12TH ICCRTS

"Adapting C2 to the 21st Century"

Results of The Johns Hopkins University Applied Physics Laboratory's (JHU/APL's) C2 Hypotheses Exercise

Tracks 6 or 7

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Abstract

The Johns Hopkins University Applied Physics Laboratory (JHU/APL) has built a Command and Control (C2) test bed for developing and testing C2 capabilities. JHU/APL also drafted a C2 Concept to describe to technologists and engineers the likely nature of future C2 environments [this concept was presented at a plenary session of the Command and Control Research and Technology Symposium (CCRTS) last June]. The intent of this draft concept was to look beyond current doctrine and operations and to point to future needs and to areas for C2 innovation. To better link concept and engineering, JHU/APL hosted a two-day C2 Hypotheses and Experimentation Conference in March 2007 to develop a set of C2 hypotheses to be the basis of future testing and experimentation. For example, a hypothesis might be: "If a joint force achieves shared situation awareness, then friendly forces achieve greater velocity in the battlespace." While this hypothesis may not prove to be true, testing and experimentation should reveal the extent to which shared awareness improves force performance and the degree of shared awareness necessary to achieve adequate results. The premise of the conference was that testing such hypotheses could lead to more informed decisions regarding C2 solutions, balancing capabilities with resources, and identifying key areas for innovation. This paper summarizes the C2 Hypotheses and Experimentation Conference, the C2 hypotheses it produced, and offers some general observations about the challenges posed by this event.

BACKGROUND

Over the last 18 months, JHU/APL has built a C2 test bed for developing and testing C2 capabilities. In parallel with this effort, JHU/APL also drafted a C2 Concept to describe to technologists and engineers the likely nature of future C2 environments. The intent of this draft concept is to look beyond current doctrine and operations and to point to future needs and, most importantly, to areas for C2 innovation.

To better link concept and engineering, JHU/APL began looking for a set of C2 hypotheses (propositional statements) to be the basis of testing and experimentation. For example, a hypothesis might be "If a joint force achieves shared situation awareness, then friendly forces achieve greater velocity in the battlespace." While many people may assume this hypothesis to be true, testing and experimentation should reveal the extent to which shared awareness improves force performance and the degree of shared awareness necessary to achieve adequate results. Testing a set of such hypotheses should lead to more informed decisions regarding C2 solutions, balancing capabilities with resources, and identifying key areas for innovation. To gain the perspectives of other C2 stakeholders, JHU/APL hosted a two-day C2 Hypotheses and Experimentation Conference on 1-2 March 2007. The task of this conference was to develop a set of C2 hypotheses for future testing and experimentation. This paper summarizes the C2 Hypotheses and Experimentation Conference, the C2 hypotheses it produced, and offers some general observations about the challenges posed by this event.

RESULTS OF THE C2 HYPTHOSES EXERCISE

The C2 Hypotheses and Experimentation Conference began with a description of the conference objectives:

- Provide a forum for C2 concept and doctrine stakeholders to influence evaluation of advanced C2 concepts and enabling technologies
- Identify 3 – 5 high payoff, high risk network-enabled command and control implementing concepts
- Develop 2 operational hypotheses for each of the implementing concepts
- Suggest an experimental design and evaluation metrics for each operational hypothesis

These objectives were intended to be bold, to encompass the entire range of network-enabled command and control. The conference overview stressed the intent to lay out a broad vista of C2 transformational activities, and that future research would hopefully build on the foundation built at this conference. Bold statements have been made by proponents of C2 transformation. This conference hoped to define an experimental blueprint for testing those bold statements and identify the knowledge needed to maximize the usefulness of current and future technologies and capabilities.

Participant introductions followed. There were 27 participants representing such diverse groups as MITRE, the Joint Staff, the Air Force Electronic Systems Center and the Command

and Control, Intelligence, Surveillance, and Reconnaissance (C2ISR) Center, United States Joint Forces Command (USJFCOM), the Chief Naval Operations (CNO) Strategic Studies Group, Boeing, Northrop Grumman, and JHU/APL. The participants had approximately 25 years of professional experience on average. As shown in Figure 1, warfighters and engineers were well represented with additional participants being analysts, testers, etc.

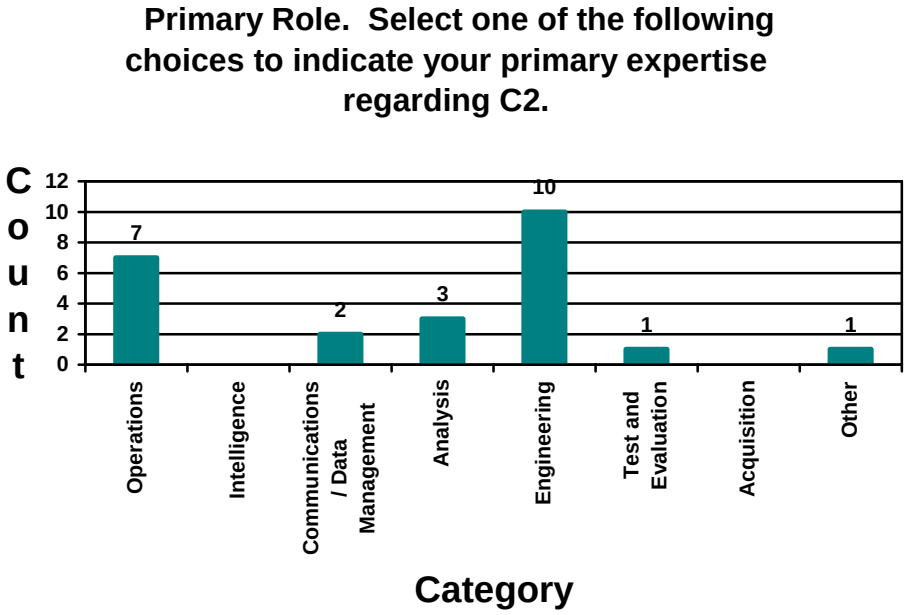

Figure 1. The participants represented both operational and technical expertise

Briefings were then presented that covered JHU/APL's command concept (Appendix A) and the Richard Kaas primer "The Logic of Warfighting Experiments" (Appendix B). Participants were then divided into three groups, with each group tasked to develop a set of operational-level hypotheses that could serve as the basis of experimental hypotheses. One group was tasked to look "outside the box" while developing their hypotheses; another was tasked to concentrate on the problems associated with vertical and horizontal command and control; and the other was tasked to look at a resource-constrained environment. It was stressed that the operational hypotheses should capture the essence of the transformational concepts currently being considered by the DoD or other sources (e.g., commercial transformation of business practices).

The hypotheses that were developed by the groups were then presented to the participants and rated by each based on their perceived importance (the complete list of operational hypotheses can be found at Appendix C). The results were captured and presented in an x-y plot (Figure 2) that shows the importance of these hypotheses and the standard deviation associated with each. Low standard deviations indicated relative agreement, while high standard deviations suggested less of a consensus. Notice that there is a cluster of the highest priority hypotheses that include hypotheses 3, 6, 14, and 20. A low score does not mean a hypothesis is unimportant…it may simply have a more limited application or describe a very specific concept. One example is the very interesting concept of using "markets" for various purposes. This might be very useful and ultimately effective, but it probably is not as significant as gaining a broad,

empirical understanding of the risks and benefits of centralized verses decentralized control in a net-centric environment.

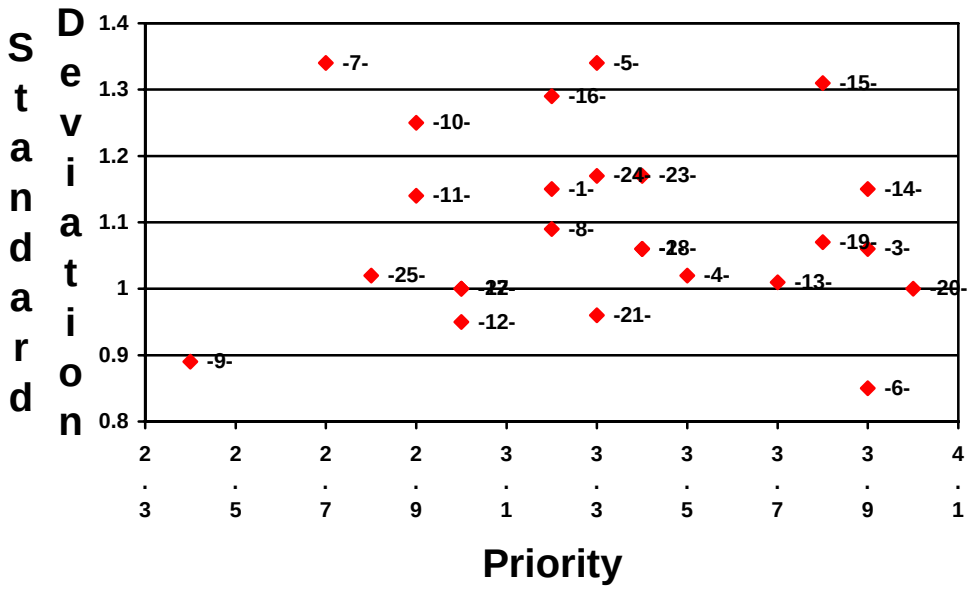

Figure 2. Ranking the hypotheses identified candidates for detailed consideration

Table 1 lists the highest ranked operational-level hypotheses. Most of these hypotheses relate to a very dynamic mode of warfare. Military objectives and actions take place not in just the physical domain, but the information, social, and cognitive domain as well. Again, all the hypotheses are potentially valuable for shedding light on key aspects of C2 transformation.

The purpose of ranking the hypotheses was to narrow the number of hypotheses that the groups would consider on the second-half day of the conference. During the second-half day's exercise, the attempt was made to take the top six rated operational hypotheses and develop appropriate detailed experimental hypotheses that could be used to test these operational hypotheses. This proved difficult given the short amount of time allotted to develop the experimental hypotheses, hence only four of the top six hypotheses were broken down. Therefore, the following examples of capability hypothesis, experimental hypothesis, and metrics should be considered illustrative examples and not a complete enumeration. Again, one of the goals of the conference was is see if the Kass framework could bridge the gap from general concepts to specific experiments with specific, meaningful measurements to prove or disprove operational hypotheses.

Capability Hypothesis (H20): If we improve our ability to share learned successes (and failures), then we will be more adaptable to a rapidly changing environment.
Experimental Hypothesis #1: Given a blog that a platoon leader reads to gain the latest insight into Techniques, Tactics, and Procedures (TTPs) appropriate for his/her situation: If the blog had a monitor/editor, then the feedback loop will be improved and the platoon leader will implement improved TTPs.

Measures: Ratio of good data to bad data in the blog, and probability of implementing a bad TTP rather than an improvement because of the blog.
Discussion: Blogs currently provide a feedback loop to allow platoon leaders (and others) to exchange information about what works and what did not. There is clearly a tradeoff between validating and vetting the ideas and suggestions versus a free flow of information. This experiment would attempt to measure the effect of providing a monitor/editor to improve the information content on the blog.

Table 1. The Top Six Hypotheses Developed

H#	Averages in Quartiles Across Matrix (highest is best)	Priority
20	If we improve our ability to share learned successes (and failures), then we will be more adaptable to a rapidly changing environment.	4.00
14	If we improve our sensing and understanding of non-physical domains, then we will create new action options for ourselves, better understand how to eliminate the enemy's options, and better predict the outcome of our actions.	3.90
3	If the same actionable data are available to the entire command structure, then there is improvement in horizontal and vertical coordination that enables decision makers to operate inside the enemy's decision cycle resulting in achieving the desired effect.	3.90
6	If provided a collaborative environment tailorable to decision makers, the quality of decision will be increased.	3.90
15	If we understand the enemy and the environment, then we will be able to turn the enemy against itself.	3.80
19	If we can influence the opponents through cyberspace, then we can effect operations anywhere in the world.	3.80

Experimental Hypothesis #2: For a platoon leader in the field utilizing a blog for TTP updates: If a blog rates the effectiveness of posts, then the feedback loop will be improved and platoon performance improved.
Measures: Ratio of good data to bad data and platoon performance parameters/metrics.
Discussion: This is similar to experimental Hypothesis #1, but it attempts to quantify the value of allowing the bloggers to identify important and useful information (as well as identify bad or wrong information).
Experimental Hypothesis #3: If separate repositories of lessons learned are automatically combined into a single, integrated, rated data repository and made available to exercise participants, then the effectiveness of the forces will be improved**.**
Measures: Percentage of duplicates, percentage of contradictory lessons, utilization of lessons learned, and number of events where lessons learned were not applied.

Discussion: This is similar to experimental Hypotheses #1 and #2, but it attempts to measure the value of integrating current "blessed" repositories of lessons learned and thereby maximize their usefulness.

Capability Hypothesis (H14): If we improve our sensing and understanding of non-physical domains, then we will create new action options for ourselves, better understand how to eliminate the enemy's options, and better predict the outcome of our actions.
Experimental Hypothesis: If we provide cell phones to the local populace in a theater of operations (or surrogate), and in a non-government forum provide infrastructure to support local needs (e.g., free water), then local sources of operationally useful information will be improved.
Measures: The target audience's adoption of technology (e.g., local eyes cell phone) to generate operationally useful information, number of non-kinetic/non-traditional options, change in number of significant actions (measure of affect), and measures of trust relationships (e.g., build a trust data base on individuals over time for transfer as units transfer).
Discussion: This hypothesis really has two parts. One is an improvement of our ability to sense the non-physical domains would be helpful. Understanding the non-physical domains would also be helpful. Both capabilities would enable feedback on how well our understanding corresponds to reality and allow us to adjust as needed.

Capability Hypothesis (H3): If the same actionable data are available to the entire command structure, then there is improvement in horizontal and vertical coordination that enables decision makers to operate inside the enemy's decision cycle resulting in achieving the desired effects.
Experimental Hypothesis: If a Command Center has a user-defined operational picture (UDOP) capability, then the coordination and decision cycle will be improved.
Measures: Cognition measures, process speed, increased collaboration, and improved decision quality (e.g., Air Tasking Order (ATO) quality).
Discussion: Much of the discussion about this hypothesis was trying to define "actionable data." The working group settled on a working definition that actionable data are timely, correct, relevant, trustworthy, and consumable and aid in making a good decision and execution. The problem with this hypothesis is that all the detailed relevant data needed at the lowest levels could not be consumable or relevant at the highest level. However, the reverse may be true. What is relevant to your commander may always be relevant to you (e.g., commander's intent is relevant to everyone).

Capability Hypothesis (H6): If provided a collaborative environment tailorable to decision makers, the quality of decision will be increased.
Experimental Hypothesis: If given two network structures, one strictly hierarchical and the other tailorable by the decision maker(s), then the tailorable network will outperform the hierarchical one in solving complex problems.
Measures: Cognition measures, process speed, increased collaboration, and improved decision quality (e.g., ATO quality).
Discussion: The information needed to solve the decision problem and discoverable throughout the nodes of the network. Competition venue could be used to compare the performance and information exchange.

SUMMARY

Employing a process for developing C2 hypotheses (summarized in Appendix B), this conference took the first step in that process by producing 25 operational hypotheses (listed in Appendix C). Following an initial prioritization of those 25 operational hypotheses, the conference focused on the four hypotheses described above.

The objectives of this conference were intended to be bold, to engender collaboration between C2 theorists, technologists, and practitioners to influence the evaluation of advanced C2 concepts and enabling technologies. The central premise of the conference was that a set of C2 hypotheses could be derived and could serve as the basis of future C2 testing and experimentation. The conference was successful in engendering collaboration. Conference discussions were a rich exchange of views among C2 theorists, technologists, and practitioners. However, it proved quite challenging to link the operational hypotheses developed on the first day with the desired products of the second day: experimental hypotheses, experimental venues, and—ultimately—metrics. More time and effort was needed for this task than was available in this short, two-day event. Many participants commented on the challenge of bridging the so-called "air gap" between the theoretical and the testable. Summary discussions identified two basic approaches for testing and experimentation. One approach is to narrowly define the experiment into testable metrics. Of course, the drawback of this approach is that in scoping the experiment to that which can be tested, the hard-to-measure virtues of shared awareness, self-synchronization, and collaboration—particularly across a large C2 enterprise—may be lost. The other, more radical approach is to measure innovations in terms of adoption; if users see value—measured or otherwise—they will adopt innovations.

Military transformation of C2 probably requires a mix of quantitative and qualitative analysis to identify key capabilities. Testing a set of hypotheses, such as those developed at this conference, could lead to more informed decisions regarding C2 solutions, balancing capabilities with resources, and identifying key areas for innovation. We are now looking at possible venues to carry on the initial progress made at this conference.

This conference was successful in that it started to engender collaboration between C2 theorists, technologists, and practitioners to influence the evaluation of advanced C2 concepts and enabling technologies. As a result, 25 C2 operational hypotheses were identified that could serve as the basis of future C2 studies. These 25 hypotheses were prioritized in importance, with 4 of the 6 most important operational hypotheses further developed into an initial experimental hypotheses, venues, and metrics. We found the process of fully developing experimental hypotheses, venues, and metrics takes more effort and time than the short time allocated to this activity during the conference. This constrained the level of detail that was hoped to be obtained from this conference. However, the conference did provide a sound basis for future investigations of the transformation of C2…specifically, the areas of complex adaptive systems and operations in the knowledge, social, and cognitive domains were identified as key areas of research.

Military transformation of C2 requires quantitative and qualitative analysis to aid in the identification of key capabilities required to enhance future operations and assist in the development of appropriate TTPs that maximize the value of these new capabilities.
Testing a set of the hypotheses such as those developed at this conference could lead to more informed decisions regarding C2 solutions, balancing capabilities with resources, and identifying key areas for innovation. Therefore, we are now looking at possible venues to carry on the initial progress made at this conference.

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APPENDIX A

DESCRIPTION OF THE OPERATIONAL ENVIRONMENT

Future operations will unfold along a wide spectrum of conflict, from routine peaceful competition on the one end, to full scale, high intensity warfare on the other. The spectrum includes conventional and unconventional operations, domestic and foreign operations, manned and unmanned platforms, and the full range of missions… from disaster relief to war. These various scenarios and missions could occur simultaneously. For example, a disaster relief operation might unfold in the midst of internecine conflict among armed factions; or a large-scale conventional military operation might quickly evolve into a humanitarian mission. Future commanders[1] will have to deal simultaneously with a wide range of scenarios, each requiring both common and different command challenges. Therefore, future C2 must be flexible enough for decision makers to conduct operations in all its many guises and variants.

It is important to remember that ***the future operational environment will be what it will be, not what we want it to be.*** It is always tempting to build capabilities to re-fight yesterday's battles, rather than to adapt to the future. It is impossible to predict fully what the future operational environment will be, but a few general trends are likely to apply.

Operational Trends

Asymmetric Warfare. U.S. superiority in conventional warfare, demonstrated during conventional operations in the Persian Gulf, Kosovo, and the conventional phase of Operation Iraqi Freedom, will encourage future adversaries to adopt asymmetric methods to dislocate American strengths. This trend is neither new nor surprising. Asymmetric warfare has always been a part of human history. Those who cannot directly oppose the strength of their adversaries have often relied upon guerilla fighting, terrorism, or other forms of attack. However, the technological and cultural complexities of modern civilization have created new vulnerabilities and targets of attack. Critical features of modern societies, such as communications grids, power grids, transportation systems, and computer systems, can be easily disrupted by either traditional sabotage techniques, or new forms of attack such as biological warfare, nuclear terrorism, and cyber-attack.

Non-state adversaries. Just as modern civilization has created new targets for attack, it has provided would-be attackers with new tools and techniques. Furthermore, global communications, transportation, and banking systems have facilitated the rise of non-state adversaries (e.g., groups of individuals united by political convictions or religious beliefs) and empowered them to strike across borders or around the globe. Future conflict will almost certainly involve a mixture of sovereign state and non-state threats, each having complex and shadowy connections with other powers.

War in the Information Age. The pervasiveness of global news media ensures that any attack is quickly and widely publicized, magnifying the power of both state and non-state adversaries to garner world attention. Likewise, the response to any attack will be quickly

[1] Throughout this paper we will be using the term commander in its military context. However, the operational environment and opposing interactions will impact civilian first responders and other key decision makers as well.

reported, analyzed, and scrutinized. Future commanders will operate in an environment in which their decisions will be quickly known to friend, foe, and a worldwide audience.

Disaster Relief. Global communications have also magnified the importance and urgency of human disasters, mandating a high-tempo response from those nations able and willing to help. Because they sometimes take place in areas of political or religious upheaval, relief operations will remain closely linked to military and security operations. The presence or reach of U.S. forces around the world makes these forces likely first-responders to natural disasters.

Interagency operations. A key feature of the future operational environment will be the number and diversity of participants. The battlespace will include journalists, non-governmental and private organizations, armed neutrals, non-combatants, criminal networks, and, as described above, a global audience. Joint and coalition forces will routinely operate with other agencies of the United States Government and those of other governments. They will likely have numerous interactions with non-governmental and private volunteer organizations. Integrating these disparate organizations cannot be thought of as an "add-on" to command and control concepts, but rather as the heart of the matter. Post-Cold War dynamics point clearly to the increasing need for cooperation among all elements of the government. The U.S. military will rarely, if ever, operate in isolation from other agencies.

Interaction of Opposites

The operational environment has also an interaction of opposing conditions and methods. The following six sets of opposites offer multiple scales for characterizing the operational environment, offering a richer, more complex perspective of the future conflicts.

Conventional and Unconventional Warfare. The future operational environment will include conditions associated with both conventional and unconventional warfare. It is tempting to emphasize the importance of one condition over the other in thinking about the future, but the two have co-existed throughout history. Decision makers will need a balanced perspective and will likely need to addresses the threats and operational methods of both conditions.

Conventional warfare normally focuses on the destruction of enemy forces and sources of military power. It requires the orchestration of the forces being brought to bear, supported by communications, engineering, logistics, and all the various elements found in joint and coalition forces. Conventional conflict places a premium on detecting, tracking, engaging, and assessing battle damage against enemy forces and infrastructure. The presumption of conventional warfare is that once the adversary is separated from his military power, he will no longer have the means, or the will, to continue the conflict.

Unconventional warfare generally occurs when the adversary's military capabilities are insufficient to engage in direct open warfare, but the adversary still has the will to fight. In such cases, the adversary resorts to fighting an insurgency in which guerilla fighting, terrorism, piracy, and all forms of warfare are carried out by non-uniformed forces. Those fighting against an insurgency can seldom target enemy formations. They must focus on individuals and small groups of assailants and address a wide variety of threats: improvised explosive devices (IEDs), suicide bombers, snipers, and the possible use of deadly toxins, biological agents, or cyber-attacks. Those fighting an insurgency must isolate the adversary from the local population by applying military force within a much broader political context. They must integrate military

action with civil and police actions involving other U.S., coalition, international, and host-nation agencies.

Hierarchy and Anarchy. The future operational environment will contain conditions of both hierarchy and anarchy. "Hierarchy" refers to the organization of forces according to a functional chain of command; relationships are well defined by law and tradition, and authority is commensurate with responsibility. "Anarchy," on the other hand, refers to relationships wherein there is no clear authority or structure. The future operational environment will always include both hierarchical and anarchic relationships, and commanders must be flexible enough to recognize and operate within a mix of both conditions.

Normally, U.S. commanders will have a hierarchical relationship (direct legal authority) over assigned U.S. forces. U.S. commanders may have to engender cooperation from coalition forces, over whom they have limited or no formal authority but with whom they may share a common mission and perspective. These same commanders may have to interact with other agencies of the United States Government, local officials, non-governmental and private organizations, and religious leaders. Commanders may have little or no authority over these elements. Indeed, in the most "anarchic" relationships, these elements may openly oppose U.S. objectives. Nevertheless, commanders must engage in all of these relationships, both the hierarchical and the anarchical, in the battlespace.

Knowledge and Uncertainty. The future operational environment will contain conditions of both knowledge and uncertainty. During recent conventional operations in the first Gulf War, Kosovo, and elsewhere, U.S. forces enjoyed an unprecedented level of knowledge about the battlespace. They achieved information superiority over their adversaries because of their superior intelligence, surveillance, and reconnaissance capabilities. In general, these experiences demonstrated that when a force has information superiority, it can move faster, strike more precisely, and better protect itself from enemy action. To achieve such results, modern C2 systems must not only give commanders a better view of the battlespace (e.g., a better knowledge of enemy strength, location, and intentions), they must also have the mechanisms to rapidly convert that knowledge into action.

A resourceful, adaptive enemy will always try to deprive U.S. forces of their information advantage, to limit their knowledge of the battlespace. Even during recent conventional conflicts when the U.S. enjoyed information superiority, adversaries successfully employed signals security, camouflage, concealment, and deception to degrade U.S. information gathering.[2] In unconventional warfare, insurgents have limited U.S. knowledge of their strength and intentions by blending in with the civilian populace, emerging only long enough to strike and then disappear.

Real-world operations will never be performed under the conditions of complete knowledge or complete uncertainty. Commanders must address the flux between knowledge and uncertainty in the battlespace. They must garner, process, and exploit knowledge. They must also address uncertainty through contingency planning, flexible execution, and risk mitigation.

Centralized and Decentralized Control. Future commanders will employ both centralized and decentralized methods of command and control, selecting the method that best addresses a particular situation. Several factors (e.g., information flow, the mission, the size and

[2] Examples in the media include Serbian passive air defense measures, and cover and concealment of forces, and employment of decoys during the operations in Kosovo. During the U.S. invasion of Iraq, the Iraqi Army was able to disguise the movement of forces by using civilian buses and automobiles. The location of Saddam Hussein was never known accurately enough to successfully target him.

nature of the area of operations, the training and capabilities of the force) will influence the degree to which a commander centralizes or decentralizes control.

Access to information will be the most critical consideration. In general, commanders will centralize C2 when they can quickly and accurately assess the situation and respond in a timely manner. When they cannot meet these criteria, they will normally decentralize C2.[3] Since relevant information flow is always in flux resulting in operations featuring a constantly changing balance between centralized and decentralized C2, the guiding principle will be that C2 authority and resources will follow the flow of relevant information.

The mission will be a strong influence on the approach to command. When an impending operation has immediate and critical political implications, the commander may need to keep a tight rein on the activities of subordinates. Conversely, if the mission requires rapid movement and combat against a dispersed or moving enemy, the commander may decide to decentralize C2 to capitalize on subordinates' agility.

The nature of the terrain in the battlespace will affect the balance between centralization and decentralization. Open terrain, as well as the air and the ocean surface, can facilitate a centralized approach to achieve maximum synchronization among the joint arms. Close, complex terrain (e.g., urban or jungle) and sub-surface seas that limit visibility, mobility, and communications will point to a greater degree of decentralization.

These and many other factors will influence the commander's choice of how to structure C2. The path to success is to avoid selecting one extreme or the other, instead perceiving the dynamic balance between both approaches. A key capability will be the speed and flexibility with which commanders can select and transition between centralized and decentralized control.

Concentration and Distribution of Combat Power. Future commanders will have to concentrate and distribute combat power, selecting the method that best addresses a particular situation. This decision is closely related to the commander's selection of centralized or decentralized control as well as the commander's knowledge and uncertainty about the enemy. When commanders have comprehensive knowledge of the enemy's dispositions, capabilities, and intentions, they can distribute combat power precisely according to purpose without having to worry too much about the enemy surprising him. When, on the other hand, they have only limited knowledge of the enemy, they may need to concentrate combat power as a hedge against uncertainty.

Throughout human history, concentration of combat power, which found expression in the classical principle of mass, was a preferred technique for defeating organized enemy forces on the battlefield. Its counterpart, distribution, was needed for many ancillary tasks, such as

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[3] The Battle of Midway offers an excellent example of decentralized control. Admiral Nimitz, the U.S. Navy commander in the Pacific, took advantage of an intelligence windfall when U.S. code breakers determined that Midway Island was the objective of the Japanese Navy's offensive in June 1942. He dispatched a naval task force under the command of Rear Admiral Raymond Spruance, placing it in position to intercept the Japanese carrier force as it struck Midway. At that point, Spruance was left to execute the tactical portion of the plan, making the critical decisions to strike, to exploit, and ultimately, to withdraw. Nimitz' selection of decentralized control allowed Spruance, the commander on-scene with the most up-to-date information, to make the critical decisions. An example of centralized control would be British fighter operations during the Battle of Britain in 1940. The Royal Air Force merged radar and ground observer information on enemy attacks with up-to-the-minute status information on its fighter squadrons. From centralized fighter direction centers, it vectored its limited number of fighters against German air attacks. In this case, centralized command had the best information, which it used to efficiently direct forces.

population control, efficient movement over road networks, logistical replenishment, and protection from weapons of mass destruction. The key to success in the future operational environment is to appreciate the need for balance between the two extremes.

In general, when commanders lack knowledge of the enemy, they will place combat power in reserve as a hedge against uncertainty. At the other extreme, when commanders have precise knowledge of the enemy, they can most efficiently employ their forces by concentrating power at critical points and economizing forces elsewhere. As a rule of thumb, greater knowledge of the enemy leads to more efficient distribution of combat power. Real-world scenarios will see a constant flux between concentration and distribution of combat power, and the C2 system must facilitate both as well as the transitions between the two.

Proactive and Reactive Decision Making. Future commanders will perform both proactive and reactive decision making. When equipped with the information advantage, U.S. commanders prefer proactive decision making—taking the initiative to exert their will upon the enemy. However, in most operational environments, there are times when the commander must react to enemy initiative.

Proactive decision making works best against an enemy that can be readily anticipated, either because the enemy's fighting doctrine and organization are predictable, or because the friendly force has the information advantage. U.S. forces have developed a targeting methodology that demonstrates proactive planning: *decide-detect-deliver*. The commander decides what effects he wants to achieve, directs his intelligence assets to detect the appropriate targets, and then delivers ordnance onto the targets.

Reactive decision making employs a different dynamic. It recognizes that knowledge of the enemy is scarce and that a commander must react to enemy action. This form of decision making acknowledges that the enemy sometimes has the initiative, particularly under the conditions of unconventional warfare, when the insurgent is skilled at choosing the time and place of attacks. In such cases, the commander must respond quickly to engage the temporarily exposed insurgents and to thwart the enemy's plans. The methodology in this case switches to *detect-decide-deliver*.

A C2 system must enable both proactive and reactive decision making, supporting the rapid and flexible transition between the two.

Conclusion: The Operational Environment is Dynamic and Perpetually Changing

The future operational environment will be rich with complexity, uncertainty, and challenges (see Figure A-1). The interaction of opposite conditions and methods will define operational environments that may change from day-to-day and from hour-to-hour. Commanders must be flexible enough to adjust to the particular demands of the moment, and robust enough to prevail in sustained operations.

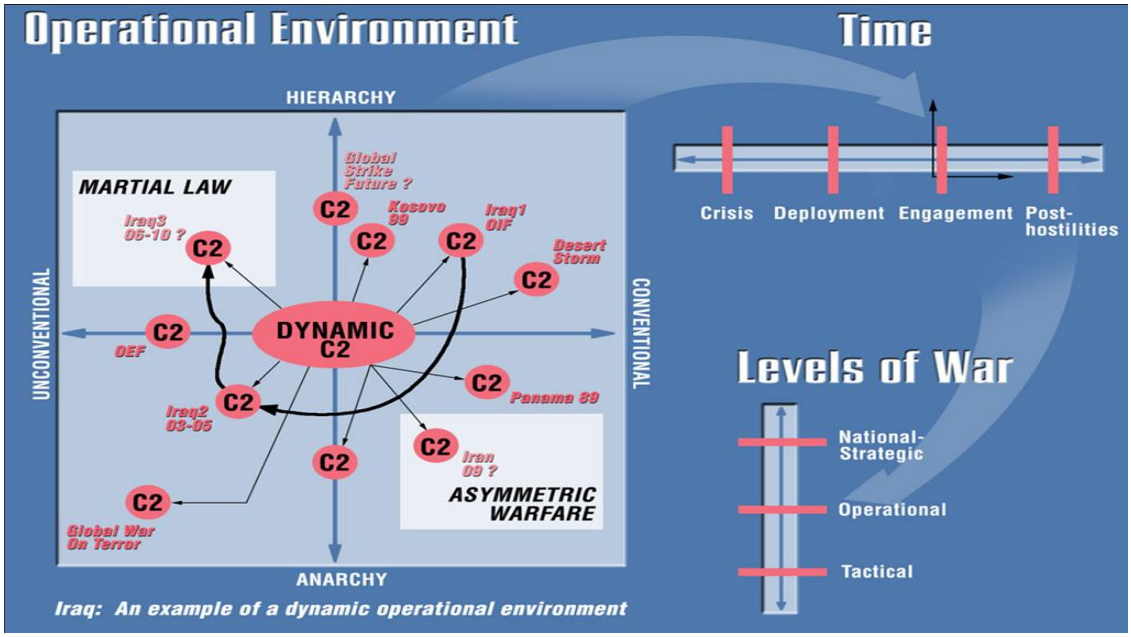

Figure A-1. The operational environment is dynamic; command must be dynamic

FUTURE CAPABILITIES

Commanders throughout the battlespace have much in common: they integrate all the resources of their commands to achieve their objectives, they direct their subordinates, and they comply with the direction of their superiors. They differ in terms of the objectives they are assigned, the resources they command, and the time frames in which they accomplish their missions. Lower echelon leaders will normally focus on events in terms of seconds, minutes, and hours. Higher echelon leaders will operate in terms of days, weeks, and months.[4]

The persistent challenge of any future C2 system is to serve the needs of the various commanders throughout the battlespace, as defined by their objectives, functions, and timeframes, while melding their activities into a single, coherent effort. This challenge must be achieved on many levels. Conceptually, future commanders must recognize and adapt to their future operational environment, modifying their C2 methods accordingly. Technologically, the C2 system must deliver the connectivity, flexibility, and features demanded. Fiscally, the U.S. can likely afford only one global C2 system, not a host of disparate ones.

As noted, C2 is not monolithic. It occurs whenever and wherever someone is exercising command or control over the actions of people and machines. Some C2 elements are quite large, staffed by hundreds of people. Other C2 elements are quite small.[5] Some C2 elements

[4] The distinctions in time scales between levels of command may become blurred when a theater commander must decide in minutes how to respond to a ballistic missile launch, or when a company commander must plot out a six-month campaign to gain the respect and trust of a civilian neighborhood.

[5] For example, an airborne C2 element may have situation awareness of an entire theater's air situation as it directs the detailed execution of an air strike. It is never in formal command of the force, but because of its location, equipment, and crew skills, the commander empowers it to make critical decisions affecting dozens of aircraft because of its minute-by-minute understanding of the situation. The airborne C2 element did not formulate the strike plan and did not make any of the key decisions reflected in the plan, but for the few hours it is on station, it is critical to the C2 of air operations. In contrast, an infantry platoon leader has situation awareness of a very small area based primarily on what he can see and hear and what information is passed up to him by subordinates and passed down to him by his company commander. He will both command and control his platoon. He will formulate plans, make decisions,

specialize in a particular battlespace function, such as targeting, air defense, engineering, or medical operations. Other C2 elements, particularly those supporting joint force commanders, integrate these functions to achieve operational effects. Depending upon the battlespace function they address, C2 elements will have very different needs in terms of the type and quality of information they require, and the timelines in which they plan, decide, and execute.

There are four general C2 functions—situation awareness, planning, decision making, and execution. While some specialized C2 elements may perform only one of these functions, the overall C2 system supporting a commander will likely perform all four functions. The following paragraphs will address each of these functions and suggest future capabilities in each area.

1. Situation Awareness. The foundation of any good decision is good information—what in modern parlance is called situation awareness. A C2 system must provide the commander with accurate, timely information on the enemy and friendly forces as well as other pertinent information on the operational environment.

Different C2 elements have different information needs. The breadth, depth, timeliness, and currency of the information are highly dependent upon the particular needs of the commander involved. For example, an area air defense commander needs situation awareness over a large volume of air space. The information must be adequate (timely, accurate, current) to support immediate decisions on whether or not to engage aerial targets. In contrast, military police brigade commanders supporting counter insurgency operations are normally not concerned with the second-by-second situation in the air. However, they do need to know when and where the enemy has fired on friendly aircraft and any other intelligence on enemy activities. They need to know friendly convoy schedules, and reports on friendly military, local police, and reconstruction activities in their area of operations. They need to know the location of key installations, schools, hospitals, power stations, communications towers, and a host of other special interest information. Other commanders, focused on functions such as close air support, medical operations, mine clearing, will likewise have information needs focused on those functions. It is important to note that these various consumers of information are also sources of information.

A flexible C2 system must enable commanders to define their own information needs and quickly collect and assess that information. Likewise, the C2 system must quickly accept and assimilate information provided from the many sources within the battlespace. The challenge of collecting, storing, delivering, and fusing information is well understood, but largely unresolved. While strides have been made in fusing some types of sensor data [radar, electro-optical/infrared (EO/IR), and signature data], the capability to fuse other types of information (intelligence reports, police reports, etc.) remains incomplete. An equally important future capability is the characterization of information in more depth, indicating its age, the confidence placed in its accuracy, and the degree to which it conforms with or contradicts other information. Presenting large amounts of information to the depth described places added emphasis on the need for better characterization and visualization of information.

Multi-level security. Any C2 system that collects and distributes information must have safeguards against enemy attack and exploitation. However, sharing information across different levels of security is a key desired capability. As noted above, future commanders will need to interact with many elements in the battlespace. The capability to grant access to selected

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and execute a fairly wide range of operations. He will perform these tasks with a relatively simple suite of equipment, day-in and day-out, for the duration of a campaign.

intelligence and operational plans will improve the commander's ability to work with other agencies—particularly when performing disaster relief, such as the distribution of food and medical supplies in hostile environments. By enabling the commander to flexibly and selectively share information, the C2 system can foster important relationships and extend the commander's knowledge and influence in the battlespace.

Shared awareness and understanding. Given that future commanders will work with extended teams that include coalition partners and others with various levels of security clearance, shared situation awareness/situational understanding, will not be identical for all participants. While emerging concepts of network-enabled warfare assume the desirability of shared situation awareness, it is conceivable that, under some circumstances, the commander will want to limit knowledge of certain aspects of the situation. Therefore, a flexible C2 system must not only enable shared awareness and understanding, but may also compartment particular information.

2. Planning. Planning and decision making overlap. Planning both informs the commander's decisions and implements them. It generates courses of action as the basis for command decisions. Once a decision is made, planning produces the detailed information and orders needed to implement the decision. Planning may involve thousands of participants and span months and years of preparation time, or it may involve only a few people over a few hours or days.

Future C2 systems can improve planning, in all its many variants, by giving planners better tools to develop, evaluate, and rehearse plans. The C2 system should give commanders and planners the requisite tools to perform accurate and timely estimates of required combat power, logistical support, and time needed for operations. The system should reduce, or eliminate, the requirement to manually research and produce information, automating processes wherever possible and allowing planners to focus on the implications of the information.

Course of action development. The commander will normally provide mission guidance to planners in order to focus their efforts and reduce planning time. Automated planning tools could improve this process by helping commanders and planners develop key information. Even at the earliest planning stages, comparisons of enemy and friendly capabilities and assessments of terrain, distances, timelines, force availability, and fuel consumption could shape the course of action development. Ideally, planning tools function like an artist's palette, facilitating the rapid development of creative and effective courses of action.

Collaboration. Collaboration plays a critical role in planning. No single organization has all the necessary information, all the capabilities, or all of the responsibilities. Commanders must address both hierarchical and anarchical relationships and operate under conditions of knowledge and uncertainty. Planning will take place in the same environment. Planning must cut across organizational boundaries, both vertically and horizontally, to share information and to synchronize action. Supported units and supporting units should be dynamically linked, sharing information throughout the planning process so that supporting functions (e.g., fire support, engineering, communications, fuel) arrive at the right locations at the right times. Collaboration tools should be the most important tools in a planner's toolbox.

Melding planning, wargaming, and rehearsal. Before the development of computer tools and digital networks, planning, wargaming, and rehearsal tended to be separate and sequential activities. Headquarters prepared plans, issued orders, and used rehearsals to instruct subordinate units and staffs on the plan. Wargames offered opportunities to evaluate plans and refine them, but their size and complexity tended to limit their use to peacetime or pre-hostilities.

In the future, tools and processes should meld these activities, allowing each to compliment the other. Plans subjected to wargames and rehearsals would benefit from the insights of those expected to execute the plans, identifying previously unforeseen events or considerations, which could be incorporated into revised plans. Likewise, those executing plans would have higher confidence in their value as a result of their validation through wargaming and rehearsal.

Obviously, some situations are more amenable to wargaming than others. Problems such as the configuration of theater air defenses, allocation of transportation assets, and placement of medical facilities, might be assessed through modeling and simulation. Other activities involving the interaction of many elements, such as ground maneuver, would be more problematic to assess. Nevertheless, the visualization and step-by-step examination of such courses of action could identify choke points, key terrain, critical events, and synchronization issues.

Orders preparation, dissemination, and presentation. The traditional method of preparing and disseminating orders is through the written word. The telegraph, teletype, and digital networks have improved the speed of delivery. Operational overlays and schematics have improved understanding. Word processing has improved production. Visualization and animation have the potential to improve the presentation of information, to migrate from voluminous text documents, to fuller, richer presentations of plans and orders.

3. Decision making. Decision making is at the heart of C2. For simplicity of presentation, this paper has generally identified the commander as the decision maker. In truth, commanders routinely delegate decision-making authority to many people whose decisions are often critical. Whether directly supporting the commander's decisions, or those of others, future C2 systems must better inform and assist—not supplant—human judgment. The following topics highlight key capabilities of future C2 systems.

Proactive and reactive decision making. As described above, commanders will fluctuate between proactive and reactive decision making. When they have the initiative, they can dictate the pace of battle and force the enemy to react. When they do not have the initiative, they will be forced to react to enemy action. Future C2 systems must support both methods.

Speed of decision. Speed of decision is a critical measure of decision making. The less time commanders consume in reaching decisions, the more time they leave to their staff and subordinates for planning and execution. In proactive decision making, speed of decision allows the commander to maintain the pace of operations, to make decisions and to execute them, faster than the enemy can react to them. In reactive decision making, speed of decision may enable the commander to regain the initiative, or at least mitigate the impact of enemy action. Future C2 systems must improve the speed of decision making.

Quality of decision. The value of quick decisions is directly related to the quality of those decisions. Military history has many examples of bad decisions made quickly and good decisions that arrived too late. The essence of command is balancing speed of decision with quality of decision; future C2 systems should assist decision makers in balancing these two attributes. Decision aids should help calculate decision time lines, identifying when decision making must occur, assessing the likely tradeoffs between hasty and deliberate decisions, and, when possible, evaluating the quality of decisions. Evaluating the quality of decisions is no simple task, but it supports two essential tasks of command: to learn from successes and failures,

and to adapt.[6] Future C2 systems should support this process of evaluation, learning, and adaptation.

4. Execution. Execution refers to the actual conduct of operations.

Integration of functions. In many ways, execution is the integration of the first three functions of C2: situation awareness, planning, and decision making. In describing these functions, it is implied that they occur in sequence: situation awareness informs planning and planning informs decision making. During execution, these functions often occur in parallel. Situation awareness continuously reveals how well the plan is progressing and whether or not new planning and decision making is needed. Likewise, planning and decision making continuously focus on situation awareness assets (directing intelligence collections, assessing target damage, assessing force capability, etc.) in anticipation of future needs.

During execution, the functions of situation awareness, planning, and decision making take on greater urgency. Many of the topics described above (timeliness of information, collaboration, rehearsal, speed of decision, and quality of decision) place a greater premium on responsiveness.

Mobile C2. Commanders are more than decision makers; they are leaders who must train, lead, and inspire. They must see and be seen across the battlespace—particularly during execution. They must be mobile within the battlespace: able to meet face-to-face with subordinates and superiors, and able to see key situations firsthand. Future C2 systems must permit commanders to exercise C2 on the move by providing situation awareness, planning, and decision-making capability to wherever the commander chooses to go, aboard whatever conveyance they select.

C2 OPERATIONAL ENVIRONMENT CONCLUSION

The demands of the future operating environment will tax the creativity and innovation of future command and control practitioners. Equally taxing are the demands of present day C2 system development, which require current C2 developers to anticipate future needs and deliver new capabilities into the battlespace. Given the complexity and diversity of C2 elements in the battlespace, it is optimistic to expect a single document to comprehensively describe C2, let alone amalgamate all C2 elements within that document. Such a goal is akin to describing such a broad topic such as "business management," and coalescing all industries, markets, and firms into a single business model. The purpose of the operational environment description is to offer a broad conceptual view of the future operating environment and to offer insights into what capabilities future commanders will likely require of their C2 systems. The intent is not to define requirements, or even to sow the seeds of innovation, but to provide fertile ground for future planting.

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[6] Decisions involving well-defined procedures and measures, are more amenable to assessment. For example, air battle management decisions in which friendly aircraft are vectored to intercept enemy aircraft, have well-defined procedures, are driven by key, discrete measures (altitude, range, speed, weapons load, engagement range, etc.), and have definitive, measurable results (target intercept and kill). With the aid of sensor logs, these events can be reconstructed and assessed. Other decisions, particularly those involving many subordinate decision makers, uncertain measures, and uncertain results, are much more problematic to assess. For example, judging the quality of decisions within a six-month counter-insurgency operation is difficult to reconstruct, let alone define measurable results and ascribe quality.

APPENDIX B

C2 HYPOTHESIS DEVELOPMENT

A major use of a proposed concept is for it to be the basis for testing and experimentation that eventually leads to programmatic decisions and the development of solution sets. In order for a concept to properly support the process, one must be able to derive from it clear and effective hypotheses—propositional statements that can be evaluated in testing and experimentation. Hypotheses might be validated in the course of this process and therefore become the basis of a solution set, or they might be disproved and discarded or modified.

In the primer "The Logic of Warfighting Experiments," Richard Kaas provides a rationale and approach for developing **warfighting experiment hypotheses**.

> "It is useful to consider three different levels of ***warfighting experiment hypotheses***. At the most abstract level, the if-then aspects are described in terms of capabilities and operational effects. These capability hypotheses, however, are not useful to experimenters who require hypotheses with implementable treatments and observable effects. The high-level "capabilities hypothesis" needs to be translated into one or more "experimental level" hypotheses. This is accomplished by translating the high-level capability into *enabling* systems that can be surrogated or modeled in an experiment." Richard A. Kaas, *The Logic of Warfighting Experiments*, CCRP, 2006.

The application methodology outlined by Kaas begins with a restated *conceptual idea* derived from current literature. Capability-level hypotheses are developed from that idea and from those hypotheses, experimental-level hypotheses are derived. These might be derived from field experiments, tabletop experiments, or war games. Lastly statistical-level hypotheses are described against which specific measurements relating to performance can be made.

The development of working hypotheses at all three levels outlined above would be beneficial to the both command and control practitioners and system developers. However, there is not a common forum within which the C2 community of interest undertakes hypotheses development. JHU/APL undertook an effort to provide a venue in which preliminary steps could be undertaken to develop a set of candidate operational hypotheses. The study team envisioned development of hypotheses related to the four major capabilities previously discussed in this paper. Further, it was intended that each hypothesis should include a brief discussion of background information (why the hypotheses is important) and offer guidance for later testing and experimentation, including recommended methods of measurement.

APPENDIX C

HYPOTHESES

H#	Averages in Quartiles Across Matrix (highest is best)	Priority	STD
1	H1. - If the quality of synchronized data meets necessary attributes to support decision authority, then flexibility exists where decisions can be made.	3.20	1.15
2	H2. - If the quality of synchronized data meets necessary attributes to support decision authority, then decision quality (timeliness, accuracy, and assuredness) will be improved.	3.40	1.06
3	H3. - If the same actionable data are available to the entire command structure, then there is improvement in horizontal and vertical coordination that enables decision makers to operate inside the enemy's decision cycle resulting in achieving the desired effect.	3.90	1.06
4	H4. - If the same actionable data are available across the command structure, then each command can simultaneously operate across the spectrum of supported and supporting with all other command nodes.	3.50	1.02
5	H5. - If you add situationally invoked security policies (bend to rules), then you can significantly increase the mission effectiveness of coalition operations.	3.30	1.34
6	H6. - If provided a collaborative environment tailorable to decision makers, the quality of decision will be increased.	3.90	0.85
7	H7. - If we create the ubiquitous network where everyone has access, then as situational stress increases, the individual will fall back on hierarchal trust relationships.	2.70	1.34
8	H8. - If there is access to the ubiquitous network that could lead to information/sensory overload, then there is an impact on how decision makers collaborate.	3.20	1.09
9	H9.- If a standards-based security capability is implemented in network management tool suites, then we can detect, in real time, intrusions into the Terrestrial GiG sub-networks [NIPR and SIPR] as measured by frequency and type of attack.	2.40	0.89
10	H10. - If the characteristics of existing networks are understood, then joint standard procedures could be developed to define how to manage and integrate the networks.	2.90	1.25
11	H11. - If a joint knowledge management capability (process and technology) is established, then military decisions would be more agile and effective.	2.90	1.14
12	H12. - If the knowledge shared with disadvantaged users is limited by technology, then decisions will be impaired.	3.00	0.95
13	H13. - If a joint collaboration capability is established that can exchange and manage knowledge, then joint military operations will be more effective.	3.70	1.01

H#	Averages in Quartiles Across Matrix (highest is best)	Priority	STD
14	H14. - If we improve our sensing and understanding of non-physical domains, then we will create new action options for ourselves, better understand how to eliminate the enemy's options, and better predict the outcome of our actions.	3.90	1.15
15	H15. - If we understand the enemy and the environment, then we will be able to turn the enemy against itself.	3.80	1.31
16	H16. - In some cases, if we turn the enemy against itself, we will achieve our objectives more quickly and efficiently than if we use our own resources alone to defeat the enemy.	3.20	1.29
17	H17. - If we had the capability to know when to delay killing an enemy asset, then we could learn more about the overall enemy activities and achieve our objectives more efficiently.	3.00	1.00
18	H18. - If we use cyberspace options, then our response time can be reduced.	3.40	1.06
19	H19. - If we can influence the opponents through cyberspace, then we can effect operations anywhere in the world.	3.80	1.07
20	H20. - If we improve our ability to share learned successes (and failures), then we will be more adaptable to a rapidly changing environment.	4.00	1.00
21	H21. - If we use shadow commanders (some of which are machines) to create a market of C2 decisions, then better COAs will be developed and selected.	3.30	0.96
22	H22. - If we use shadow commanders to create a market of C2 decisions, then those personnel who consistently perform well will be easily identified.	3.00	1.00
23	H23. - If procedures are altered to allow improved feedback, then learning will be improved.	3.40	1.17
24	H24. - If we can use rewards and incentives effectively, we will be able to influence the behavior of groups (NGOs, partners, local population) that we don't "control."	3.30	1.17
25	H25. - If we used market-based (dispersed) planning function, then we could rapidly plan and replan.	2.80	1.02

The color coding scheme for the priority and standard deviation is that green is the best (highest priority or lowest standard deviation), white or gray is near the median, and red is the worst (lowest priority or highest standard deviation). High standard deviation suggests disagreement as to the value of the hypothesis or statement in question.