Enablers of Self-Synchronization for Network-Centric Operations: Design of a Complex Command and Control Experiment

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Abstract

Modified human decision-making processes are required—in addition to new tactics and technology that are also currently under development—to enable Joint military forces to operate in a time span that is shorter than an adversary's. Self-synchronization is viewed as an essential process within military organizations that can increase speed of command and thus accelerate execution of the mission. This process of self-synchronization is described as the ability of a well-informed force to organize and synchronize complex warfare activities from the bottom up. The organizing principles are unity of effort, clearly articulated commander's intent, and carefully crafted rules of engagement. Self-synchronization is viewed as a mechanism to overcome the loss of combat power inherent in top-down, command-directed coordination that is characteristic of conventional command and control doctrine. The planning that took place to prepare for a complex, command and control, team-in-the-loop experiment, examining self-synchronization, is the focus for this paper. The objective of the experiment was to determine the conditions under which self-synchronization can most effectively be achieved. In particular, we discuss the activities that led to formulating the hypotheses for the the experiment, and the efforts that were needed to actually run the experiment. These efforts included conducting a pre-experiment seminar game, crafting the scenario, experimental design development, independent variable manipulation, data collection methods and instruments, and simulator software modification. Some initial results and lessons learned will also be discussed.

1. Background

Self-synchronization is viewed as an essential process within military organizations to increase speed of command and accelerate execution of the mission. Cebrowski and Garstka (1999) describe self-synchronization as, "the ability of a well-informed force to organize and synchronize complex warfare activities from the bottom up. The organizing principles are unity of effort, clearly articulated commander's intent, and carefully crafted rules of engagement." (p. 35) One enabler of self-synchronization is a high level of knowledge of one's own forces, enemy forces, and all appropriate elements of the operating environment. Self-synchronization is viewed as a mechanism to overcome the loss of combat power inherent in top-down, command directed

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coordination that is characteristic of conventional command and control (C2) doctrine. This new style of coordination offers the potential to convert combat from a step function to a high-speed continuum (Cebrowski and Garstka, 1999).

Novel concepts, technologies, and innovations—that parallel those that have already occurred in the business sector—are currently being examined for potential integration into today's military. The underlying concept is that advances in technology are leading to dramatic changes in how the military forces are organized, trained, and equipped for future operations. Developments in the private sector that allow businesses to dominate the market by developing and exploiting information superiority provide a model for changes that are underway in the military. These changes include our enhanced capability to sense and understand the battlespace and most important of all – our ability to command and control.

Networks that combine information gathering, command and execution are key to both business and military success. The navy is transitioning from its reliance on large ships to coordinated, multi-service networks that combine information gathering, command and control, and firepower. Synchronizing "from the bottom up" focuses on the emergent behavior from within the organization rather than what occurs in the boardroom or the flag staff offices. The term "network-centric operations" reflects this fundamental change in thinking in terms of notions involving such new ideas as self-synchronized versus command-synchronized forces.

1.1 Advanced Command and Control Study

The Naval Postgraduate School (NPS) Adaptive Architectures for Command and Control (A2C2[2]) research team, in partnership with the Chief of Naval Operations (CNO), Special Assistant for Strategic Planning, (N6C), SAIC, and Aptima, Inc., recently completed an experiment in support of CNO N6C's Advanced Command and Control (AC2) Study. The objective of the AC2 study is to investigate the nature of command and control as the US Navy evolves toward a network-centric concept of future maritime operations. The focus of the experiment was the conditions (or "enablers") that promote DMs' ability to self-synchronize their efforts. This concept of self-synchronization was examined within the context of a task force responding to time-critical strike and theater air-missile defense missions.

An innovative "hybrid" approach that combined concept development seminar games with an experiment process composed of integrated activities, tools, and methods that capitalize on the NPS A2C2 research team's capabilities, was used to support an area requiring investigation by OPNAV, N6C. A multi-disciplinary approach, including seminar games, models and simulations, interviews, surveys, and other knowledge capture method, matches these methodologies to the requirements of the AC2 study.

A precursor event, Concept Development Game 1 (CDG 1), occurred in December 2000, at NPS. This seminar-style concept development game was used as a data-gathering activity to derive hypotheses about how self-synchronization will occur within the organization. CDG 1 served as a link between N6C's overall objectives for the AC2 Study and the planning that was necessary for integrating formal experiments into the AC2 study process. CDG 1 was the first event in a two-stage "focus" process. The first stage in the focus process sought to identify and explore the characteristics, conditions, and factors that enable self-synchronization in a maritime force.

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[2] The A2C2 research program is an ONR-sponsored, multidisciplinary effort to: establish a body of knowledge in current and future joint command and control, and develop and test theories of adaptive architectures.

Among the characteristics identified as necessary for a future self-synchronizing force were *trust*, a *common relevant operational picture*, *clear commander's intent*, and *empowered actors* (Furrer, 2001). The second stage in the focus process was the conduct of the experiment.

The planning that took place to prepare for a complex, command and control, team-in-the-loop experiment, that occurred over a two-week period in February-March 2001, is the focus for this paper. In particular, we will discuss the activities and results that led to the research questions addressed in the experiment, and the efforts that were needed to prepare for conducting the experiment. These efforts included conducting the pre-experiment seminar game, design of the scenario, experimental design development, independent variable manipulation, data collection methods and instruments, and simulator software modification. In addition, we will discuss some preliminary findings and lessons learned.

1.2 Time-Critical Targets

A task force engaging in ongoing mission tasks must also process time-critical targets, and these targets, by definition, have compressed vulnerability windows and time-dependent values. Time Critical Strike (TCS) operations are conducted against targets that pose a "clear and present danger to friendly forces or are highly lucrative, fleeting targets of opportunity that require an immediate response" (Time Critical Strike Concept of Operations). Timing constraints inherent in TCS place additional emphasis on coordination and synchronization of these strikes with other theater operations. Network-centric operations provide the basic foundation required for a successful TCS mission to occur: (*i*) rapid information sharing, (*ii*) more timely development of situation awareness, (*iii*) more efficient use of available resources — all lending support to achieving faster decision cycles. A command and control system capable of rapidly synchronizing across the battlespace is critical to support performance of TCS missions. Emerging technologies contribute the essential infrastructure that provides the foundation for rapid sharing of information, however, the *human decision-making process* must also be accelerated by enabling self-synchronization to occur. In addition to new tactics and technology, modified human decision-making processes are required to enable Joint military forces to operate in a time span that is shorter than an adversary's.

Crafting the scenario included developing a realistic mix of TCS and Theater Air Missile Defense (TAMD) missions that must be sequenced, deconflicted, coordinated and synchronized with other ongoing operations. TCS missions include mobile rocket launchers, mobile high-threat surface-to-air missiles, tactical ballistic missiles and their launchers, long-range attack aircraft, weapons of mass destruction, mobile C2 equipment, or forces maneuvering in the open. TAMD missions include the prioritized protection of critical assets, friendly forces, and US interests from air and missile attack.

2. Enablers of Self-Synchronization

The basic idea of self-synchronization is to push decision-making authority down to the lowest level within the organization by relaxing the traditional hierarchical approach to command and control. In the concept development game seminar the potential attributes, enablers and inhibitors of self-synchronization were examined. One point that emerged from this discussion is that self-synchronization is not necessarily a new concept; instead, self-synchronization is *enhanced* by modern technology, enabling it to occur in a wider execution space. (Furrer, 2001). Game participants were selected to represent the spectrum of the US Navy command and control community of interest (comprising O-2 to O-6) and to provide expert judgment in response to research issues vital to the future of command and control. A brief discussion of what participants in the concept development seminar game indicated are the enablers of self-synchronization follows.

Trust was mentioned many times as an essential ingredient when DMs are required to make critical decisions in a distributed environment; mutual trust is essential. This means knowing that the other people in the organization will interpret things the same way and react the same way to a particular situation. Trust is reinforced when DMs share common training and culture, and by personal relationships that are developed among DMs. Senior leaders must trust and empower subordinates, while peers must trust one another to take the correct action within the framework of existing guidance. Another aspect of trust is that DMs must trust the information in the network, especially the sources of information used to develop shared situation awareness.

Possessing a common relevant operational picture means that everyone has access to the same information and this can enable a local on-site commander to make decisions because that person has all the information needed, whereas in the past, information was not shared by all the participants. *Commander's Intent* refers to an overarching set of goals that is necessary to ensure people are working with the same guidance. Commander's Intent, as well as other forms of guidance given, needs to be clearly written and commanders must also ensure that their subordinates have a clear, common understanding of this guidance. *Empowered actors* is another critical element necessary to create an environment that will promote self-synchronization.

A *Command Structure* that balances the flexibility of the network with the stability of the C2 hierarchy is viewed as important to commanders making informed, self-synchronized decisions. A command structure with reduced organizational friction, relational complexity, and reduced policy restrictions in both formal and informal communications paths will facilitate self-synchronized actions. *Building informal networks* for enhancing coordination is also viewed as an essential enabler of self-synchronization. For example seminar participants indicated they can often obtain information more easily through the "backdoor." *Shared culture and training* is achieved through training and similar experiences in how people react and interpret a given situation. If a force is going to self-synchronize it should share a common framework: rules of engagement, doctrine, Commander's Intent. These standard processes and procedures must be common across all fleets and between battle groups if units are expected to be able to "plug and play."

Th*e ability and authority to "adapt"* refers to the ability to shift from one command authority for one task to another command authority for another task depending on what is most relevant. We see what are referred to as "communities of interest" where a subset of people will come together to work on a particular problem and then go back to their original locations once the problem is taken care of. This can occur remotely through virtual organizations and through collaboration using network-based decision support and collaboration tools. This suggests that what is needed for a command and control structure is decentralization with built in coordination mechanisms. (For a discussion of this topic see Hocevar, 2000.)

2.1 Independent Variable Manipulation

The objective of the experiment was to determine the conditions under which self-synchronization can most effectively be achieved. Based on the outcome of the concept development game, briefly described above, and Cebrowski and Garstka's definition of self-synchronization, two variables were selected for manipulation: the *command focus* held by the team and the team's *mutual mental model*. These two independent variables were manipulated when participants responded to scenarios that included TCS and TAMD missions. Command focus was manipulated over two levels*: semi-traditional/functional,* where commanders were assigned both a warfare area responsibility as well as their individual platform roles resulting in functional command responsibilities distributed across the team, and *independent unit operations,* where commanders were assigned only platform roles. Mutual mental model was manipulated on two levels (high and low) and for purposes of this experiment included three dimensions: situation awareness, commander's intent, and rules of engagement (ROE). The high mutual mental model condition included issuance of periodic situation reports by the commander, detailed, clearly written and unambiguous commander's intent, and clear, specific ROE where guidelines were established for time-critical decision processes for each phase of the operation. Periodic situation reports were envisioned to help team members maintain a high level of situation awareness by focusing the team on the current tactical and operational priorities. These dimensions of mutual mental model correspond to Cebrowski and Garstka's description of the enablers of self-synchronization: a well-informed force, clear unambiguous guidance and carefully crafted rules of engagement.

2.1.1 Command Focus

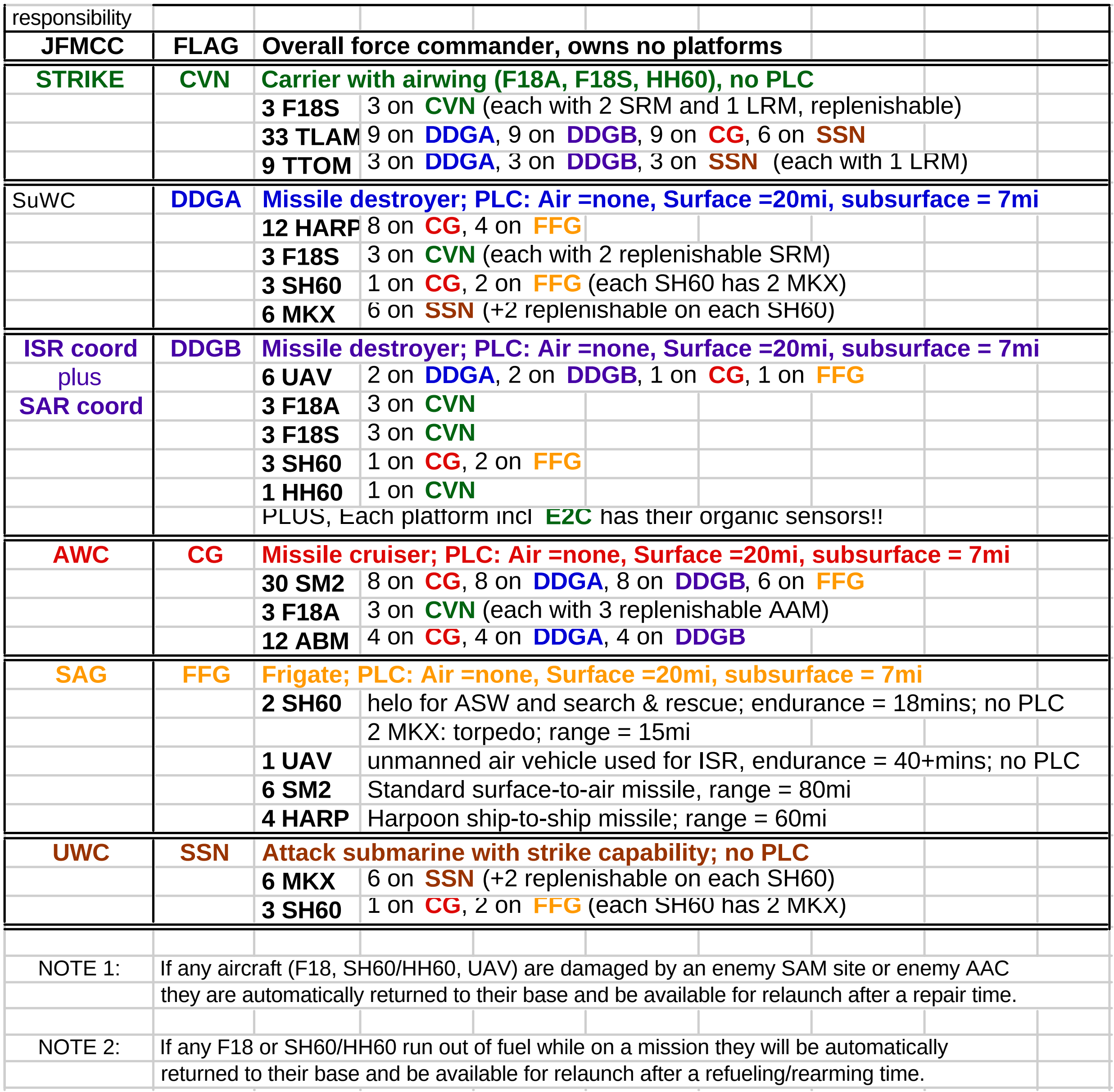
Six major platforms were included in the TSC/TAMD scenario: a carrier, two destroyers, a cruiser, a submarine, and a frigate. Each platform, along with its weapons systems and/or aircraft, was controlled by a single DM in the experiment. The first independent variable was command focus and this was manipulated over two levels: a semi-traditional/ functional command focus, and an independent unit operations command focus. In the semi-traditional/ functional focus, each of the six Task Force commanders were assigned a composite warfare command function (i.e., strike, air warfare, surface warfare, undersea warfare, ISR, or a surface action group) in addition to being responsible for their individual platform. In the independent unit operations, each Task Force commander was assigned only platform roles.

Instructions provided to participants in the two command focus conditions are provided below. For the independent unit focus, participants were told:

> "Each of you is the Captain of a multi-mission capable ship and its assets. In your immediate geographical area you are to: monitor all activity in your geographical area; determine which tasks in your geographical area should be handled, with what assets, and when; handle the tasks in your geographical area that should be handled by your assets; coordinate handling of tasks in your geographical area that should be handled by teammates' assets; and ensure that all selected tasks in your geographical area are handled. For the battlespace as a whole you are to respond to requests by teammates to handle tasks in other geographical areas using your assets. You are responsible as a team for the overall JFMCC mission."

For the semi-traditional/ functional focus, participants were told: "The FFG Captain is commanding an independent SAG guarding the flank. The rest of you are dual-hatted as both a ship captain and a mission area commander. The rest of the instructions were similar to the instructions given above except "mission area" was substituted for "geographical area."

For purposes of this experiment, the six Task Force commanders reported to a Joint Force Maritime Component Commander (JFMCC) who in turn reported to a Commander, Joint Task Force (CJTF). The JFMCC was provided with direct command authority over the naval organizations in both conditions. In the case of the semi-traditional/functional organization, functional warfare area command responsibilities were distributed across the team, but a CWC was not represented explicitly. Under the functional focus, commanders were trained to focus on both global and local roles. Under the platform focus the participants were directed to define their task priorities first in terms of their platform and it's local geography; but they were also briefed as to the overall Task Force mission goals. Table 1 depicts the six composite warfare command functions included in the experiment, which ship captain was responsible for which area, and what assets each warfare area commander had to accomplish the mission area tasks.



responsibility			
JFMCC	**FLAG**	**Overall force commander, owns no platforms**	
STRIKE	**CVN**	**Carrier with airwing (F18A, F18S, HH60), no PLC**	
		3 F18S	3 on **CVN** (each with 2 SRM and 1 LRM, replenishable)
		33 TLAM	9 on **DDGA**, 9 on **DDGB**, 9 on **CG**, 6 on **SSN**
		9 TTOM	3 on **DDGA**, 3 on **DDGB**, 3 on **SSN** (each with 1 LRM)
SuWC	**DDGA**	**Missile destroyer; PLC: Air =none, Surface =20mi, subsurface = 7mi**	
		12 HARP	8 on **CG**, 4 on **FFG**
		3 F18S	3 on **CVN** (each with 2 replenishable SRM)
		3 SH60	1 on **CG**, 2 on **FFG** (each SH60 has 2 MKX)
		6 MKX	6 on **SSN** (+2 replenishable on each SH60)
ISR coord	**DDGB**	**Missile destroyer; PLC: Air =none, Surface =20mi, subsurface = 7mi**	
plus		**6 UAV**	2 on **DDGA**, 2 on **DDGB**, 1 on **CG**, 1 on **FFG**
SAR coord		**3 F18A**	3 on **CVN**
		3 F18S	3 on **CVN**
		3 SH60	1 on **CG**, 2 on **FFG**
		1 HH60	1 on **CVN**
		PLUS, Each platform incl **E2C** has their organic sensors!!	
AWC	**CG**	**Missile cruiser; PLC: Air =none, Surface =20mi, subsurface = 7mi**	
		30 SM2	8 on **CG**, 8 on **DDGA**, 8 on **DDGB**, 6 on **FFG**
		3 F18A	3 on **CVN** (each with 3 replenishable AAM)
		12 ABM	4 on **CG**, 4 on **DDGA**, 4 on **DDGB**
SAG	**FFG**	**Frigate; PLC: Air =none, Surface =20mi, subsurface = 7mi**	
		2 SH60	helo for ASW and search & rescue; endurance = 18mins; no PLC
			2 MKX: torpedo; range = 15mi
		1 UAV	unmanned air vehicle used for ISR, endurance = 40+mins; no PLC
		6 SM2	Standard surface-to-air missile, range = 80mi
		4 HARP	Harpoon ship-to-ship missile; range = 60mi
UWC	**SSN**	**Attack submarine with strike capability; no PLC**	
		6 MKX	6 on **SSN** (+2 replenishable on each SH60)
		3 SH60	1 on **CG**, 2 on **FFG** (each SH60 has 2 MKX)
NOTE 1:	If any aircraft (F18, SH60/HH60, UAV) are damaged by an enemy SAM site or enemy AAC		
	they are automatically returned to their base and be available for relaunch after a repair time.		
NOTE 2:	If any F18 or SH60/HH60 run out of fuel while on a mission they will be automatically		
	returned to their base and be available for relaunch after a refueling/rearming time.		

Table 1. Roles and assets owned by composite warfare commander functional areas.

Table 2 depicts the six platforms included in the experiment and the assets owned by each platform commander. The assets are color-coded to denote who owns what assets, e.g., all assets belonging to the CVN were green. Assets were color coded when they appeared on the simulation monitor to facilitate participants monitoring their location. Participants used the color of their platform as their “call sign” when communicating during the experiment.

0	**FLAG**	**Overall force commander, owns no platforms**	
1	**CVN**	Carrier with airwing (F18A, F18S, HH60), no PLC	-
		3 F18A aircraft for air-to air defense; endurance = 12mins; no PLC	-
		3 AAM: anti-air missiles, range = 30 mi	AAW
		3F18S aircraft for strike misions; endurance = 12mins; no PLC	-
		2 SRM: short range strike munitions, range = 15mi	STRK/ASuW
		1 LRM: long range strike munition, range = 45 mi	STRK
		1 HH60 helo for search and rescue; endurance = 18mins; no PLC	SAR
		2 E2C prelaunched airborne ISR platform; endurance = , no PLC	-
2	**DDGA**	**Missile destroyer; PLC: Air =none, Surface =20 mi, subsurface = 7 mi**	PLC
		2 UAV unmanned air vehicle used solely for ISR, endurance = 40+mins; no PLC	-
		3 TTOM positionable weapon platform-carries one LRM; endurance 4 mins	-
		1 LRM: long range strike munition, range = 45mi	STRK
		8 SM2 Standard surface-to-air missile, range = 80 mi	AAW
		4 ABM Anti-ballistic missile, range = 70mi	BMD/AAW
		9 TLAM Tomahawk land attack missile; range = 250mi	STRK
3	**DDGB**	**Missile destroyer; PLC: Air =none, Surface =20 mi, subsurface = 7 mi**	PLC
		2 UAV unmanned air vehicle used solely for ISR, endurance = 40+mins; no PLC	-
		3 TTOM positionable weapon platform-carries one LRM; endurance 4 mins	-
		1 LRM: long range strike munition, range = 45mi	STRK
		8 SM2 Standard surface-to-air missile, range = 80 mi	AAW
		4 ABM Anti-ballistic missile, range = 70mi	BMD/AAW
		9 TLAM Tomahawk land attack missile; range = 250mi	STRK
4	**CG**	**Missile cruiser; PLC: Air =none, Surface =20mi, subsurface = 7mi**	PLC
		1 SH60 helo for ASW and search & rescue; endurance = 18mins; no PLC	SAR
		2 MKX: torpedo; range = 15mi	ASW/ASuW
		1 UAV unmanned air vehicle used for ISR, endurance = 40+mins; no PLC	-
		8 SM2 Standard surface-to-air missile, range = 80 mi	AAW
		4 ABM Anti-ballistic missile, range = 70mi	BMD/AAW
		9 TLAM Tomahawk land attack missile; range = 250mi	STRK
		8 HARP Harpoon ship-to-ship missile; range = 60mi	ASuW
5	**FFG**	**Frigate deployed as a SAG; PLC: Air =none, Surface =20mi, subsurface = 7mi**	PLC
		2 SH60 helo for ASW and search & rescue; endurance = 18mins; no PLC	SAR
		2 MKX: torpedo; range = 15mi	ASW/ASuW
		1 UAV unmanned air vehicle used solely for ISR, endurance = 40+mins; no PLC	-
		6 SM2 Standard surface-to-air missile, range = 80 mi	AAW
		4 HARP Harpoon ship-to-ship missile; range = 60mi	ASuW
6	**SSN**	**Attack Submarine with strike capability; no PLC**	-
		3TTOM positionable weapon platform - carries one LRM; endurance 4mins	-
		1 LRM: long range strike munition, range = 45 mi	STRK
		6 TLAM Tomahawk land attack missile; range = 250mi	STRK
		6 MKX Torpedo; range = 15mi	ASW/ASuW

Table 2. Assets owned by ship captains in the independent unit operations condition.

2.1.2 Mutual Mental Model

The concept of a shared, or mutual mental model (MMM) among team members is used in the human factors literature as a construct for explaining team coordination under stressful decision-making situations. A MMM is conceptualized as providing team members with a shared understanding of who is responsible for what task and the information requirements for tasks. This shared understanding enables DMs to anticipate the needs of other team members so they can coordinate their decisions and behaviors. A common, or consistent, model of the tactical situation among the team members is considered to be a principle component of a MMM (Entin & Serfaty, 1999). High-performing teams employ MMMs to anticipate both events in the evolving situation and the information and resource needs of other team members. Cebrowski and Garstka's definition of self-synchronization indicates that unambiguous guidance is a key enabler of self-synchronization. For purposes of this experiment, this guidance was limited to statements of commander's intent, ROE, and situation report updates to facilitate development of situation awareness; these three elements varied in specificity across the experimental conditions.

2.1.2.1 Commander's Intent. Commander's intent in the high MMM condition differed from that in the low condition in that it contained greater specificity regarding prioritization of the mission tasks. For example, "The highest priority is to defend our designated protected assets against missile attack… To reduce the possibility of a successful missile attack against defended assets, every effort will be made to destroy launch sites before missiles are fired," illustrates the level of detail contained in the commander's intent in the high MMM condition. In the low MMM condition all the mission tasks were listed but without this level of detail and without prioritization of the tasks. Similarly, in the high condition specific air and naval bases that were to be destroyed were clearly designated as well as the fact that enemy ground troops were not to be engaged. Moreover, in the high mutual mental model condition participants were given the opportunity to discuss the commander's guidance to ensure they thoroughly understood all aspects of this guidance. Commander's intent is a two-way proposition: the commander has to communicate clearly and the followers need to hear, understand, embrace, and internalize as the commander intended. In contrast, in the low mutual mental model condition participants were not given an opportunity to discuss this guidance with the person who player JFMCC. An additional difference between the two conditions was that the teams in the high mutual mental model condition were "empowered to self-synchronize" by the JFMCC's explicit statement that he would rely on their initiative and command by negation. In contrast, the degree of empowerment of task force commanders reporting to the JFMCC in the low MMM condition was vague. When a team member in the low MMM condition asked the JFMCC a question about taking certain actions he would ask them for their recommendation or tell them he had to check with higher authority and then reply back to them a few minutes later in the scenario. This protocol was arranged to emulate the situation that occurs when clear guidance is not provided and the ensuing delays that can occur in the decision cycle.

2.1.2.2 Rules of Engagement. ROE in the high and low conditions had the same level of specificity, or non-specificity, respectively, as was included in the commander's intent. The purpose of these experimental manipulations was to examine the impact that variation in the clarity and specificity of ROE had on the nature and degree of self-synchronization and the resulting impact on performance. The idea was to create ambiguity, unnecessary detail and fuzziness in the "bad" set of ROE which might lead to a delay in responses due to hesitation, confusion, and additional communications needed to clarify the situation. In contrast, for the “good” ROE condition, enhanced clarity was predicted to reduce “waste” of scarce assets and allow greater speed of response to time critical targets.

2.1.2.3 Situation Reports. The third component used to produce the high level of MMM was the issuance of periodic situation reports during the scenario in an effort to maintain a high level of situation awareness. Situation reports were issued by the commander (JFMCC) to the task force approximately every eight minutes; most of these reports were to alert the team to new intelligence regarding new SCUD launch sites.. These situation reports were envisioned to help team members update their mental models of the situation because the commander’s information focuses the team on the current tactical and operational priorities and updates their understanding of the situation (Entin and Serfaty, 1999). Periodic situation reports have been demonstrated to increase overall team performance. To produce the low level of MMM no situation reports were exchanged.

3. The Process of Scenario Design

The process of scenario design involved the following steps: (1) specification of “Blue” and “Red” orders of battle (OOB), that is, the assets that were to be included in the scenario for use by Blue and Red; (2) tailoring tasks and “seeding” the scenario in order to assist in operationalizing the (independent) variables being manipulated in the experiment; and (3) instantiation of assets and tasks within the confines of the game simulation software. Overall, this process, involving N6C and NPS, proceeded well and involved iteration and adjustments to achieve a balance between external “reality” (operational fidelity) and the reality of what could be implemented (and controlled) in a laboratory environment. Each of these steps will be elaborated upon in the following paragraphs.

3.1 Seeding the Scenario with Crafted Tasks

A major aspect of scenario design involved seeding the scenario with “crafted” tasks in order to provide enough situations where self-synchronization would be necessary among the participants. A second aspect of scenario design was to introduce a sufficient degree of uncertainty, confusion and conflict so that both team performance, and the processes employed by the teams, would be sensitive to differences in a team’s mutual mental model.

3.1.1. Specification of friendly and enemy order of battle

Specification of the friendly and enemy OOB involved three steps. The first step was to cull from a comprehensive list of all potential assets held by Blue and Red down to a subset of assets that represented the range of types of assets that would come into play during the envisioned scenario. The number of differing types of assets was reduced to bring the “asset management” within reasonable limits for a single individual. Reducing the number of different types of assets also meant fewer types of assets had to be modeled in the simulation software.

The second step associated with OOB specification involved establishing parameters (e.g., range, speed, capability) associated with all assets to be included in the scenarios. Parameters for some assets were modified from their initial settings based on actual asset characteristics. For example, the ranges of intelligence, sensors, and reconnaissance (ISR) platforms (e.g., unmanned aerial vehicles) were extended to enable these assets to detect Red assets faster so that the tasks could be performed when the scenario was played at a 1:10 time ratio. Some platform speeds were increased to enable more tasks to be performed during a 40-minute scenario, thus more data points were possible. Some asset capabilities were increased to allow greater flexibility in the way the DMss could process the tasks and to better represent the capabilities envisioned for future platforms.

A third step entailed adjusting the number of weapons carried on various platforms (ships, submarines, and aircraft) to create the right ratio of weapons available to perform the tasks included in the scenario. A corollary goal for this step was to create the right level of “tension” via both the scarcity of assets and the timing requirements levied by TCS and TAMD missions. Each of these steps involved an iterative process to ensure an acceptable level of operational fidelity and experimental control was achieved.

3.2 Ensure Differences in Process and Performance Due to Mutual Mental Model

A major concept underlying this examination of enablers of self-synchronization is that the degree of clarity regarding the situation will have a significant impact on both the processes employed by the team and the resultant performance. This clarity regarding the situation is conceptualized as being provided by clear, well-written commander’s intent, clearly understood, well-crafted, specific rules of engagement and periodic situation reports provided by the commander. Thus, sufficient ambiguity, uncertainty, and conflict (all representing the “fog” of war) needed to be an inherent part of the scenario so that manipulation of the variables of interest (independent variables) could have an impact on performance and the processes employed.

An example of providing sufficient conflict involved including enough tasks that needed to be performed during a given time period that a conflict might be created when a DM may have two or three tasks vying for attention and needing to be prosecuted concurrently. These situations required the DM to prioritize which task was most critical or which resource was most appropriate. It was hypothesized that the prioritized listing of targets included in ROE provided in the high MMM condition would facilitate these decisions occurring through self-synchronization among the task force commanders. The contrasting hypothesis in the low MMM condition was that self-synchronization would be impeded and DMs would likely adopt a more random approach to deciding which target to process first, for example, when confronted with, a TCS target, a threatening patrol boat, and an approaching hostile aircraft.

An example of a crafted task that produced uncertainty were the pop-up SCUD missile launchers that were only visible to the team when an ISR asset was within detection range of the launcher. Each time a new SCUD launcher occurred in the scenario a new intelligence report was shown on the computer display for all team members. However, the complexity and workload in the scenario was such that there would be variation in the self-synchronization of task force members in the use of ISR and strike assets to prosecute these threats.

3.2.1 Embedding Requirements for Self-Synchronization in the Scenario Design

Several aspects were involved in performing the tasks that required self-synchronizing: these aspects dealt primarily with the temporal processing of tasks. It should be noted that virtually all tasks have a finite time window of opportunity, and as such were time-critical, albeit to different extents.

3.2.1.1 Serial/sequential processing. Ostensibly these tasks required self-synchronization by two or more DMs in a time-phased manner. Examples in the scenario deal mainly with the need for ISR to locate missile launchers and to determine whether or not a platform is hostile, as a precursor to weapon assignment. (Many tasks could not be attacked until they were positively identified.) In addition, destroying the surface-to-air missile sites were (soft) prerequisites to the unimpeded movement of blue aircraft.

3.2.1.2. Defense in depth. Similar to conditional sequential processing, defense in depth involves successive layers of task processing wherein a task not accomplished by one DM becomes the problem of another DM. Examples in the scenario include the patrol boats, submarines, destroyers, and aircraft. Additionally, the SCUD launchers and coastal defense launchers fall into this category as well.

3.2.1.3 Parallel processing involving two decisionmakers. The requirement for continual ISR coverage of a target during weapon fly-out and engagement necessitated temporal coordination between the DM controlling the ISR platform and the DM who fires the weapon.

3.2.1.4 Planning and coordination. The scenario was constructed with purposeful overlaps in capabilities (and weapon systems) among DMs to foster the need for coordination. Thus, it was critical for the team to establish general rules concerning who should do what (tasks) and with what assets. For example, one mission task was to destroy an airbase and a naval base. To accomplish this required eight or nine missiles to be launched against each base. Participants were told that destroying a base required between five-ten missiles. When a team did not coordinate the use of their missiles to accomplish these tasks, they could have either (a) wasted missiles by launching more than was required (because typically two or more DMs launched weapons for this task) or (b) not launched enough missiles to be successful due to not knowing how many they launched compared to the number required.

3.2.1.5. Time critical tasks. The primary tasks in this group were the SCUD missile launchers and coastal defense missile launchers. These tasks required the following subtasks to be performed in the following order: (1) detection of location, (2) ensure an ISR asset is within illumination range of the newly detected SCUD missile launcher, and (3) allocation of a weapon – all to be done before the launcher fired its missile. The coastal defense missile launcher tasks presented a lesser problem as their a priori locations were more confined (along the coast), ship-based weapons could reach them quickly, and there were several means to kill the fired missile(s). The SCUD missile launchers, on the other hand, presented a major problem to the teams. This higher level of complexity was due in part to the wide area in which they could be resident, the (relatively) short time in which they must be engaged, and the longer flight time required for a Blue missile to reach the more distant SCUD sites.

Pilot trials during scenario testing showed that SCUD-hunting was nearly impossible using the original scenario implementation. Thus, we (1) increased the ground detection ranges of ISR assets, (2) increased speed on the UAVs, and (3) provided cueing – in the form of intelligence reports – on upcoming SCUD missile launcher activity. These actions were all intended to increase the likelihood of timely SCUD-missile launcher detection. It was then up to the team to attack the SCUD-missile launcher before it launched – not an easy job due to the need to tightly synchronize ISR and weapon activities. However, the scenario was built such that the first launch of a SCUD missile provided the team with a location of the launcher, thus the team could potentially destroy the launcher prior to it launching a second missile.

3. 4 Exploiting Weakness in a Team's Mutual Mental Model

Testing the hypothesis that a shared mutual mental model among DMs would lead to more effective self-synchronization and better performance required us to seed the scenario with tasks that would be sensitive to a shared view of the battlespace, clear ROE, and commander's intent. This was done by deliberately introducing uncertainty into the scenario tasks and manipulating weapons load and overlap among the DMs. The ways in which these factors were manipulated is described in the remainder of this section.

3.4.1. Uncertainty and vagueness in task processing. The scenario had a number of neutral shipping and neutral air tasks that r to add clutter and the need for ISR. Other tasks, specifically the potentially hostile ships, aircraft, and submarines required proactive use of sensor/ISR assets to determine whether these were in fact hostile. Acting in haste on these tasks could result in engaging a non-hostile. Clear ROE and/or team planning are required to specifically delineate procedures for dealing with these tasks. Another set of tasks was introduced that, although they were Red forces, they provided no threat to Blue forces, and in turn did not require attacking. These included reconnaissance aircraft and Red ground forces — assets for which a vague commander's intent would lead to uncertainty as to whether these assets were to be attacked.

3.4.2. Confusion and conflict. Confusion with respect to whom should do what increases with an overlap in platform or DM capabilities, and must be managed by the team through planning and coordination. We adjusted the (functional) overlap so that roughly three or four of the six platforms shared capability in each of the relevant warfare areas. As the platforms were fixed in location we designed many task locations and trajectories to "split the defenders" in order to require real-time negotiation between platforms on a task by task basis. Good team coordination, or self-synchronization, was required to rapidly allocate who would process which target/s, with what combination of resources. It was anticipated that the extent to which a team did *not* coordinate their overlapping capabilities would be reflected in a waste of weapons and dual attacks. Targets that appeared on the "seams" between two or more platforms' areas of responsibility might, for example, possibly be engaged by two platforms if they did not coordinate their actions. This was expected to be particularly relevant for the strike mission area, as all platforms (except the frigate) had strike capability, and, there were many targets of opportunity.

3.4.3. Resource/weapon scarcity. A major driver of the need to coordinate activities was weapon scarcity. Too many weapons promote waste and poor planning, whereas too few weapons makes a perfect solution to the problem impossible; and the "best possible" solution requires coordination among resource elements. Pre-experiment pilot trials were "played" to determine the feasibility of accomplishing tasks, as well as to debug the software. The goal was to create scenarios such that a well-coordinated team, following a clear commander's intent and ROE, would have sufficient weapons to meet the threat. Validation of these allocations of tasks and resources was accomplished through pilot testing the scenarios, and necessary adjustments were made. For example the scenario was constructed such that if the SCUD-missile launchers were not successfully engaged prior to launch, the team would not have enough anti-ballistic missiles to destroy every incoming SCUD missile. This was an intentional design to insure there was a need for and benefit to self-synchronization or a cost to performing without self-synchronization.

3.5 Additional Issues Related to Scenario Design

Several additional issues were involved in preparing to conduct this fairly ambitious experiment. Two of these issues will be addressed.

3.5.1 Time Scaling. We conducted the experiment at a 10:1 time scale. Thus a 40-minute laboratory scenario corresponded to about 6.6 hours of "real" time. This seemed too fast for the air picture and so maximum aircraft speeds were reduced somewhat. It also seemed too slow for surface and subsurface tasks and so these were increased in (relative) speed. Finding a satisfactory compromise among disparate warfare areas was a challenge. Moreover the 10:1 time compression was at or near the limit at which a team could plan activities and perform in a synchronized manner in response to events in the scenario, as opposed to merely being in a reactive mode. Post-experiment discussions with participants did seem to indicate that once teams were trained well the time compression became less of a factor and they generally did not favor a slower time pace.

3.5.2 Parameter Adjustments. These have been discussed above, and loom important in the successful outcome of any experiment. Parameters include numbers and types of weapons on each of the platforms, relative speeds of assets, refuel/endurance times, and a host of ranges: detection, measurement, identification, attack, and the range at which Blue assets could be-attacked. A key factor in selecting suitable values is the representation of "real-world" capabilities. However, we must adjust these values to fit the modeling construct of the Distributed Dynamic Decisionmaking (DDD-III) simulator (Kleinman, Young & Higgins, 1996), and to be in a range where levels in our independent variables are likely to be reflected in significant differences in the collected dependent variables. Another factor to consider is the expected distribution of workload among DMs. For example, in this experiment the commander on the carrier had a fairly high workload and aircraft were "chunked" (i.e., each aircraft represented two actual aircraft) to reduce the number of assets being controlled at any one time. Short of pilot testing, parameter values can be adjusted via precursor model-based simulations and sensitivity studies.

4. Experimental Procedure

Forty-two officer-students (O-2 to O-4) representing all US military services and some foreign service officers, from two classes at NPS, Monterey, CA, were organized into seven teams of six individuals. NPS's Distributed Dynamic Decision-making (DDD-III) simulation, located in the Systems Technology Battle Laboratory, was used to drive the experimental scenario and collect data for subsequent analysis.

The two independent variables were completely crossed to form four experimental conditions (i.e., two levels of command focus by two levels of MMM produced four experimental treatments or conditions). The four experimental treatments were semi-traditional/functional focus and high MMM, semi-traditional/functional command focus and low MMM, independent unit command focus and high MMM, and independent unit command focus and low MMM. Command focus and MMM were both manipulated as between-subjects factors (where the subject element is team). Two of the seven teams were randomly assigned to each of the first three experimental treatments and the seventh team was assigned to the last treatment condition.

Participants were scheduled for two three-hour blocks of time. During the first block they were trained to engage in the simulation and to operate under one of the command focus conditions. The training scenarios were less complex than the scenarios used for data collection. The MMM condition was introduced during the second block, prior to the two data runs, where two role players (one for the high and one for the low MMM conditions) briefed the commander's intent and ROE. Following these briefings, the participants engaged in a “warm up” scenario and then conducted two 40-minute data run scenarios.

5. Data Collection Measures and Metrics

Several performance and process variables were assessed throughout the experiment. These measures came from three sources: measures derived from the log files of the DDD simulation, measures obtained by trained observers and coders, and self-report measures form the participants. Two observer-based assessments were used during the experiment; one to rate performance outcome and one to rate teamwork behavior. These observer-based assessments comprised behaviorally-anchored rating scales to rate the behaviors of interest. Ten items comprised the performance outcome assessment and six teamwork dimensions (communication, monitoring, feedback, back-up, coordination, and team orientation) were included in the teamwork assessment.

DDD Derived Measures. A coordination performance measure will be developed from the log file data derived from the number of assets required to perform a task and the number of assets actually used to process the task. The ratio formed by the number of assets used divided by the number of assets required (converted to percent) will yield the percentage of coordination effectiveness. Latency is another measure that can be derived from the DDD. This consists of the time from when a task first appears until it is processed, averaged for all tasks processed (by category). Several other dependent measures in the DDD log files will be analyzed.

6. Conclusion

Data is currently being analyzed and reports will be forthcoming. Performance differences we expect to see include the following: Allocation of scarce resources, i.e., weapons across the battlespace, the processing of time-critical targets; the ability of the force to effectively destroy time-critical targets; and the matching of force engagements with commanders intent.

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