 nodes in the specific command structure, is managed by the communication sub-agent of each node. This sub-agent is also responsible for supervising the information flow in the organization according to the defined communication structure. The database in each C^2 node holds the assignment of resources to the node, according to the specifics of the control structure. As noted above, each node can only send direct tasking orders to its own assets. The planning/scheduling sub-agent shapes the task-asset-DM structure of the organization. This structure is influenced by the KSAOs of the C^2 nodes. In the simulated ESG organization, the C^2 nodes are designed to hold the same levels of knowledge, skills, and abilities to manage their resources (i.e., process the tasks). Each node is also defined by its local goals in the sense that each node will ensure that its own task responsibility is addressed first before coordinating with others. This characteristic will play a significant role in shaping the organization's collaboration pattern, such as the S-S construct. This affects task processing, and ultimately the organizational performance.

It is noted above that the deliberative element of the DDA planning/scheduling manages the organizational redesign/adaptation. Organizational adaptation accounts for various environmental and organizational dynamics, ranging from local disturbances, such as asset unavailability and local uncertainties due to misaligned KSAOs, to broader disturbances, such as DM unavailability, and environment uncertainties due to mission shifts. The DDA adopts the contingency theory [Burton et al., 2002] that relates organizational performance with congruity between the mission and the organizational design.

B.3. Mission Scenario and Modeling

In order to model a mission environment, we first recognize that a mission is decomposable into a set of tasks (objects). In our model, a task represents a sequence of probabilistic activities, which depend not only on the dynamics of the environment, but also on the actions taken by the organization. Each task processing activity entails the use of relevant assets, and is carried out by an individual or a group of C^2 nodes to accomplish the mission objectives. Every task in itself represents a small mission, and can often be further decomposed into more elementary tasks. For each task, we characterize its attributes, location, appearance time, duration, and deadline; and for each task-type (i.e., a task with a set of specific attribute values), we define its resource requirements to process it.

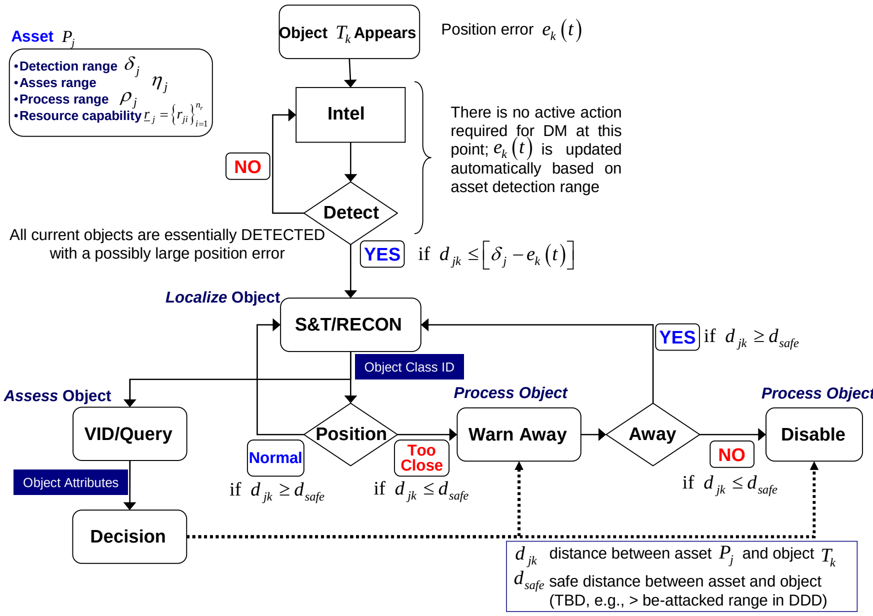


Fig. 4: Rules of Engagement of an MSO/MIO-related Task

In order to illustrate the model-based organization analysis of the ESG organization, we consider two missions, viz., the Maritime Security Operations (MSO) and Maritime Interdiction Operations (MIO), which are particularly relevant to GWOT operations. An MSO/MIO mission aims at protecting specific sea lanes from terrorists, smugglers and pirates. In order to achieve this goal, it requires persistent Intelligence Surveillance and Tracking (ISR&T), heavy patrols, ship boardings, as well as a means to warn away or disable potential threats. Consider the following hypothetical scenario, which illustrates the range of MSO/MIO-related tasks conducted by the ESG. The ESG is tasked to assist in protecting the oil platforms and high-value assets in the Northern Arabian Gulf. The mission is to warn ships away from oil platforms and to enforce sanctions on contraband goods. On a medium intensity (medium task-load) mission, the ESG conducts approximately 25 queries per day, and approximately 18 boardings per day (a combination of "compliant" and "non-compliant" boardings). Related tasks include: conducting surveillance operations, dealing with pirates who were harassing small boats, and maintaining the air defense posture. The Air Control Element (ACE), comprised of six CH-46 helicopters (Marine assets), are used to conduct ISR in support of the mission. During this same time period, the ESG personnel are involved, on a daily basis, in conducting multiple Visit-Board-Survey-Seizure (VBSS) of local shipping traffic to intercept illegal goods.

ID	Resources
1	AW – Air Warfare
2	USW – Under Sea Warfare
3	SUW – Surface Warfare
4	ASHORE – Intel Ashore
5	VID – Visual Identification
6	MINE-EOD – Mine Explosive Ordinance
7	MIO-INSPT – MIO Inspection
8	VBSS-HIGH – Visit Board Survey Seizure
9	VBSS-LOW – Visit Board Survey Seizure
10	ISR-G – Ground Intelligence Surveillance and Reconnaissance
11	ISR&T – Intelligence Surveillance and Tracking
12	CSAR – Combat Support Air
13	XPORT – Transport
14	MSO-DETER – MSO – Deterrence
15	GUARD
16	AMP-GSALT – Amphibious and Ground Assault
17	FIRES – Artillery Support
18	CAS – Close Air Support
19	AARM – Anti-Armor
20	STRK – Strike

Object Type	Description	Resource Requirements for Deterrence	Resource Requirements for Processing
S-000	Ship: small, compliant, no-contraband	MSO-DETER (h)	--
S-001	Ship: small, compliant, contraband	MSO-DETER (h)	VBSS-L (h), GUARD (l)
S-010	Ship: small, noncompliant, no-contraband	MSO-DETER (h)	MSO-DETER (l)
S-011	Ship: small, noncompliant, contraband	MSO-DETER (h)	SUW (l), VBSS-L (h), GUARD (h)
S-100	Ship: large, compliant, no-contraband	MSO-DETER (h)	--
S-101	Ship: large, compliant, contraband	MSO-DETER (h)	VBSS-H (h), GUARD (m)
S-110	Ship: large, noncompliant, no-contraband	MSO-DETER (h)	MSO-DETER (h)
S-111	Ship: large, noncompliant, contraband	MSO-DETER (h)	SUW (l), VBSS-H (h), GUARD (h)

Fig. 5: List of Resources and Resource Requirements for MSO/MIO-related Tasks

To model this mission in our enhanced DDD simulation environment, we define a hypothetical region of containment of radius 120 miles, wherein any approaching object must be tracked, checked (ISR&T, visually identified, or queried), warned-away, boarded, or disabled. During the course of a mission simulation, the objects' initial positions, attributes, and times of appearance are modeled as uniform random variables. The rules of engagement (ROE) for the MIO/MSO related tasks are described in Fig. 4. An object that appears within the containment region is initially assumed to be 'unknown' type, with unknown initial location, and attributes; this assumption leads to persistent intelligence, detection, and tracking. It is further assumed that the errors related to the estimated values of the type, location, and attributes of an object are proportional to the relative distance between the object and the ESG assets that track it. The ISR&T action determines whether an unknown object is an object of interest, i.e., a ship. The Visual Identification (VID) detects the attributes of the ship, whether it is small/large, compliant/non-compliant, carrying contraband/non-contraband. The ROE requires that any ship, regardless of its attributes, should be warned-away from ever approaching any ESG asset. Further actions, i.e., disabling, will be taken if the ship is not successfully deterred after the warning, or if its attributes indicate that the object poses a potential threat. Note that, for this particular example, all objects are designed not to run-away after warning (i.e., prompting disarming actions).

	Asset Name	Description	Maximum Velocity (mph)	Estimated Range	AW	USW	SUW	ASHORE	VID	MINE EOD	MIO Inspt	VBSS High	VBSS Low	ISR-G	ISR&T	CSAR	XPORT	MSO Deter	GUARD	Amp/G Aslt	Fires	CAS	Aarm	STRK
1	AV-8	Harriers, CAS	630		l		m		h		m			l	l				l			h		l
2	AH-1	Supressive Fire, Escort	160				m		l					l					m		h	m		
3	CH-46	Troop Carriers	160												l		h	m	h	h				
4	HARP	Harpoon A/S missiles	500	70 m			h																	
5	HH60	Armed Helo	160	4.5hr							m				h	h		m	m					
6	LCAC	air cushion craft	50								h	l	l				h	m	h					
7	LCU	landing craft utility	35														h	m	h					
8	MK-48	torpedo	30	9 m		h	h																	
9	MPA: P-3	Maritime patrol a/c, P-3	450	6hrs											h									
10	MSPF	maritime sp purpose force						h			h	h	m	m				l						
11	NSW	Navy Coastal Warfare						h			h	h	h	h				l						l
12	PC	patrol craft	30				m				h	m	m		m			h	h					
13	RHIB	Rigid Hull inflatable 7m	25	4hr							h	m	h		m									
14	SH-60B	LAMPS-III helo	160	4.5hr		h	h				m				h	m		m	h					
15	SM-1	short range missile	1500	25	h		m																	
16	SM-2	std missiles	2000	80	h		m																	
17	UH-1	utility helo, "jeep"	130						l							l	m		m					

Fig. 6.a: List of Resource Capability for MSO/MIO-related Assets

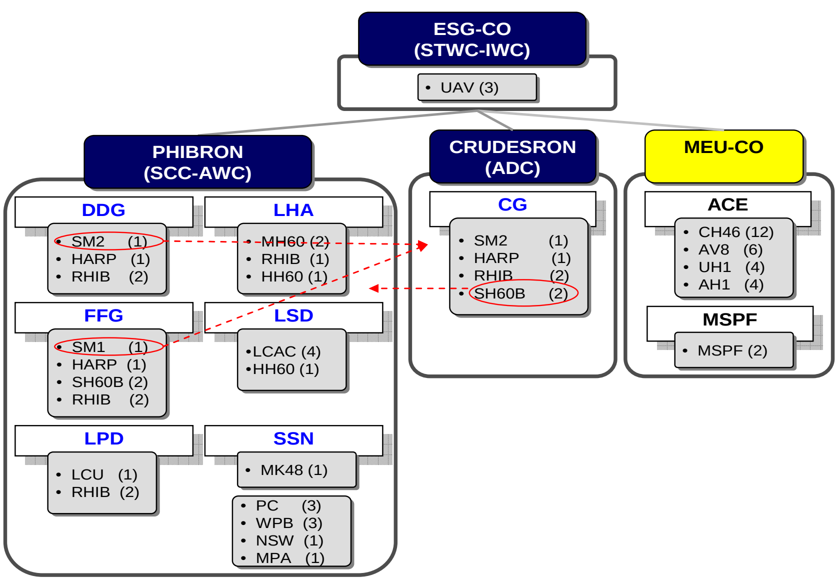


Fig. 6.b: Abridged Asset Ownership of the ESG

Based on the values of their attributes, the MIO/MSO related tasks are modeled as eight object types, which are listed in Fig. 5. The resources required in the processing of such tasks include: Surface Warfare (SUW), Visual Identification (VID), Visit-Board-Survey-Seizure (VBSS), Intelligence Surveillance and Tracking (ISR&T), MSO Deterrence (MSO-DETER), and GUARD. These resources are distributed among assets belonging to the available C^2 nodes: PHIBRON (SCC-AWC), CRUDESRON (ADC), MEU-CO, and ESG-CO (STWC-IWC). The resource capabilities of the MIO/MSO-related assets are listed in Fig. 6.a. The ownership of assets of the ESG, pertinent to only the MIO/MSO related tasks, is shown in Fig. 6.b.

C. Simulation and Analysis

In our analysis, we varied the *task-load* (in terms of the number of MIO/MSO contacts), *mission difficulty* (in terms of resource availability), and *Supporting-Supported relationships*. For the first controlled element, i.e., task-load, we hypothesize that there will be higher workload, especially for PHIBRON and MEU-CO, as the number of MIO/MSO contacts increases. This will eventually force the C^2 nodes to shed their task-load and alter the coordination patterns among nodes. Our intent here is to identify the organizational processing limits with respect to increases in task-load: low (20), medium (40), and high (60) per 48 hours (approximately 17.5 minutes of simulation time).

If the increase in the number of MIO/MSO contacts is coupled with a decrease in resource availability (operationalized by increasing the levels of mission difficulty), the organization will start to shed its tasks at higher rate. The effect on internal and external workload patterns among the C^2 nodes should also be more pronounced than previously observed in the first assessment. The second assessment is therefore conducted to identify the organizational processing limits with respect to increases in mission difficulty. The mission difficulty is also categorized into three levels: low (mixed tasks – all resources can participate in the disabling process), medium (high number of S-111 contacts – most resources can participate in the disabling process), and high (high number of S-110 contacts – only MSO-DETER resources can participate in the disabling process).

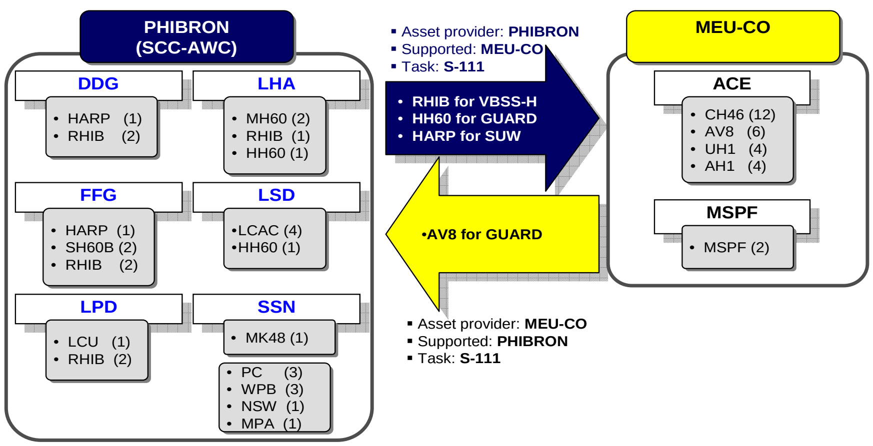


Fig. 7: Illustrative Example of Supporting-Supported Relationships in Task Processing

MIO/MSO mission differs significantly from other maritime duties that PHIBRON is accustomed to undertake. It requires different staff expertise and information utilization, as well as necessitates utilization of assets that are unique to these operations, such as the Visit-Board-Survey-Seizure (VBSS) tasks. Due to these demands, the MIO/MSO-related tasks necessitate high coordination among C^2 nodes, especially between PHIBRON and MEU-CO. Due to the existence of dual doctrines within the ESG organization, i.e., the CWC and Amphibious doctrines, the coordination between PHIBRON and MEU-CO is handled as supporting-supported (S-S) relationship (which is similar to the Amphibious doctrine and somewhat incongruent with the CWC doctrine where coordination is accomplished through apportionment and tasking). The third assessment is performed to identify the optimal rules to govern supporting-supported relationships, i.e., determining leadership assignment. In this case, the leadership rules are classified into three categories: Marine in supported role (i.e., Navy in supporting role), Navy in supported role, and dynamic leadership assignment (supported role is assigned to the largest asset contributor).

The S-S concept is better understood through an example. Take as an example the S-S lateral collaboration between PHIBRON and MEU-CO for disarming an S-111 task (a non-compliant ship carrying contraband). See Fig. 7. One possible case is positioning the PHIBRON (SCC-AWC) as the supported commander (when the leadership rule is Navy in the supported role or dynamic leadership assignment because PHIBRON is the largest asset provider). Here, the PHIBRON requests assets from resource provider, in this case the MEU-CO. If the MEU-CO can fulfill the request, the C^2 node provides the AV8-Harrier asset for GUARD. Another case is when the MEU-CO is in the supported role. In this role, MEU-CO can request assets from PHIBRON to conduct VBSS and provide GUARD and SUW (Surface Warfare) capabilities. Only if the PHIBRON is able to comply with the request does the MEU-CO get the necessary assets.

C.1. Performance Measures

The ESG performance measures include *effectiveness* and *accuracy* (e.g., mission completion time, completion percentage, completion accuracy, and balance of workload and coordination load), and *efficiency* (e.g., task processing throughput or average task latency).

The completion percentage denotes the ratio of the number of activities successfully processed to the activities required to be completed. This measure is a good indicator of processing capacity (limit).

$$\text{Overall Completion Percentage} = \frac{\sum_{k=1}^{n_K}\sum_{i=1}^{n_T}\sigma_{ik}}{n_T} \times 100\% \tag{1}$$

Here, n_K and n_T denote the number of activity types (i.e., ISR&T, VID, Deter, Disable) and the number of all activities, respectively; and

$$\sigma_{ik} = \begin{cases} 1, & \text{if activity } i \text{ of type } k \text{ has been completed} \\ 0, & \text{otherwise} \end{cases} \tag{2}$$

The overall task processing throughput, which is the ratio of the number of tasks processed to the mission completion time, indicates the rate at which the activities are accomplished by the ESG:

$$\text{Overall Processing Throughput} = \frac{\sum_{k=1}^{n_K}\sum_{i=1}^{n_T}\sigma_{ik}}{\max_i\left(0, s_i + t_i\right)} \tag{3}$$

The denominator of the above equation is the mission completion time, which indicates the speed with which the mission is completed. The variables s_i and t_i represent the start and processing times of activity i, respectively.

The internal workload of a C^2 node is equal to the number of assets belonging to the node that are actively utilized in task activities:

$$\text{Internal Workload of } C^2 \text{ Node } m = W_I\left(m\right) = \sum_{k=1}^{n_P}\sum_{i=1}^{n_T} x_{mk} y_{ki} \tag{4}$$

Here, n_P denote the number of assets; whereas

$$x_{mk} = \begin{cases} 1, & \text{if } C^2 \text{ node } m \text{ is the owner of asset } P_k \\ 0, & \text{otherwise} \end{cases} \tag{5}$$

and

$$y_{ki} = \begin{cases} 1, & \text{if asset } P_k \text{ is assigned to conduct activity } i \\ 0, & \text{otherwise} \end{cases} \quad (6)$$

The balance of internal workload of a C^2 node is expressed in terms of the percentage of its contribution:

$$\text{Percentage of Internal Workload Contribution of C}^2 \text{ Node } m = \frac{W_I(m)}{\sum_{n=1}^{n_D} W_I(n)} \times 100\% \quad (7)$$

where, n_D denotes the number of decision-makers.

Direct coordination between two C^2 nodes is defined as the number of activities simultaneously processed by these nodes. The external coordination of a C^2 node is the sum of its direct coordinations with other nodes:

$$\text{External Coordination of C}^2 \text{ Node } m = W_E(m) = \sum_{\substack{n=1 \\ n \neq m}}^{n_D} \sum_{i=1}^{n_T} \min(u_{mi}, u_{ni}) \quad (8)$$

where

$$u_{mi} = \begin{cases} 1, & \text{if C}^2 \text{ node } m \text{ is assigned to conduct activity } i \\ 0, & \text{otherwise} \end{cases} \quad (9)$$

The balance of external coordination load among C^2 nodes is expressed in terms of the percentage of the contribution of each node:

$$\text{Percentage of External Coordination Contribution of C}^2 \text{ Node } m = \frac{W_E(m)}{\sum_{n=1}^{n_D} W_E(n)} \times 100\% \quad (10)$$

C.2. Results and Discussion

The results on organizational processing limit with respect to three levels of task-load exhibit the following trends. From activity completion, throughput, and internal and external coordination workload plots in Figs. 7.a and c, it can be seen that, as the number of contacts increases, the organization starts to shed some of its tasks and the internal and external workload patterns begin to change.

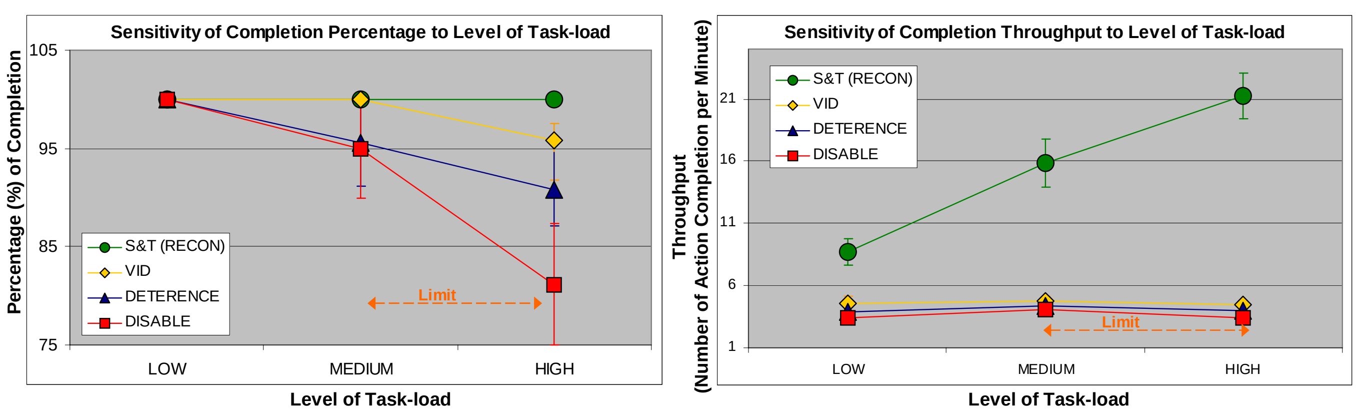


Fig. 7.a: Identifying Organizational Processing Limits due to Increases in the Level of Task-load

We utilize a one-sided hypothesis test of the standard Z-test to evaluate the statistical significance of the degradation in the completion percentage. Here, our null hypothesis H_0 claims that there is no difference between the values of the mean of the completion percentage for two levels of task-load, e.g., the low (μ) and medium (μ_0) task-load, so $H_0 : \mu = \mu_0$. The alternative hypothesis H_a claims that the mean of the completion percentage for the low task-load level is higher than that of the medium task-load level, so that $H_a : \mu > \mu_0$. We consider a significance level of $\alpha = 0.01$. Let us take, as an example, the cases of the low and medium task-load in deterrence activity. The mean completion percentage of the medium task-load is $\mu_0 = 95.6$ and the standard deviation is $\sigma_0 = 4.4$. Therefore, the Z-test statistic, given the mean completion percentage of the low task-load is $\mu = 100$ ($n = 5$), yields $P\text{-}value = 0.013 > 0.01$. The result indicates that the two levels of task-load yield the same mean values with 0.01 significance, i.e., the completion percentage at the low level of task-load is statistically the same as that at the medium level. The results of the Z-test for the completion percentage at various levels of task-load are presented in Fig. 7.b. The results indicate that the degradations in the completion percentage are statistically significant for VID, deterrence, and disarming activities with the increasing task-load. These, coupled with the throughput results, indicate that the organization reaches the processing limit at some point between the medium and high task-load.

	μ_0	σ_0	μ	n	*P-value*
S&T (RECON) - low and medium levels of task-load	100	0	100	5	-
S&T (RECON) - low and high levels of task-load	100	0	100	5	-
VID - low and medium levels of task-load	100	0	100	5	-
VID - low and high levels of task-load	95.8	1.7	100	5	1.65E-08
DETER - low and medium levels of task-load	95.6	4.4	100	5	1.27E-02
DETER - low and high levels of task-load	90.8	3.7	100	5	1.35E-08
DISABLE - low and medium levels of task-load	95	5	100	5	1.27E-02
DISABLE - low and high levels of task-load	81.2	6.2	100	5	1.47E-08

Fig. 7.b: Z-Test Results for the Completion Percentage at Various Levels of Task-load

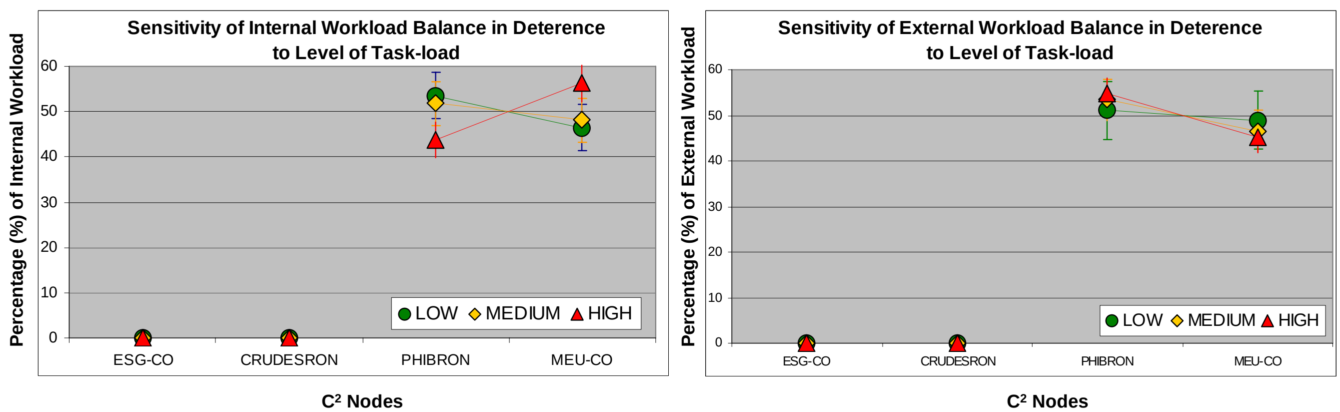


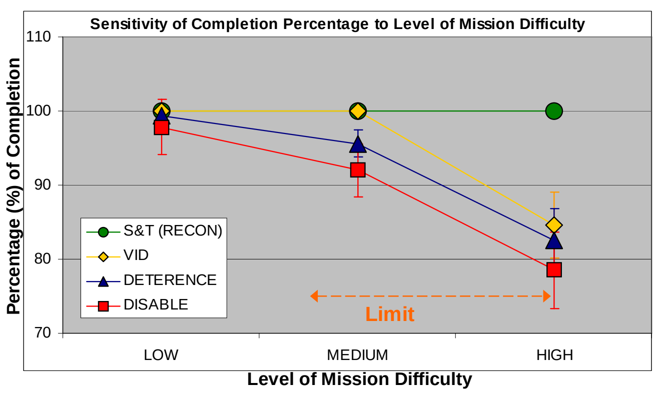
Fig. 7.c: Sensitivity of Internal and External Workload Balance with respect to Increases in Task-load

The shift in internal workload patterns can be observed in Fig. 7.c.i. The results indicate that at low and medium task-load, the workload pattern between PHIBRON and MEU-CO is higher on the PHIBRON side. However, as the task-load increases to high level, the internal workload balance reverses toward the opposite. Note that the Z-test indicates that the internal workload balance of the PHIBRON is higher at the low level (μ) than at high level (μ_0) of task load, i.e., $P\text{-}value = 7.19\text{E}-06 < 0.01$ for $H_0 : \mu = \mu_0$. By the same token, the internal workload balance of the MEU-CO is statistically higher at the high level (μ) of task load when compared to the low level (μ_0) of task load, i.e., $P\text{-}value = 2.94\text{E}-08 < 0.01$ for $H_0 : \mu = \mu_0$. This trend also indicates that, at the high level of task-load, PHIBRON's involvement in task execution decreases, i.e., suggesting that its processing limit has been reached.

The coordination patterns among the C^2 nodes can be observed in Fig. 7.c.ii. The results indicate that the PHIBRON maintains higher external workload values than the MEU-CO; the PHIBRON's external workload increases slightly, as the level of task-load increases from low to high level. The results strengthen the previous observation that, at a higher level of task-load, the PHIBRON is less able to complete the activity demand independently (has a higher external workload value than the MEU-CO) even at a lower internal workload value. Note that the results shown are from simulation runs with medium mission difficulty, and Marine (MEU-CO) fixed in supported role; other simulation runs exhibit similar patterns.

The results of the second assessment identify the organizational processing limits with respect to increases in the levels of mission difficulty (see Figs. 8.a and c). The results shown are from simulation runs with high level of task-load with dynamically assigned S-S leadership at three levels of mission difficulty. The results demonstrate that, as the number of MIO/MSO contacts increases and resource availability decreases, the organization starts to shed its activities at higher rate.

The results of the Z-test for the completion percentage at various levels of mission difficulty are presented in Fig. 8.b. The results indicate that the degradations in the completion percentage are statistically significant for VID, deterrence, and disarming activities with increasing mission difficulty.. These coupled with the throughput results in Fig. 8.a.ii indicate that the organization starts to reach its processing limit at the medium level of mission difficulty. This shows that, if the number of contacts of medium level difficulty or higher increases, the organization may have to be reinforced with additional resources.



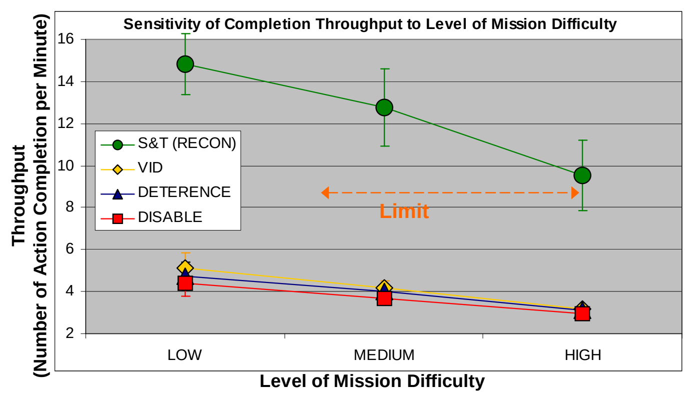


Fig. 8.a: Identifying Organizational Processing Limits due to Increase in the Level of Mission Difficulty

	μ_0	σ_0	μ	n	P-value
S&T (RECON) - low and medium levels of mission diificulty	100	0	100	5	-
S&T (RECON) - low and high levels of mission diificulty	100	0	100	5	-
VID - low and medium levels of mission diificulty	100	0	100	5	-
VID - low and high levels of mission diificulty	84.7	4.5	100	5	4.60E-04
DETER - low and medium levels of mission diificulty	95.6	1.8	99.3	5	2.15E-06
DETER - low and high levels of mission diificulty	82.6	4.3	99.3	5	4.94E-02
DISABLE - low and medium levels of mission diificulty	92	3.5	97.8	5	1.06E-04
DISABLE - low and high levels of mission diificulty	78.5	5.2	97.8	5	1.91E-04

Fig. 8.b: Z-Test Results for the Completion Percentage at Various Levels of Mission Difficulty

The results in Fig. 8.c.i indicate that at low and medium level of mission difficulty, the internal workload balance between PHIBRON and MEU-CO is higher on the MEU-CO side. However, as the level of mission difficulty increases to high, the workload balance shifts toward equilibrium. This trend indicates that, at this level of mission difficulty (and a high task-load level), not only the PHIBRON's contribution in task execution decreases, but also the MEU-CO's contribution decreases as well, i.e., it indicates that the processing limits of both nodes may have been reached. The results in Fig. 8.c.ii reinforce the earlier finding that, at a higher level of mission difficulty (and a high task-load level), the PHIBRON is less able to complete the activity demand independently (has a higher external workload than the MEU-CO).

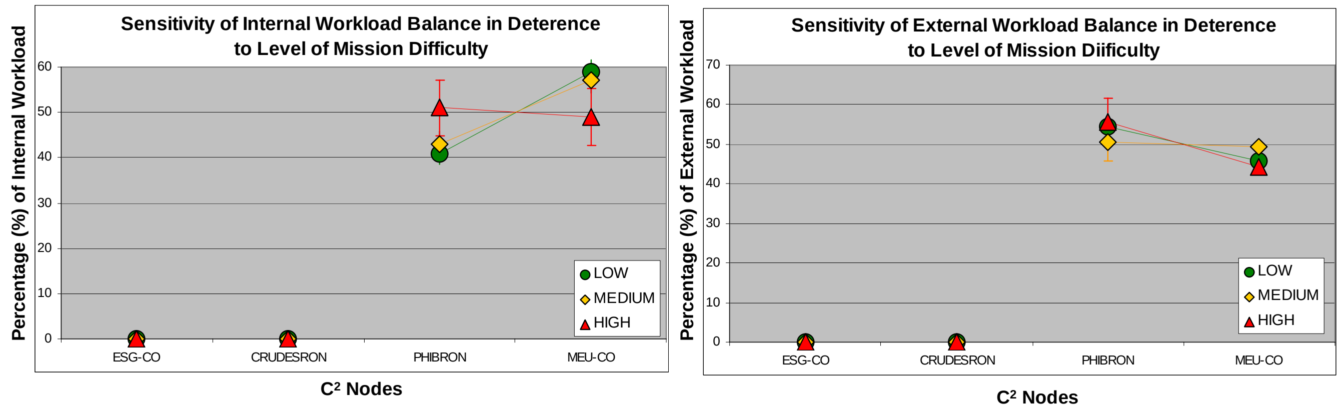


Fig. 8.b: Sensitivity of Internal and External Workload Balance with respect to Increase in the Level of Mission Difficulty

The third assessment was performed to identify the optimal leadership assignment in the S-S construct. The results in Fig. 9.a.i for medium-mission-difficulty (high number of S-111 contacts) in terms of completion percentage indicates that dynamic leadership assignment yields the best performance and that fixing the Marine in the supported role is a good alternative. The Z-test confirms that there is no statistical difference between assigning the S-S leadership dynamically (μ) and fixing the Marine in the supported role (μ_0), i.e., $P\text{-}value = 0.014 > 0.01$ for $H_0 : \mu = \mu_0$. The same test indicates that the dynamic leadership (μ) is better than fixing the Navy in the supported role (μ_0), i.e., $P\text{-}value = 5.35\text{E}-03 < 0.01$ for $H_0 : \mu = \mu_0$.

The same measure for high-mission-difficulty (high number of S-110 contacts), shown in Fig. 9.a.ii suggests that both dynamic leadership assignment and fixing the Navy in the supported role yield the best results. The Z-test shows that there is no statistical difference between the values of the mean of the completion percentage between assigning the S-S leadership dynamically (μ) and fixing the Navy in the lead role (μ_0), i.e., $P\text{-}value = 0.031 > 0.01$ for $H_0 : \mu = \mu_0$. By the same token, the mean of the completion percentage is statistically higher for the dynamic leadership (μ) than for fixing Marine in the lead role (μ_0), i.e., $P\text{-}value = 8.20\text{E}-03 < 0.01$ for $H_0 : \mu = \mu_0$.

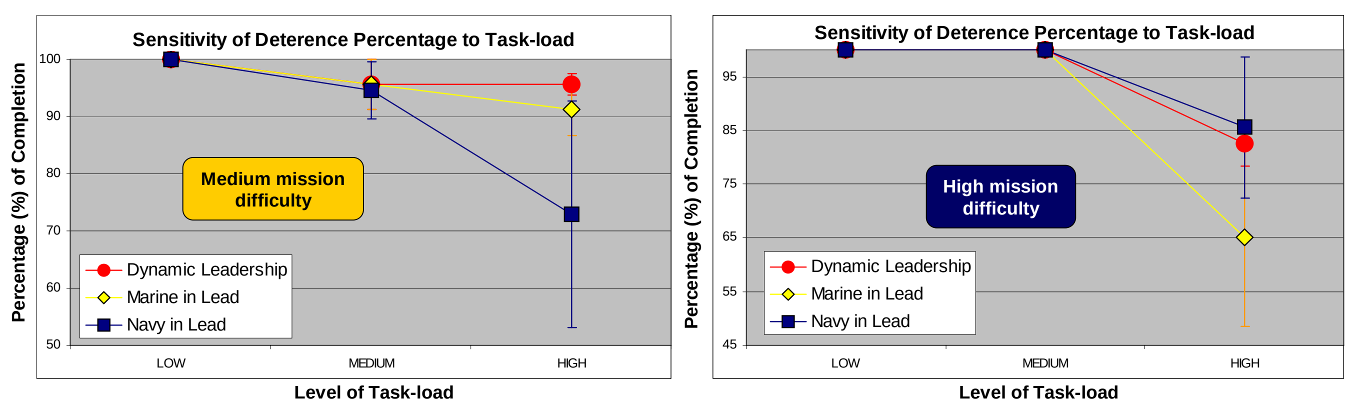


Fig. 9.a: Assessing Leadership Assignment – Rules to Govern Supporting-Supported Relationships

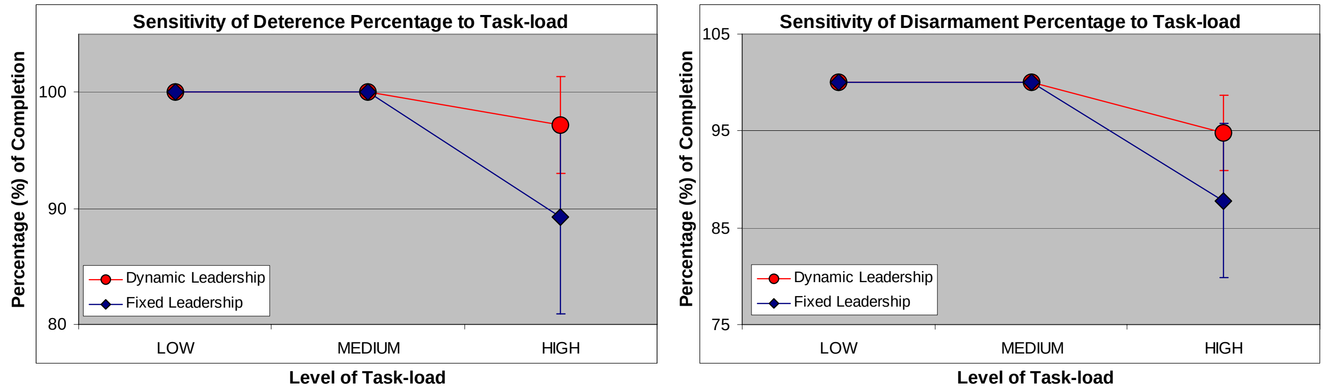


Fig. 9.b: Assessing Leadership Assignment – Rules to Govern Supporting-Supported Relationships

The above findings indicate that fixing the supported roles on a mission-by-mission basis may prove to be a good strategy to employ in assigning leadership role in the S-S construct. The results displayed in Fig. 9.b support the hypothesis. The results were collected from simulation runs with fixed mission-based leadership assignment, namely, Marine in the supported role for S-111-type mission (medium level of mission difficulty) and Navy in the supported role for S-110-type mission (high level of mission difficulty). The results show that there are virtually no discernable differences between the performance of dynamically assigned S-S leadership role and the mission-based leadership assignment. The Z-tests on both cases displayed in Fig. 9.c show that these leadership assignments yield statistically the same results.

Case	Level of Task-load	Leadership Assignment	μ_0	σ_0	μ	n	*P-value*
Deterrence activity for medium (S-111) level of mission difficulty	High	Dynamic and Marine in Lead	91.2	4.5	95.6	5	1.44E-02
		Dynamic and Navy in Lead	73	19.8	95.6	5	5.35E-03
Deterrence activity for high (S-110) level of mission difficulty	High	Dynamic and Marine in Lead	65	16.4	82.6	5	8.20E-03
		Dynamic and Navy in Lead	85.6	13.2	82.6	5	3.10E-01
Deterrence activity for mix (S-111 and S-110) level of mission difficulty	High	Dynamic and fixed	89.2	8.3	97.2	5	1.56E-02
Disarming activity for mix (S-111 and S-110) level of mission difficulty	High	Dynamic and fixed	87.8	8	94.8	5	2.52E-02

Fig. 9.c: Z-Test Results for Assessing Leadership Assignment

D. Conclusion and Future Work

In this paper, we propose a model-based organizational design and analysis framework to systematically assess an ESG organization. The somewhat simplified approach allows us to abstract the mission environment and to glean various organizational issues of interest. The heart of the proposed framework is the utilization of an agent-based simulation to capture key organizational processes, and identify strengths potential limitations of an organization. Based on the assessment, a set of recommendations for organizational changes are put forth to mitigate the potential limitations.

The first step in our model-based framework is to design an ESG structure, which addresses the goal of suitably blending the ARG/MEU and Amphibious Squadron. The proposed design structure puts the PHIBRON to assume the dual roles of an AWC and a SCC, the CRUDESRON to assume his traditional role as an ADC, and the MEU-CO to assume the role of a Principal Warfare Commander (see Fig. 1). In order to provide adequate means to resolve resource and task assignment conflicts in this structure, we introduce a superior to the existing three C^2 nodes, i.e., the ESG-CO. The ESG-CO node has the capability to direct coordination relationships among the sub-ordinate C^2 nodes when necessary, and permits S-S relationships when applicable. This ESG C^2 structure assumes a hybrid (adaptable and heterarchical) form that allows the ESG to adapt to various mission environments and achieves the benefits of both a hierarchy and a heterarchy.

The second step in the model-based organizational framework is to assess the performance of the ESG structure and identify the organizational strengths and shortcoming. We identify several areas of concern. The first concern is the PHIBRON. The potential issues here include high expected workload on the C^2 node, especially in MIO/MSO; the presence of dual doctrines (Amphibious and CWC); and the high expected external coordination with other C^2 nodes. The second area of concern is the hybrid S-S structure and internal control. The potential issues include when to adopt S-S relationships, how to determine these relationships (static or dynamic), how to handle conflicts, and determining when such relationship break down.

In order to address the concern in the PHIBRON node, we performed two sets of sensitivity analyses with respect to increases in the levels of task-load and mission difficulty. The results suggest that, as the number of contacts increases to a high level, the PHIBRON may have reached its processing limit and is less able to complete the activity demand independently. As the high level of task-load is coupled with the decreases in resource availability, the results indicate that both PHIBRON and theMEU-CO may reach their processing limits.

Several organizational improvements can be made to address the potential shortcomings in the PHIBRON node. On the resource allocation aspect, the remedy is to reinforce the organization with the necessary resources, as well as to provide better resource allocation; thus alleviating the internal workload imbalance and expanding the organizational processing capacity. Another approach is to increase the organizational capacity through re-organization, e.g., by stream-lining the coordination process. This can be accomplished by establishing self-contained MIO/MSO commanders and placing them as the sub-ordinates of PHIBRON along with other additional commanders (e.g., SCC).

The third sensitivity analysis was conducted to study the hybrid S-S structure and internal control. In particular, we address the question of static and dyanamic S-S relationships. The results indicate that fixing the supported roles on a mission-by-mission basis may prove to be a good strategy to employ in assigning leadership role in the S-S construct. The simulations show that there are virtually no discernable differences between the performance of a dynamically assigned S-S leadership role and that of a mission-based leadership assignment. The benefit stemming from utilizing the mission-based strategy is the comparative ease in personnel training and organizational planning.

References

[1]. M. E. Bratman, D. J. Israel, and M. E. Pollack. (1988) "Plans and Resource-bounded Practical Reasoning," *Computational Intelligence*, 4: 349-355.

[2]. R. M. Burton, J. Lauritsen, and B. Obel. (2002) "Return on Assets Loss from Situational and Contingency Misfits," *Management Science*, 48: 1461-1485.

[3]. K. Chmiel, D. Tomiaka, M. Gawineckia, P. Kaczmareka, M. Szymczaka, and M. Paprzyckia. (2004) "Testing the Efficiency of JADE Agent Platform," *Proceedings of the 3rd International Symposium on Parallel and Distributed Computing (IEEE Computer Society Press)*, Los Alamitos.

[4]. W. Kemple, D. L. Kleinman, et al. (2005) "ONR in Support of ESG-1 Top Ten Organizational Issues for the ESG: A Preliminary Qualitative Analysis," *ONR Internal Briefings*.

[5]. D. L. Kleinman, P. Young, and G. S. Higgins. (1996) "The DDD-III: A Tool for Empirical Research in Adaptive Organizations," *Proceedings of the 1996 Command and Control Research and Technology Symposium*.

[6]. G.M. Levchuk, Y.N. Levchuk, J. Luo, K.R. Pattipati, and D.L. Kleinman. (2002) "Normative Design of Organizations – Part I: Mission Planning," *IEEE Trans. on Systems, Man, and Cybernetics Part A* 32(3): 346-359.

[7]. G.M. Levchuk, Y.N. Levchuk, J. Luo, K.R. Pattipati, and D.L. Kleinman. (2002) "Normative Design of Organizations – Part II: Organizational Structures," *IEEE Trans. on Systems, Man, and Cybernetics Part A* 37(3): 360-375.

[8]. G. M. Levchuk, W. Kemple, and D. Serfaty. (2003) "Expeditionary Strike Group: Modeling Concepts and Design Directions," *White Paper*.

[9]. G.M. Levchuk, Y.N. Levchuk, C. Meirina, K.R. Pattipati, and D.L. Kleinman. (2004) "Normative Design of Project-based Organizations - Part III: Modeling Congruent, Robust and Adaptive Organizations," *IEEE Trans. on Systems, Man, and Cybernetics Part A* 34(3): 337-350.

[10]. C. Meirina, F. Yu, S. Ruan, L. Zhu, K. R. Pattipati, and D. L. Kleinman. (2004) "Agent-based Decision Support System for the Third Generation Distributed Dynamic Decision-making (DDD-III) Simulator," *Proc. 2004 Command and Control Research and Technology Symposium*.

[11]. C. Meirina, G.M. Levchuk, S. Ruan, K.R. Pattipati, and R.L. Popp. (2006) "Normative Framework and Computational Models for Simulating and Assessing Command and Control Processes", in print, *Simulation Modeling Practice and Theory, Special Issue on Simulating Organizational Processes*.

[12]. T. C. Pierce. (2004) "Expeditionary Strike Groups Are Misaligned," *USNI Proceeding Magazine* Vol. 130/5/1,215.

[13]. Joseph G. Wohl, (1981). "Force management decision requirements for Air Force tactical command and control," *IEEE Trans. on Systems, Man, and Cybernetics*, 11(9):618-6391.