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COALITION COMMAND AND CONTROL IN THE NETWORKED ERA

Modeling and Measuring Network Centric Warfare (NCW) With the System Effectiveness Analysis Simulation (SEAS)

Topics: Network-Centric Metrics, C2 Modeling and Simulation, C2 Analysis

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Abstract

Significant advances in technology, especially in the areas of communications and data processing, over the past few decades have fueled the continual and rapid development of an information-based world. As a result of these technology advances, Network Centric Warfare (NCW) has become the buzzword of the young millennium within the Department of Defense (DoD). NCW is quickly becoming a popularly shared vision and rallying cry for transformation among United States military leaders. The U.S. military is beginning to understand how to effectively go about the business of warfare and conflict resolution within the framework of this brave new information centered age. An essential aspect to implementing this net-centric way of thinking is to formulate and develop pertinent measures that can help to gauge the effectiveness and efficiency of both our military networks and our strategic NCW constructs. This research is focused towards establishing clear and realistic measures that can be captured within a simulated combat environment and serve as metrics for determining the strength or weakness of our military network structures. We utilize the System Effectiveness Analysis Simulation (SEAS), a mission-level combat model, to serve as a tool in exploring the use of these NCW metrics in military worth analysis.

Introduction

In the current Information Age, success or failure of operations often relies heavily on the ability to gather, translate, and process a large amount of data and information. Evidence of this phenomenon can clearly be seen within two distinct environments: the American business arena and the World Wide Web. In the American business arena, Wal-Mart has moved from a traditional retailer to a *precision retailer* by achieving information superiority in its domain [Alberts, Gartska, and Stein, 1999:46]. The end result of Wal-Mart's highly network and information-focused approach to retail sales is that its stores reign as the nation's top retailer, having $256 billion in annual sales for 2004 [Wal-Mart, 2005:2]. As for the World Wide Web, the multitude of applications for networking and sharing information on a global scale continue to be developed and applied.

The same principles of information dominance and power which have transformed the U.S. market place and linked the world via the internet apply equally to the United Stated military. Information technology has significantly changed our concepts of time and distance. Distance is becoming less relevant as large amounts of information are able to be transmitted and received with increasing ease and speed. Within the battlespace, this shrinking of distance and time translates into increased combat capability and the potential for orders of magnitude increases in mission effectiveness and efficiency. The key to realizing this potential is the ability to fully utilize our systems of sensors, data processors, communication links, and decision-making methods.

A ground-breaking concept that moves the U.S. military towards the goal of achieving maximum combat success and efficiency through utilization of network technology has emerged over the last five to ten years. This revolutionary idea is called Network Centric Warfare (NCW). The defining characteristics and exact applications of NCW are continually evolving, as are its applications. NCW finds itself being explored and studied as part of a larger initiative within the DoD, that of transformation. A primary goal of transformation is to keep the United States military at the forefront of warfare technology, tactics, and knowledge of the enemy.

The technological advances of the Information Age have not only increased capacities of information exchange and decreased information processing time, but have also increased levels of complexity involved with sorting through data and information to find the packets that are pertinent to a certain decision or problem. The higher levels of complexity involved in vast information networks and systems make it difficult to assess the relative worth and efficiency of these networks and systems. The development of basic, definable, and measurable metrics is required in order to serve as diagnostic tools for rating the effectiveness of network performance and impact on command and control, especially within a military system or tactical engagement.

We first define Network Centric Warfare (NCW) from reputable research literature and doctrinal documents pertaining to the subject for use in our combat modeling context. This definition is formed against the back-drop of the larger picture of force transformation currently being employed within the Department of Defense. Once defined, various modeling techniques and metrics for NCW are addressed and established. From these proposed models and metrics, a specific modeling option is selected and utilized in order to measure the military worth of NCW in a well-defined mission level scenario. Our simulation study is designed to contrast the performance of an NCW-enabled force in a given combat scenario versus the performance of that same force acting at selected degraded levels of NCW capability. The outputs resulting from the baseline case and the NCW degraded cases are analyzed to provide insight into how to best model and measure NCW capabilities in a combat simulation.

Methodology

This research effort focuses on representing NCW characteristics and capabilities within a combat model, specifically within the System Effectiveness Analysis Simulation (SEAS). With this specific application in mind, a customized definition of NCW was formulated to conceptually match this application and provide a sufficient doctrinal baseline. The following definition of NCW is used for our effort: Network Centric Warfare is the conduct of military operations through the utilization of networked information systems, which supply the warfighter with the right information at the right time in the right form to the right person being put to the right use, in order to achieve desired effects across the physical, information, and cognitive domains of the battlespace. Sources consulted for this definition include [Alberts, 1999; Fewell, 2003; DoD, 2000].

Definition in hand, Agent-Based Modeling (ABM) is now examined as an appropriate approach to represent NCW in a combat simulation. ABM provides an effective representation of what Kewley and Larimer [2003:10] call the critical gap in military modeling capabilities, the ability to model how a combat soldier makes a tactical decision. The ability to represent agent decision making relates well to modeling NCW because the utility and overall effectiveness of a network cannot be properly evaluated without an accurate representation of the entities using the network and interacting within the network. Kewley and Larimer [2003], state that the increased capability of network-centric forces, if it really exists, is an emergent property that cannot be proven with attrition-based equations of combat. ABM has the capability to effectively capture the cognition and judgment stages that occur in between the data/information levels and the final decision to act.

Agent-based logic and programming is a relatively new approach to modeling in the military M&S community, tracing its roots to an initiative started within the U.S. Marine Corps. In October 1995, at the direction of the Commanding General of the United States Marine Corps Combat Development Command in Quantico, two scientists embarked on what is now called *Project Albert* [Brandstein, Home, and Friman, 2000:64]. Project Albert used a combination of new models and tools, multidisciplinary teams, and the scientific method to understand how agent-based modeling techniques could be correctly applied to represent a broad spectrum of military operations. In summary, Project Albert was designed to develop new tools to capture emergent behavior in synthetic environments that over time will lead to more effective maneuver warriors [Brandstein, Home, and Friman, 2000:65].

ABM has since emerged as a modeling technique that is more realistic for today's combat scenarios than are the classical Lanchester-based models. Lanchester equations are deterministic differential equations. The unalterable outcome of combat adjudication is based on the starting troop strengths and their attrition rates. These equations provide a very simplistic and intuitive framework for modeling warfare. However, Lanchester equations are very limited when it comes to representing the complex interactions of real-world combat because of their high degree of aggregation and constant attrition rate factors [Tighe, 1999]. Perhaps the greatest strength of ABM is its ability to effectively represent the random and unpredictable behavior of entities within a system, as well as the consequent outcomes resulting from interactions of such entities. The effects of random individual agent behavior and of the resulting interactions of agents are phenomenon that traditional Lanchester equation-based models simply cannot capture.

The basic idea of agent-based modeling is that autonomous agents are given a set of rules, which determine how they will respond to a set list of inputs or conditions within the model. An agent-based model is one in which the connections and interactions among the agents has significant effects, as compared to the individual actions of any particular agent [Kewley and Larimer, 2003:11]. ABM results in a realistic simulation of a system because it emulates the manner in which the world really operates [Cares, 2002:935]. In a combat modeling context Red (enemy) and Blue (friendly) forces make up a dynamic, non-linear, complex adaptive system in which the overall system behavior emerges from the aggregate interactions among individual agents [Cares, 2002:936].

SEAS is a constructive, agent-interaction based simulation designed specifically for exploratory analysis of transformational, information-driven warfare across surface, air and space domains [SPARTA, Inc., 2005]. It is an agent based combat model developed and maintained by SPARTA, Inc. for the Space and Missile Systems Center Directorate of Transformation and Development (SMC/TD). SEAS is one of the models in the Air Force Standard Analysis Toolkit and is quickly becoming a popularly utilized software tool in the defense M&S community, especially within the USAF.

SEAS has the ability to model the presence and interaction of a large variety of unique agents within a combat mission scenario. Some examples of the agents that can be represented in SEAS are tanks, SAM sites, UAVs, fighter jets, and satellites. A typical mission scenario which SEAS has the capability of representing is shown in the Figure 1. As illustrated SEAS can not only represent various combat agents, but also their respective sensors and communication devices.

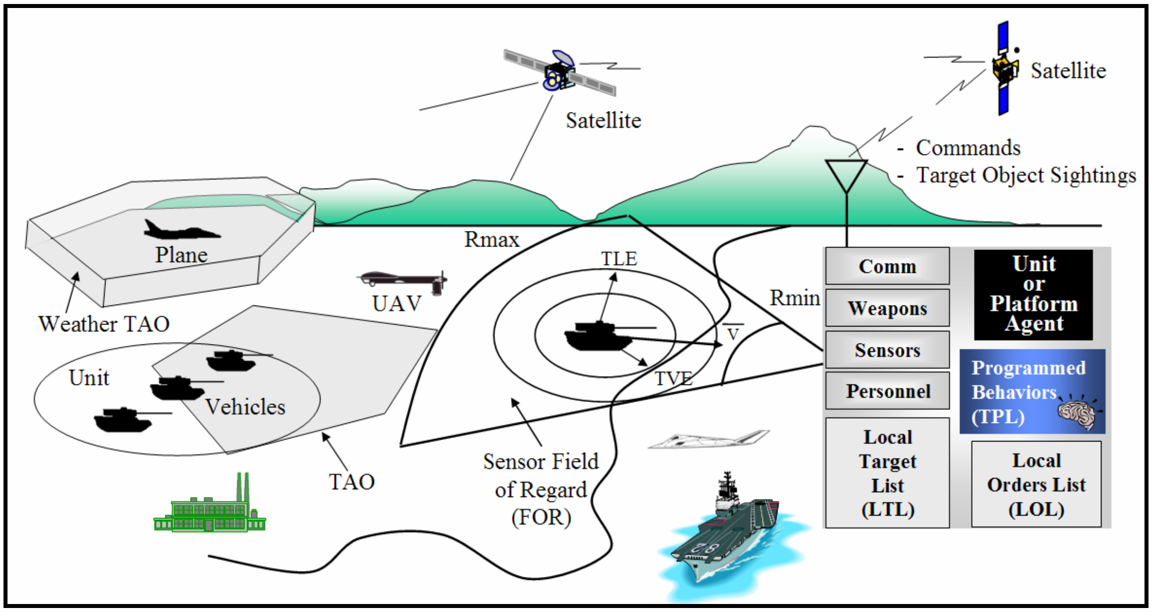

Figure 1. SEAS mission scenario representation [SPARTA, 2005:slide 2]

SEAS is built around three simple entities: agents, devices and environments. Agents interact through the use of devices (weapons, sensors, communication) with each other and the environment. Conflict outcomes emerge from these resulting interactions. Agents are logical members acting within the combat mission scenario. They can be units, such as a brigade or multi-ship formation of planes, or subunit members such as a vehicle, individual plane, or satellite. Devices include communications, sensors, and weapons. The environment is the battlespace, which consists of events, locations, terrain, weather, jamming, and day/night characteristics.

A SEAS agent has the capability to move around, sense things, talk to other agents, utilize and acquire resources, and kill other agents in an environment. Agents can be assigned orders from superiors and can also be given "local programming" that will override the original orders in a given situation, if certain requirements and conditions are met. Agents can also play various roles such as an observer, killer, or even leader/controller of other agents. Each agent with sensing capability keeps a list of targets to be prepared to carry out an order either to 1) do nothing, 2) move toward them, 3) move away from them, 4) tell others about them, or 5) kill them or perform some combination of the above [SPARTA, Inc., 2005:slide 5]. Agents and their respective interactions follow four key concepts: the local target list (LTL), local orders list (LOL), target interactions range (TIR), and broadcast interval (BI). All four of these key concepts interact with each specific type of agent and the scenario environment to produce conflict outcomes within SEAS.

Measures of NCW

There are several difficulties faced when trying to form a clear definition of NCW and formulate an appropriate model to represent it. The task of determining appropriate and measurable metrics for NCW also poses a difficult and unique challenge. There are a wealth of measures that have been formulated to date and recorded in various documents and references. For example, Fewell and Hazen [2003] provide a comprehensive list in the form of several tables which describe a large number of possible NCW metrics. Alberts et al. [1999] developed a basic guideline for metrics, shown in Figure 2.

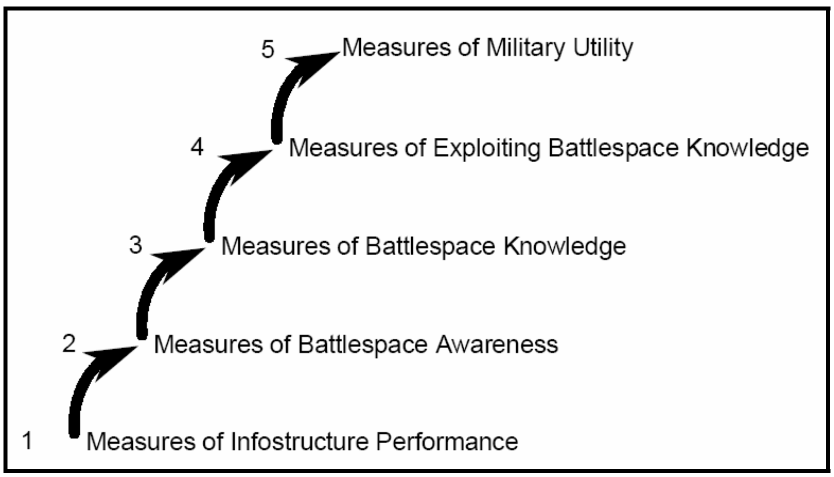

Figure 2. NCW Baseline Metrics [Alberts, Gartska, and Stein, 1999:219]

Infostructure Performance, Battlespace Awareness, Battlespace Knowledge, Exploiting Battlespace Knowledge, and Military Utility are general categories under which more exactly defined metrics for NCW fall. Fewell and Hazen [2003] describe metrics for the characteristic ‘speed of command’, force agility and the ability to amass effects, the ‘degree of autonomy’ aspect of self-synchronization, the level of shared situational awareness, the conduct of effects-based operations, reachback operations, information superiority, the degree of interoperability, and mutual trust. All total, thirty-three different metrics falling under these main headings are described in their document. However, as Fewell and Hazen [2003:37} point out, none of these metrics serve as an indicator of the level of network centricity even though they do describe characteristics of net-centric systems. Further, they propose that the key characteristic of network centricity is the broadening of warfighter focus away from the individual, unit or platform concerns to give primacy to the mission and responsibilities of the team, task group or coalition. Quantifying this ‘broadening of focus’ is a difficult problem, especially when one tries to do so in a sense that is independent of a specific scenario.

Ling, Moon, and Kruzins [2005] propose more quantifiable metrics for measuring network centric warfare in the form of connectivity, reach, richness, and characteristic tempos. Figure 3 shows interactions between the OODA loop and these various metrics.

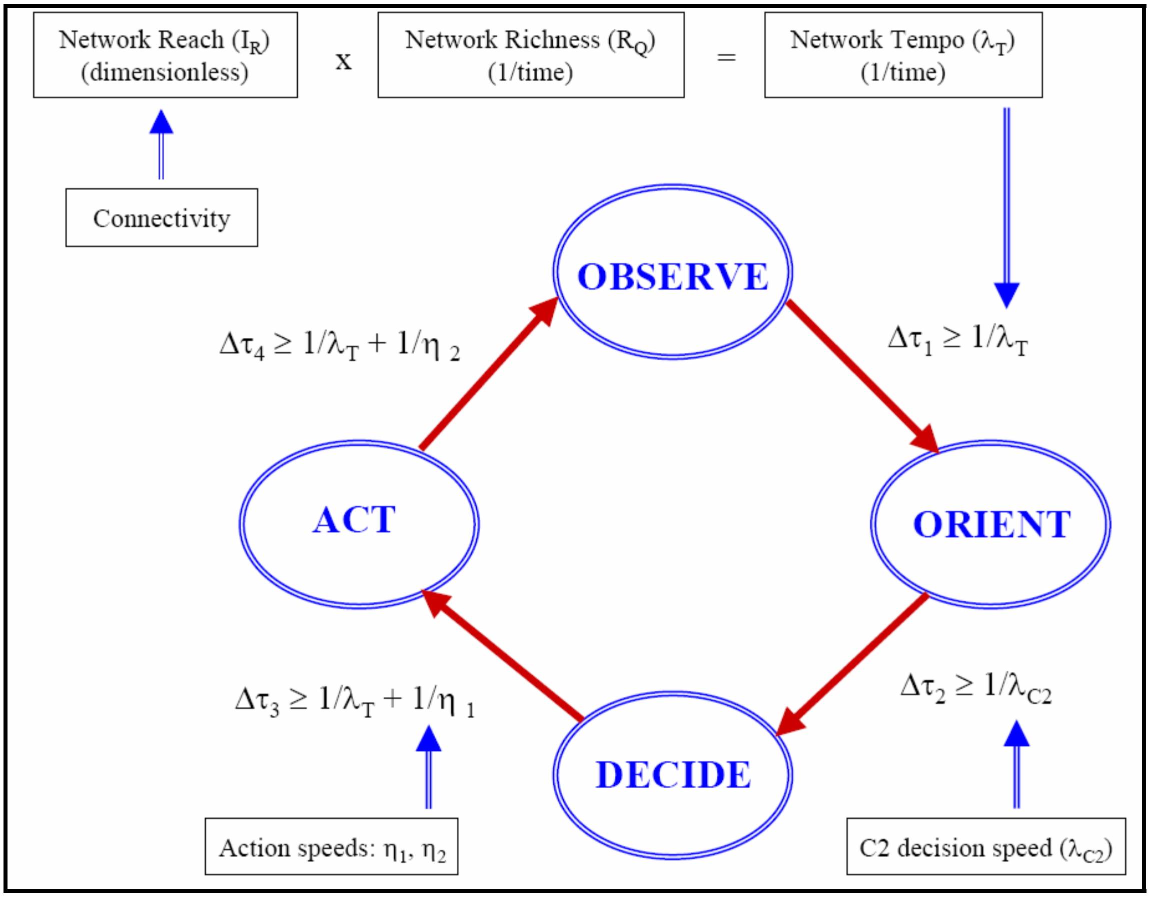

Figure 3. OODA Cycle with Proposed Metrics [Ling, Moon, and Kruzins, 2005:10]

Perhaps the simplest and most straight-forward place to start in quantifying and measuring a force's degree of NCW capability is to focus on network transmission delay time and the corresponding time required to make a decision to act. This second metric, decision time, may be more difficult to track and measure than network delay time. SPARTA proposes the use of the NCW End-to-End (NETE) model and SEAS as a way to measure network delay time, stating that one way to use these tools together is to use measures of performance (MOPs) from NETE to represent network delay times in the SEAS model where the overall campaign is simulated [Walsh, Roberts, and Thompson, 2005:6].

NCW Modeling

A SEAS scenario possessing a relatively high degree of complexity is required to adequately characterize the key elements of conducting NCW, namely the operation and coordination of sensors, communication devices, weapons systems and decision-making entities. An appropriate scenario which meets these criteria was utilized by DeStefano [2004] and Zinn [2004] for their collaborative thesis efforts. This particular scenario was written to represent a mission scenario typical of the Kosovo conflict during 1999. The SEAS warfile for this Kosovo scenario was created for the Air Force by the MITRE Corporation in Hampton, VA [DeStefano, 2004:3-1]. The scenario consists of a Blue United States Air Forces in Europe (USAFE) force, a Red Serbian force, and a Brown Kosovar force of militia and civilians, all programmed to operate and interact within the context of typical operations in the Kosovo conflict during 1999. It essentially models Red forces conducting "ethnic cleansing" operations against the Brown civilians [Zinn, 2004:48]. Blue force's objective is to stop the Red force from killing the Brown force. Blue achieves this objective by attacking the Red force and by attempting to contain their military operations and movements.

A graphical depiction showing several of the key locations for the scenario is illustrated in Figure 4. This figure shows several Tactical Area of Operations (TAO) areas, all of which are shown as irregular shapes bounded with black lines. The largest TAO, *BalkanWxTAO*, represents a region of weather whose attributes, primarily altitude range and intensity factor, degrade communication signals' transmission/reception and sensor performance occurring in the areas bounded by the TAO. Another significant TAO, *KosovoTAO*, lies within the *BalkanWxTAO*. Also shown in this figure are the *GH_Orbit*, *Predator_Orbit*, *Gunship_Orbit*, *JSTARS_Orbit*, and *SOF Patrol* TAOs which specify aircraft orbits and troop patrol areas, respectively.

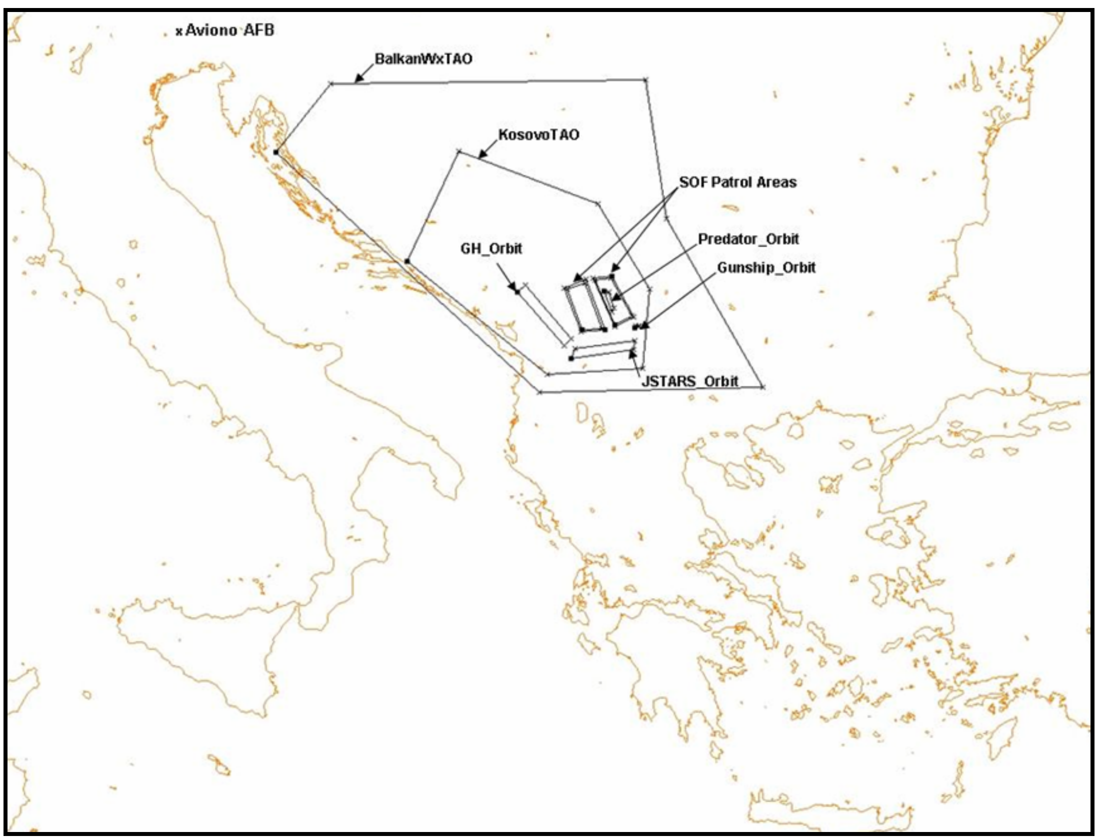

Figure 4. Kosovo Scenario Locations

Figure 5 illustrates the specific attributes within SEAS that are affected by weather and terrain TAO areas. Weather is listed as affecting platform speed, sensor probability of detection, weapon probability of kill, and communications reliability. Terrain is listed as affecting platform speed, sensor range, weapon range, and communications range. It is important to keep in mind that the degradation effects implemented in the Kosovo scenario are being utilized as generic ways to degrade network performance on a large-scale (*BalkanWxTAO*) and more local scale (*KosovoTAO*), both of which affect unique aspects of performance. The *KosovoTAO* draws the boundary for a terrain region whose degradation factor degrades the ability of the Blue Force's UAV to see targets and therefore makes the simulation of the UAV patrolling the area more realistic. In other words, agents will occasionally be hidden from the UAV's view because the terrain factor (which ranges from 0 to 1 in SEAS and is set at 0.8 for the *KosovoTAO*) is applied to all sensing operations within that TAO and will only allow a percentage of line of sight detections to occur. For instance, within the *KosovoTAO*, only eighty percent of the modeled target sightings in that region will be recorded as a detection.

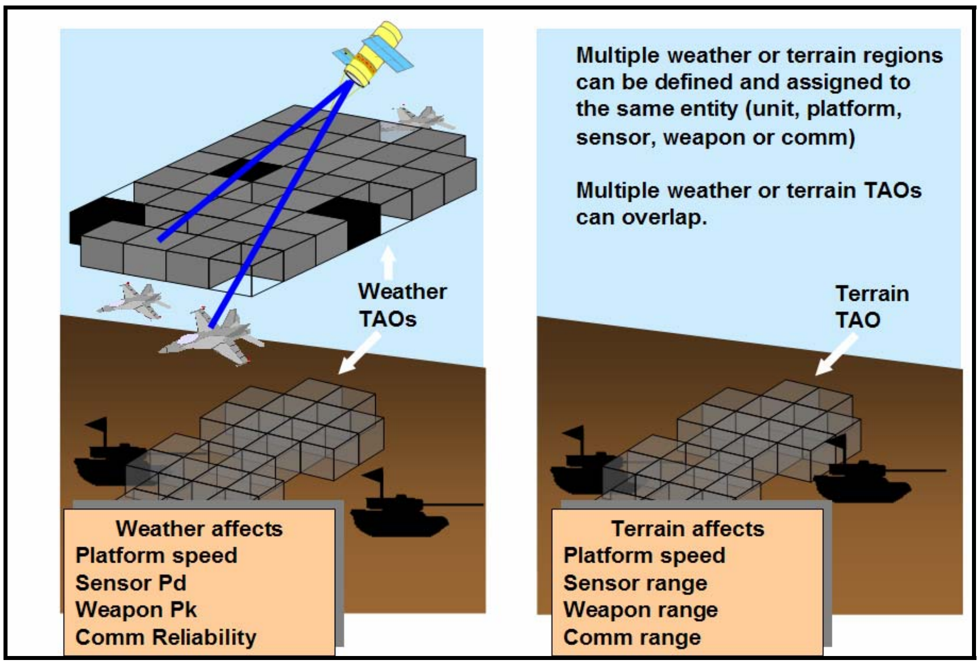

Figure 5. Weather and Terrain Effects in SEAS [SPARTA, 2005]

Now that the timing, location, TAO, weather, and terrain blocks have been covered, we briefly describe the forces, units, and vehicle hierarchy of the scenario. As previously mentioned, there are three forces in the Kosovo scenario: a USAFE force, Serbian force, and Kosovar force. Figure 6 gives a graphical depiction and breakdown of the Blue USAFE force.

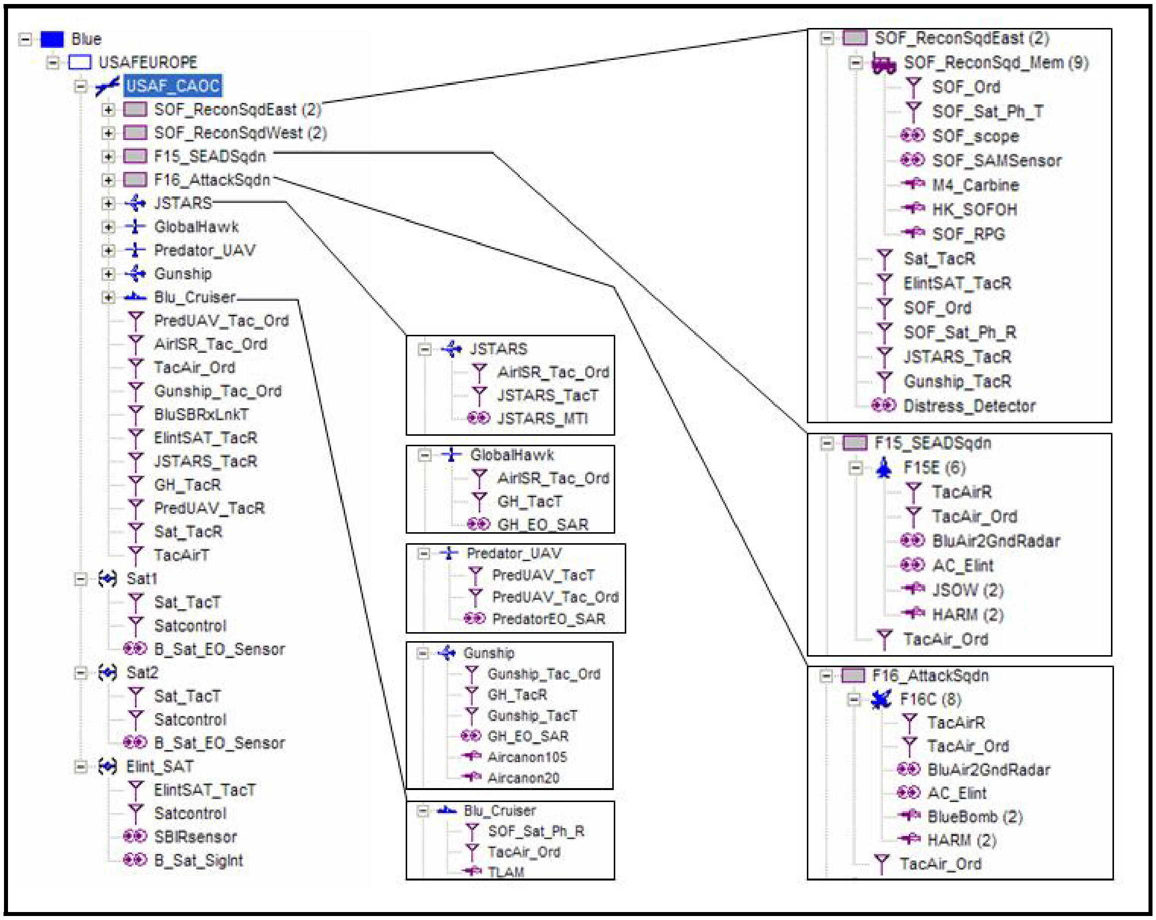

Figure 6. Blue Force Structure

As can be seen from Figure 6, the Blue force has a considerable number of units and vehicles, especially in relation to the Red and Brown forces, which are discussed later. All units for the Blue force fall under and are owned by the USAF Combined Aerospace Operations Center (CAOC), which is referred to as the "parent unit" for the Blue force. The significance of the parent unit is that a parent's orders take precedence over any orders that each individual "child unit" (units that are subordinate to the parent) may have within their own code block. The Blue Force Structure illustration depicts the typical force breakdown within SEAS, in which units are composed of vehicles (e.g. the F15_SEADSqdn is composed of multiple F-15s), each having the potential of owning sensors, communication devices, and weapons. For example, the Special Operations Forces (SOF) units of East and West (West unit breakdown is not shown in the figure since its composition is identical to the East unit) both own the communication device *SOF_Ord*, the sensor *SOF_scope*, and the weapon *M4_Carbine*. The numbers in parenthesis following any name in the hierarchy indicates the quantity of a particular unit or vehicle within the Kosovo scenario. For instance, the Blue Force has two *SOF_ReconSqnEast* units, nine *SOF_ReconSqd_Mem* vehicles, and the *F-15Es* each have two *JSOW* and two *HARM* weapons. While the Blue force is quite capable on the ground with the SOF units, the major emphasis of the force is on air assets and the application of air power.

The Red Serbian force, shown in the Figure 7, is much simpler in comparison to the Blue force. The Serbian force is not centralized as is the blue force possessing the CAOC unit agent, which owns all other blue agents. The Red force consists solely of ground assets of the Serbian Army. Serbian unit agents include air defenses, ground targets, and three army divisions. [DeStefano, 2004]

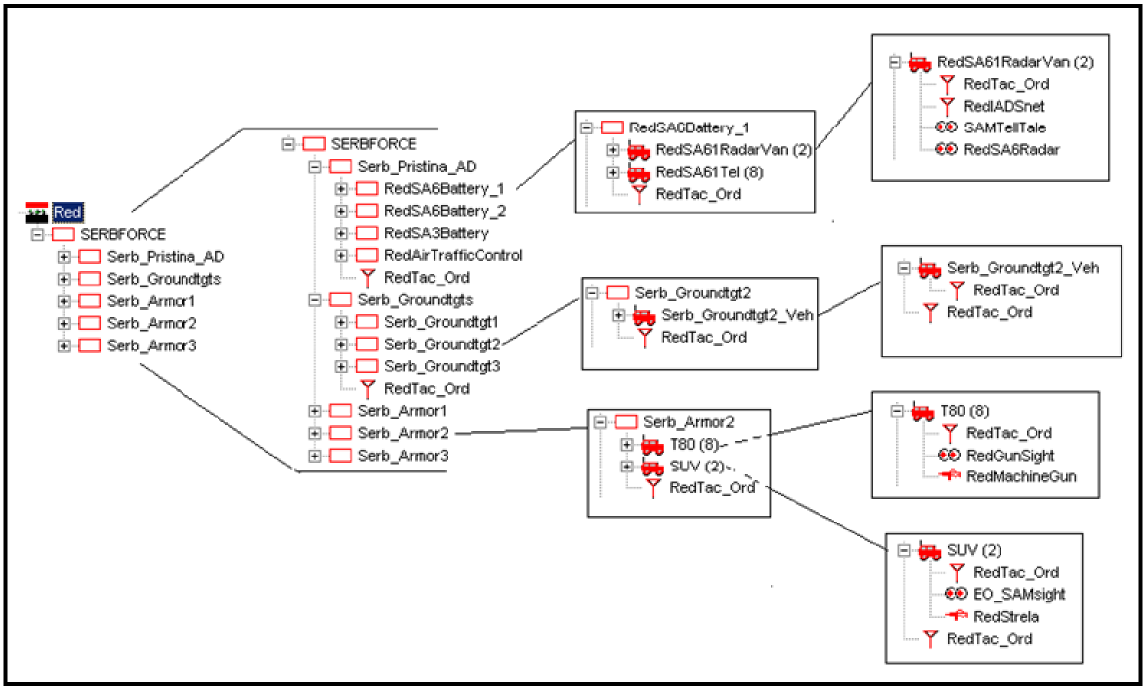

Figure 7. Serbian Force Structure [DeStefano, 2004:3-6]

The Serbian surface-to-air missile capabilities present the greatest threat to the Blue force in terms of attrition, based on initial experimental runs of the scenario. However, since the goal of the Blue force in the scenario is to minimize the impact of Serbian Army operations on the Kosovars, ultimately the three Serbian armor units are the most threatening members of the Red force in terms of Blue achieving its objective. Orders are passed from the five main Serbian unit agents to their subordinate agents, but there is not the degree of coordination of the Blue force since these five units essentially act autonomously. This is an obvious, and yet true to life, weakness for the Serbian force. The Serbian force behaves according to a realistic concept of operations. For instance, the surface to air radar vans are given orders to hide when information is passed that an F-15 is near, or to hide and move after firing a missile [DeStefano, 2004:3-5].

The Brown Kosovar force is similar to the Red Serbian force in the sense that there is no centralized command structure, as seen in Figure 8. The Kosovars force consists of farmers, refugees, villagers, or militia members. The militia members are the only armed agents of the Brown force and they are enemies with the Serbian force, but are neutral in relation to the Blue force. The Kosovar agents have extremely rudimentary sensing and transmitting capabilities such as unaided human eyes, cell phones, and even bells, all of which are coded in the warfile as devices whose attributes have been assigned to match the low strength and low range of these types of sensors and communication devices. Instead of the Kosovars being placed in aggregated masses at certain locations they can be modeled as agents who can pass along information to the U.S. forces and hide from the enemy. In this sense, the Kosovars can be viewed as allies to the Blue force. However, since they are only able to offer limited combat support, they would more accurately be labeled as a neutral force in this scenario.

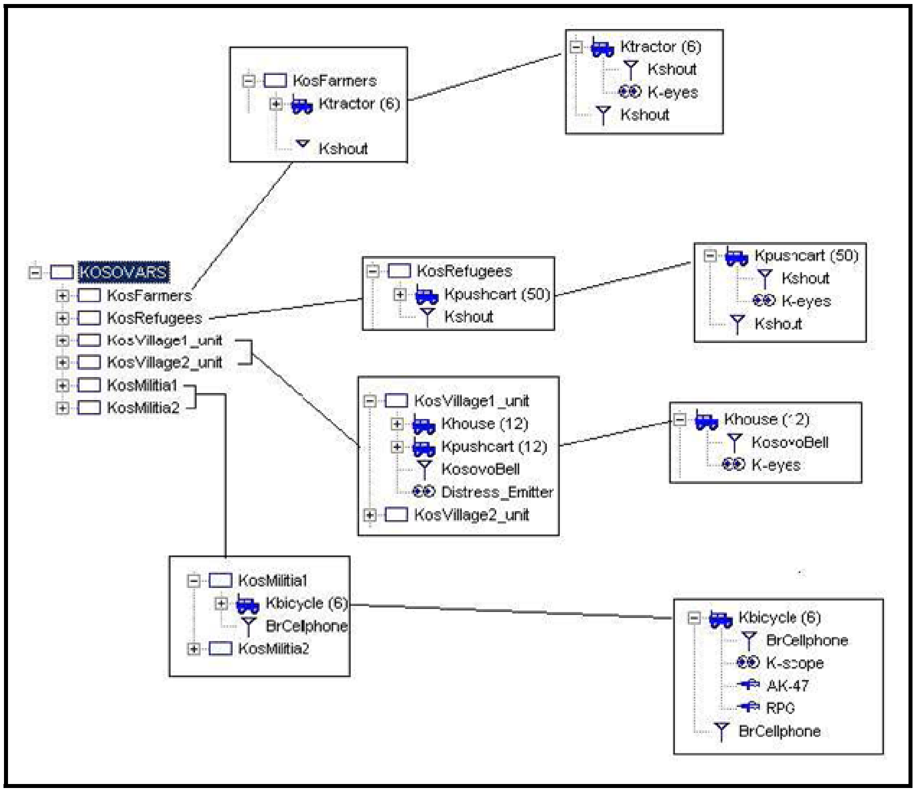

Figure 8. Kosovar Force Structure [DeStefano, 2004:3-7]

There are several key elements of the Kosovo scenario that allow it to be used as a scenario which legitimately represents and applies the concepts of NCW, specifically linked sensors and linked communications. A count of sensors in the Kosovo warfile shows that 20 total sensors are used in the scenario: 13 sensors belong to the Blue USAFE force, four sensors belong to the Red Serbian force, and three sensors belong to the Brown Kosovar force. Some of these sensors are shared, such as the *BluAir2GndRadar* and *AC_Elint* used by both the *F-15Es* and *F-16Cs*. The Kosovo scenario holds 23 total communication channels: 17 channels belong to the Blue USAFE force, three channels belong to the Red Serbian force, and three channels belong to the Brown Kosovar force. Many of these communication channels, especially on the Blue force side, are shared between several different units and vehicles. The linked sensors and communications aspects of NCW are definitely captured in the Kosovo scenario. This interconnected grid of sensing and communication devices allows for the operation of linked weapons systems and creates shared situational awareness in the scenario, especially among the Blue USAFE force units and vehicles.

Analysis

Based on the outputs available from SEAS and the analysis options provided by the SEAS Post Processor (an Excel-based analysis tool), we selected measures to represent the physical, information, and the cognitive (indirectly) domains of NCW. For the physical domain, the most appropriate measure seems to be sensor detection distance. Our analysis looks at results from single replications as well as average results over 30 replications for a baseline case (no degradation effects), and three additional cases with varying levels of degradation as illustrated in Figure 9 (weather, terrain, or both).

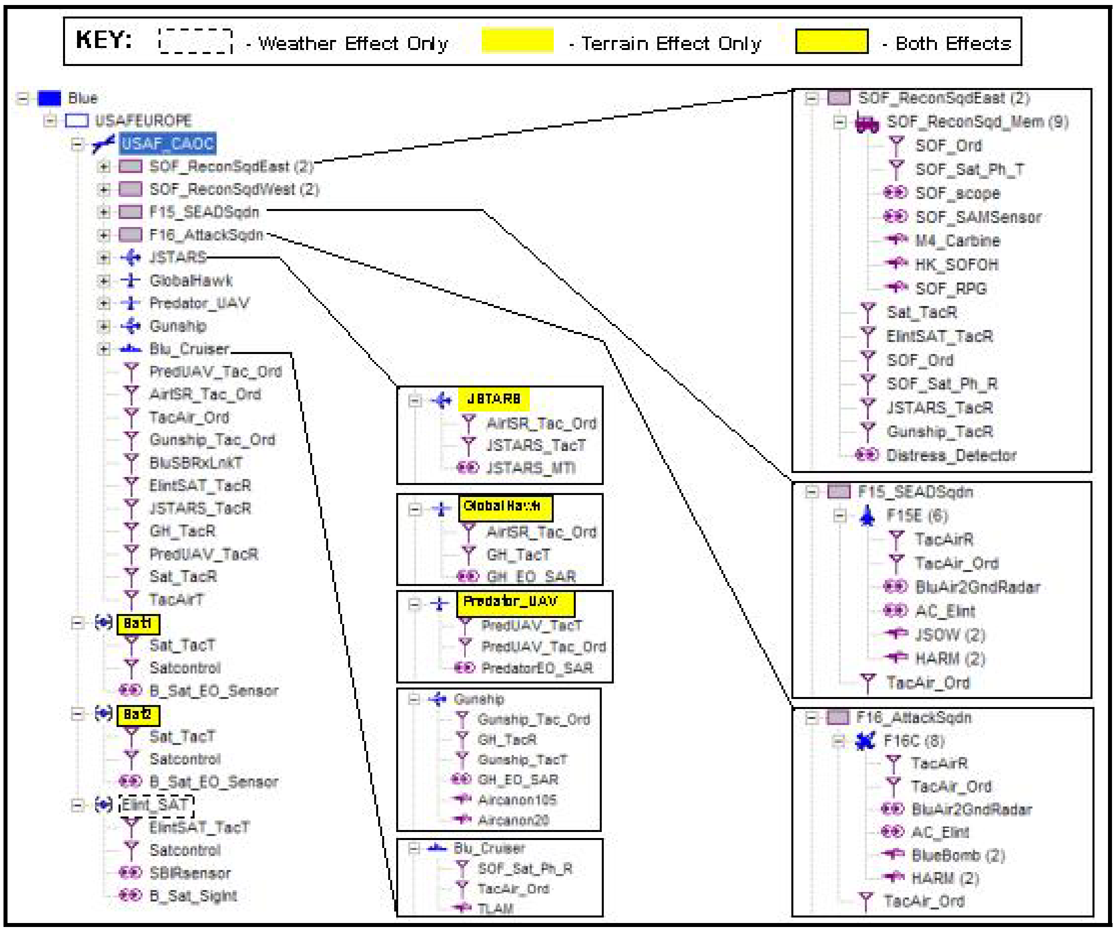

Figure 9. Blue Force Sensors Affected by Network Degradation Effects

Preliminary analysis of sensor detection distances for the physical domain of NCW began with determining which sensors were programmed in the Kosovo warfile as being affected by the degradation effects. The illustration in Figure 9 was used as a guide throughout the detection distance analysis. The figure helped to track which sensors were influenced by which TAO degradation effects. The figure illustrates that *Sat1*, *Sat2*, *GlobalHawk*, and *Predator_UAV* were all coded in the Kosovo warfile as being effected by both weather and terrain effects, while the *Elint_SAT* was affected only by the weather TAO and the *JSTARS* was affected only by the terrain TAO. Weather affects platform speed, sensor probability of detection, weapon probability of kill, and communications reliability. Terrain affects platform speed, sensor range, weapon range, and communications range. The degradation effects are implemented to degrade network performance in the two distinct TAO regions according to their respective influence on performance attributes.

Graphical trends seen in average detection distance plots for a single run of the Kosovo scenario helped to focus the subsequent analysis of data gained from thirty replications. Figure 10 plots average detection distance data from one run of the full effects case. The agents listed on the "Sensors" and "Targets" axes are not all inclusive for the sake of space and clarity of reading in the figure. Therefore, the hash marks on the "Sensors" axis listing *F15E#1*, *F15E#3*, and *F15E#6*, for example, represent the whole group of F-15E agents. Similarly, the specific listings on the "Targets" axis for individual members of the *RedSA6*, *Serb_Armor*, and *Ktractor* units are not representative of those types of agents for that region of the axis.

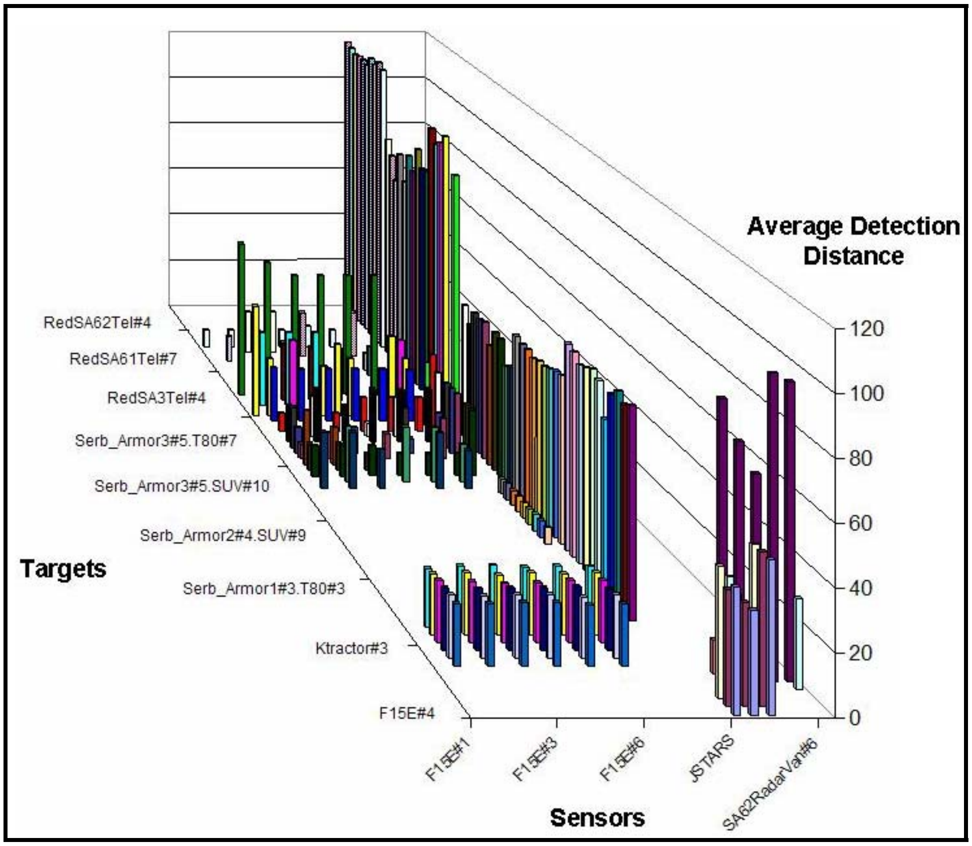

Figure 10. Average Detection Distance Versus Various Targets and Sensors

Several trends and points of interest can be gleaned concerning the behavior of agents within the Kosovo scenario from this plot. First of all, the *JSTARS* is the most active and effective Blue force sensor, clearly seeing the most Red targets and at the farthest average ranges, anywhere from 20 to 120 kilometers. Also, the F-15's are fairly effective at detecting Red armor and surface-to-air threats, but not nearly to the range of the *JSTARS*. Last, the Red radar vans are detecting the F-15's fairly consistently and from distances of 20 to 100 kilometers, which is much farther away than the F-15's are seeing their targets, although the F-15's can be cued by other Blue ISR assets.

Seeing these detection trends from single run output data was very helpful in better approaching the thirty runs analysis. From this single run analysis, it was learned which sensor platforms would be most worth focusing comparative performance analysis on for the three degraded scenario cases versus the baseline case. Also, knowing which targets were being detected by which sensors helped to provide a fuller understanding of what types of detections the more aggregated data for thirty runs was truly representing.

The second phase of analysis conducted for detection distances of the Kosovo scenario was to compare average detection distance outputs from thirty runs of the baseline case, which has no weather or terrain effects, versus average detection distance outputs from thirty runs of the three states of network degradation (represented as the application of weather only, terrain only, and weather and terrain effects combined). The goal of this analysis is to determine whether the difference between case outputs is statistically significant. A 95% paired-*t* confidence interval was used to test for this difference between the baseline and each of the degraded cases.

Table 1 shows $\overline{Z}(n)$ (sample mean) and the 95% confidence interval for *Sat1*. The full paired-*t* test results can be found in Honabarger [2006]. Results illustrate that both satellites' average detection distance ranges are clearly reduced, especially in the full effects and terrain only cases. It is a bit surprising that the weather case did not hinder the average detection distance more severely for both satellites. This could be due to the fact that both satellites are detecting targets less frequently in the weather case. Detections are still possible for the satellites on the edges of the weather TAO, but a smaller number of detections may be limiting observance of the true degradation affect in the weather only case.

Table 1. Satellites Paired-*t* Test Detection Distance (km) Analysis

Satellite #1				
Difference Between Baseline and:	$\overline{Z}(n)$	95 % Confidence Interval	Statistical Difference?	Percentage Change from Baseline:
Full Effects	178.30	(166.38,190.23)	**Yes**	**-13.75**
Terrain Only	174.57	(165.88, 183.26)	**Yes**	**-13.46**
Weather Only	15.91	(3.18, 28.63)	**Yes**	**-1.23**
Satellite #2				
Difference Between Baseline and:	$\overline{Z}(n)$	95 % Confidence Interval	Statistical Difference?	Percentage Change from Baseline:
Full Effects	176.66	(164.02, 189.30)	**Yes**	**-13.80**
Terrain Only	164.00	(154.65, 173.35)	**Yes**	**-12.81**
Weather Only	18.05	(0.36, 35.75)	**Yes**	**-1.41**

Table 2 shows results for changes in average detection distances versus the baseline case for *F-15E#1*, *F-15E#4*, and the F-15 squadron as a whole. This table illustrates that, except for the *F-15#1* comparison of the baseline with the terrain only effect, there is no statistical difference between the average F-15 squadron detection distances for all of the three case comparison variations versus the base case. This is the expected result since the F-15's are not coded in the Kosovo warfile as being affected by the weather or terrain TAO. However, the improvement in *F-15#1*'s average detection distance in the case where only terrain effects are applied is not clearly understood. Perhaps this improvement in average detection distance is due to the fact that the satellites' detection distances are severely hampered and therefore *F-15#1* is not able to rely on cueing information from the satellites, but rather must more actively seek out targets on its own. *F-15#1* is the first F-15 to deploy from the Blue base and it is able to relay this information on to the rest of the squadron, which rely on both the satellites' and *F-15#1*'s detection information to guide them to targets. This may explain why *F-15#1*'s average detection distance undergoes this change for the terrain only case while *F-15#1*'s average detection distance, as well as that of the squadron as a whole, are not significantly different. In summary of the data analysis presented in Tables 1 and 2, terrain and weather effects are seen to significantly affect the NCW physical domain metric of detection distance for the satellites in the Kosovo scenario, but not for the F-15's. Similar analysis was performed for the JSTARS and GlobalHawk detection distances with no statistically significant differences for either platform from the baseline case and any of the degraded cases. See Honabarger [2006] for a full discussion.

Table 2. F-15 Squadron Paired-*t* Test Detection Distance Analysis

F-15E#1				
Difference Between Baseline and:	$\overline{Z}(n)$	95 % Confidence Interval	Statistical Difference?	Percentage Change from Baseline:
Full Effects	-0.44	(-6.19, 5.31)	**No**	**1.05**
Terrain Only	-6.56	(-11.71, -1.41)	**Yes**	**15.78**
Weather Only	1.56	(-4.75, 7.87)	**No**	**-3.75**
F-15E#4				
Difference Between Baseline and:	$\overline{Z}(n)$	95 % Confidence Interval	Statistical Difference?	Percentage Change from Baseline:
Full Effects	0.38	(-8.22, 8.97)	**No**	**-0.92**
Terrain Only	-2.15	(-8.45, 4.16)	**No**	**5.20**
Weather Only	3.07	(-2.83, 8.97)	**No**	**-7.42**
All 6 F-15's Together				
Difference Between Baseline and:	$\overline{Z}(n)$	95 % Confidence Interval	Statistical Difference?	Percentage Change from Baseline:
Full Effects	0.49	(-3.39, 4.37)	**No**	**-1.18**
Terrain Only	-3.07	(-7.05, 0.91)	**No**	**7.38**
Weather Only	0.62	(-2.99, 4.23)	**No**	**-1.49**

The metric selected for the information domain in the Kosovo scenario was a performance measurement of the networks' communication channels. Specifically, the number of messages handled by each channel was analyzed for key platforms of the Blue Force. The focus was on determining the affect of regional TAO degradation on each channels' ability to handle and transfer messages pertaining to target detections, agent orders, and a few variable types of messages. All three types of messages are tracked in SEAS for each channel specified in the TPL and designated in the communications output file as the channel name followed by *_Sit_*, for situation report (i.e. target sighting), *_Var_*, for broadcast variables (which can be various message types such as target priority arrays), and *_Ord_*, for orders and command messages.

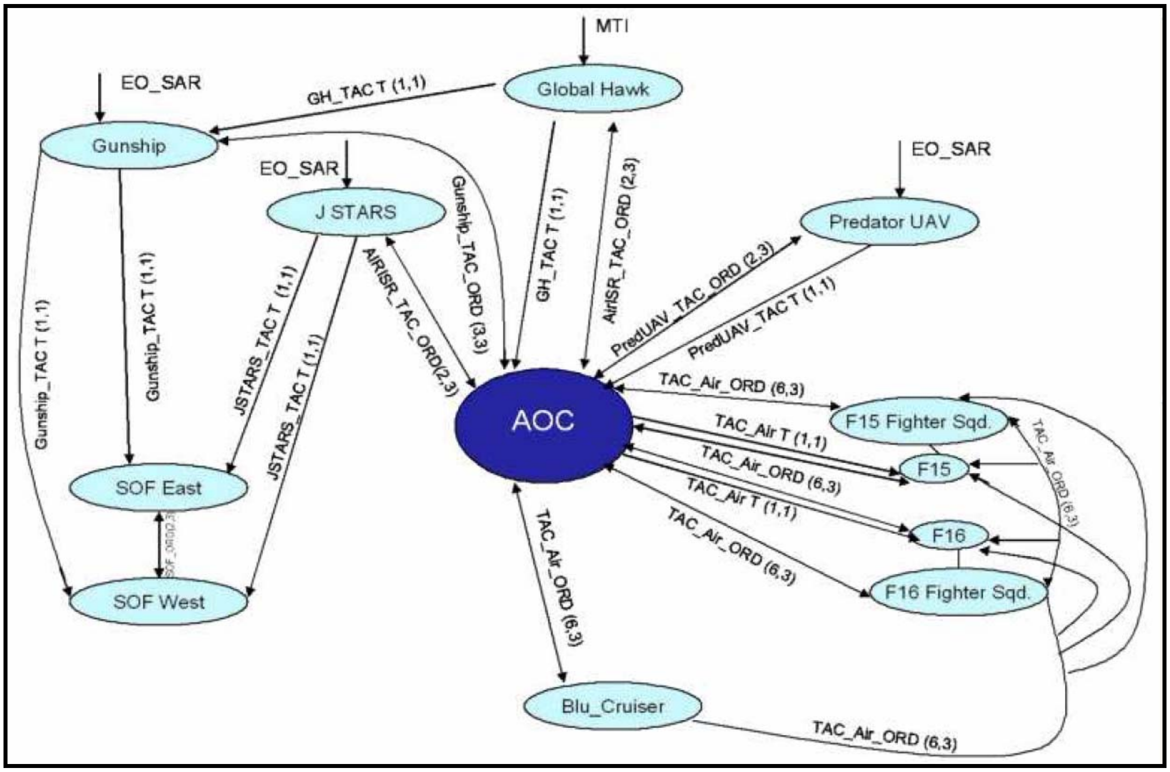

Figure 11. AOC Communication with Group & Air Assets [DeStefano, 2004:3-10]

Figure 11 is a graphic illustration of the Blue Force communications network from DeStefano {2004]. The figure shows that the *TAC_Air_ORD(6,3)* and *TAC_Air_Ord(1,1)* communications lines provide a critical link between the AOC and several key Blue platforms, including the F-15 squadron, F-16 squadron, and *Blu_Cruiser,* which is a Navy carrier agent that launches the TOMAHAWK Land Attack Missile (TLAM). Analysis of message loading and activity across all channels conducted for this thesis effort confirms that the *TAC_Air* communication device's primarily used channel, *TacAirQ_Sit*, is one of the most highly active channels in the scenario. It relays target sightings to the aforementioned platforms.

A number of approaches were taken to try to capture and explain the differences between our cases using SEAS communication data for this domain. We present one approach here, please see Honabarger [2006] for a full discussion of the other analysis done for the information domain. In the approach taken below we plot the overall average message load for the top four active channels over ten ten-hour segments of one simulation run. The resulting plots are illustrated in Figure 12 and 13. The average number of messages per ten-hour time block is calculated over all 60 minute time-steps for the baseline and full effects cases using the same starting random number seed. There was no adjustment made to filter out time-steps when the channels are broadcasting zero messages. Four out of five of the communications channels selected for the previous phase of analysis are presented in these plots. *SBRQ_Sit* was excluded on these plots because this channel's average message activity per ten-hour time segment is exactly the same as the *TacAirQ_Sit* channel's average number of messages and this holds true for both the baseline case and full effects case.

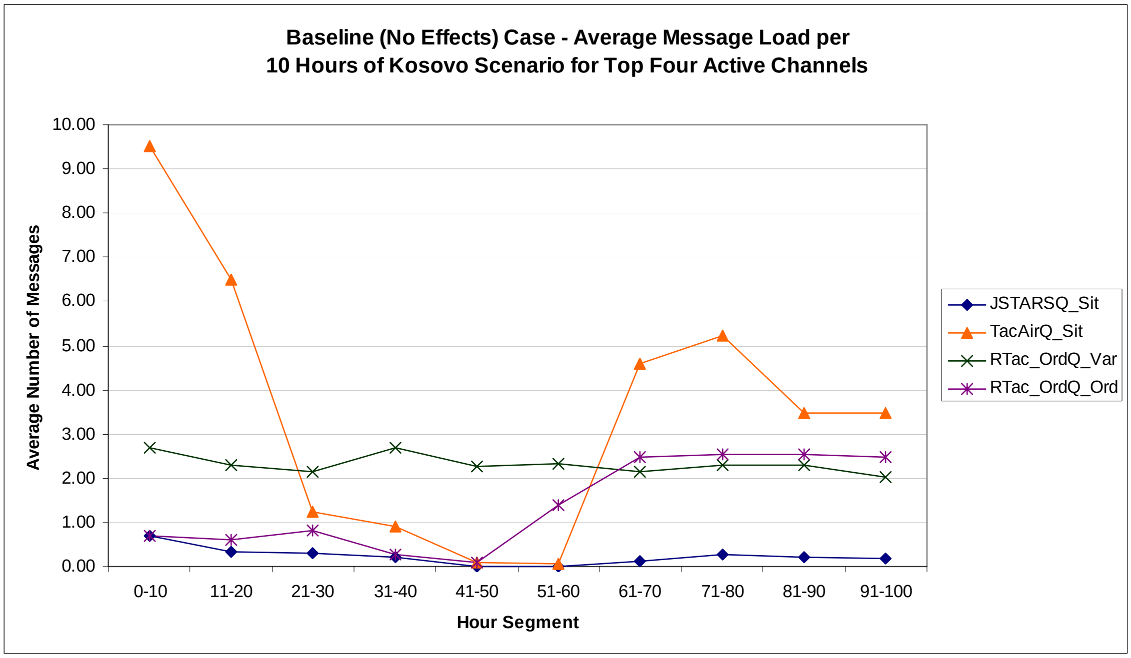

Figure 12. Baseline Case Average Message Load per 10-hour Segment

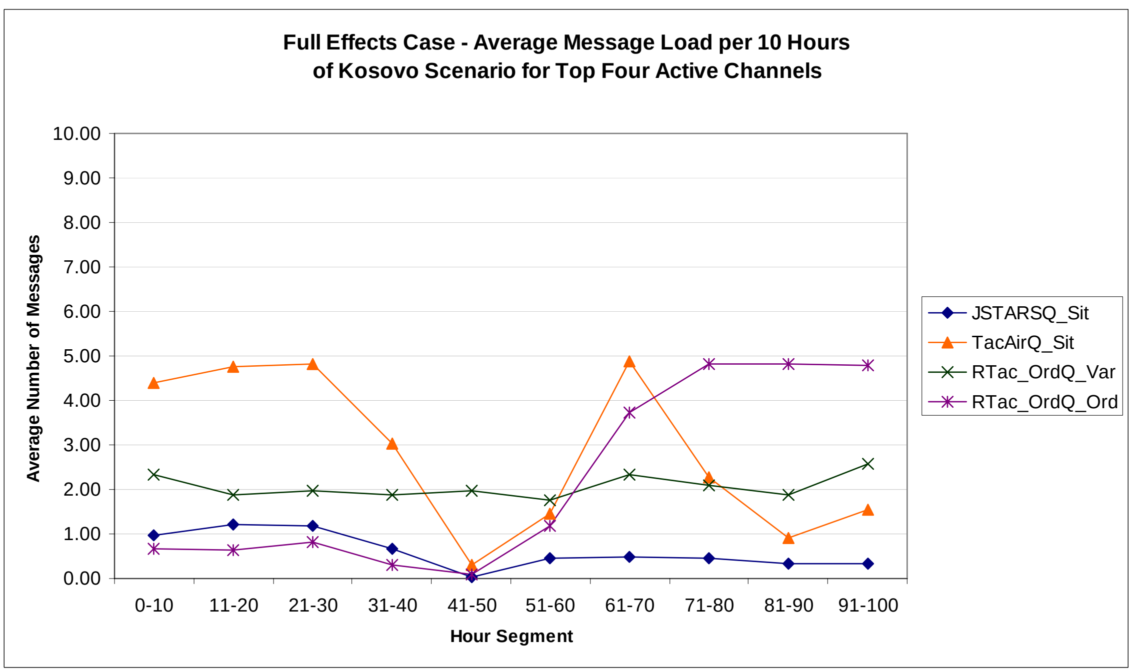

Figure13. Full Effects Case Average Message Load per 10-hour Segment

A few trends can be seen in the average communication loading for these top four active channels. A pattern of relatively high message activity on *TacAirQ_Sit* for approximately the first 20 hours, then decrease up until approximately 50 hours, followed by a rise until about the 70 hour mark and fall after that, holds true for both cases. These two distinct phases of communication activity match up closely with DeStefano's findings concerning phases of war for the Kosovo scenario.

The chosen measure for the cognitive domain of NCW is the somewhat indirect metric of number of kills per platform. Kill data is representative of decision-making behavior because the recording of a kill in the scenario is conclusive evidence of the outcome resulting from a decision made to attack. The kill numbers measure the "act" part of the OODA (Observe, Orient, Decide, Act) loop. Unlike the physical and information domain metrics, the outputs for kill numbers used to measure the cognitive domain of NCW are relatively clear and definitive. This section illustrates that, in general, the no degradation effects (baseline) case is the best case for the Blue USAFE Force both in terms of higher number of Red killed and lower number of Brown killed.

Results of the paired-*t* confidence interval analysis are presented in Table 3. The full paired-*t* test results along with further analysis can be found in Honabarger [2006]. On average over thirty runs, Blue kills more Red SA Tels and Radar Vans in the degraded cases, but a statistically significant difference is not found at a 95% confidence level. Each degraded case resulted in higher losses for the number of Kosovar houses destroyed by Red. While no statistically significant difference is seen for the terrain and weather only comparisons, the difference was statistically significant at a 95% confidence level for the full effects versus baseline comparison. This result leads to the conclusion that Blue is more successful at achieving its mission of saving Kosovars when its network capability of sensing and communicating is not fully degraded.

Table 3. Paired-*t* Test Results for Red and Brown Victim Counts Over Thirty Runs

Blue Kills of Red SA Tels and Radar Vans			
Difference Between Baseline and:	$\overline{Z}(n)$	95 % Confidence Interval	Statistical Difference?
Full Effects	1.37	(-0.32, 3.05)	**No**
Terrain Only	0.13	(-1.22, 1.48)	**No**
Weather Only	0.83	(-0.88, 2.54)	**No**
Kosovar Houses Destroyed by Red			
Difference Between Baseline and:	$\overline{Z}(n)$	95 % Confidence Interval	Statistical Difference?
Full Effects	-2.20	(-4.33, -0.07)	**Yes**
Terrain Only	-0.40	(-1.50, 0.70)	**No**
Weather Only	-0.43	(-1.75, 0.88)	**No**

Conclusion

This effort demonstrates that the task of developing appropriate measures for NCW within the context of a SEAS model can be quite challenging. This analysis also illustrates that determining whether a particular metric is fundamental enough to serve as a useful measure for the degree, or performance, of NCW is not a very clear-cut proposition. Average sensor detection distance seemed to be a fitting and effective measure of performance in the physical domain for the satellites in the Kosovo scenario, but didn't seem as applicable for measuring the performance of other agents, such as the *JSTARS* and *GlobalHawk*. Analysis of the information domain provided different approaches and ways of looking at the average number of messages being handled by the network for various communication channels. The metric of average channel message load seemed to be a suitable measure for some channels, such as for *TacAirQ_Sit*, but not as suitable a measure of performance for other channels, such as *JSTARSQ_Sit*. Using the number of Red and Brown losses for measuring outcomes pertaining to the cognitive domain seemed to be the most consistent and reliable measure (although indirect), as compared with the measures for the physical and information domains. Positive trends for the Blue Force were seen in comparing the case of no degradation effects to those three cases employing effects that would degrade performance of the sensors and communication devices. In the no effects case as compared with the three cases of varying degradation, Blue killed more Red and spared more Brown agents. An increase of Kosovar houses killed in the full effects degradation case was found to be statistically significant.

DISCLAIMER

The views expressed in this paper are those of the authors and do not reflect the official policy or position of the United States Air Force, Department of Defense or the U. S. Government.

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