Cover Sheet

Student Paper

Title:
Distributed Command and Organizational Situation Awareness

Authors:

Norman K. Ma Ph.D. student, Research Assistant Department of Computer Science Texas A&M University 301 H R Bright Building, 3112 TAMU College Station, TX 77843-3112 normankma@tamu.edu (979) 845-1871	Thomas R. Ioerger, Ph.D. Associate Professor Department of Computer Science Texas A&M University 301 H R Bright Building, 3112 TAMU College Station, TX 77843-3112 ioerger@cs.tamu.edu

Point of Contact:
Norman K. Ma, normankma@tamu.edu

Organization:
Texas A&M University

Distributed Command and Organizational Situation Awareness

Norman K. Ma[1], Thomas R. Ioerger[2], PhD
Department of Computer Science
Texas A&M University,
301 H R Bright Building, 3112 TAMU
College Station, TX 77843-3112
normankma@tamu.edu, ioerger@cs.tamu.edu

Abstract

Situation awareness is an essential cognitive-domain object of the command and control decision process. This paper places an organization's SA in the context of OODA (Observe, Orient, Decide, Act) interaction between opposing teams. In addition, a hierarchical SA structure is used to organize SA generated from the physical entities in the corresponding physical domain. A rich Modal Logic-based language (SALMA) is proposed to represent and also to communicate awareness within an organization to form the Organizational Situation Awareness. An example of increase of knowledge due to Organizational SA is given. An additional example of strategic maneuver based on Organization SA is also given. The paper concludes with an assessment of technology-led innovation and the significance of measurement in situation awareness.

An entity in the physical domain could have a state of awareness of the present situation. That awareness is the basis for generating actions. There is no situation awareness without the physical entity, and decision would be necessarily random without high-quality situation awareness. The combination of these states of awareness form the organization situation awareness. Cognitive, information, and physical domains form a foundation for the analysis of military operations. Decision makers form situation awareness in the cognitive domain and make decisions based on knowledge, experience, and observation of the world. Physical realities can be directly observed, or more likely pass through intermediate information systems before being received by the decision makers. Eleven primitives (Sensing, Observations, Information, Knowledge, Awareness, Understanding, Sharing, Collaboration, Decisions, Actions, and Synchronization) were defined within the three domains to develop a theory on the relationship between performance and information within the military operation context. This paper focuses on awareness in the cognitive domain.

Network Centric Warfare [ALBERTS03] opens up the possibility of change to the existing cognitive, information, and physical domains. Within the context of command and control, we are interested in the relationship between the organization's structure and

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[1] Ph.D. student with focus on Intelligent Systems and Software Agents.
[2] Associate professor of computer science with interests in Artificial Intelligence, Machine Learning, Intelligent Agents, Bioinformatics.

situation awareness (SA). While the tri-domain ontology gives theorists partitioned focus on the military process, the three domains are intrinsically connected and interdependent. Moreover, the domains are grounded in the physical reality. Whereas we might want the opponent to attain a particular cognitive state, it is a fact that without the physical entities as grounding, it would not be necessary to set cognitive objectives for the opponent. Thus, a significant amount of analysis is predicated upon physically obstructing or eliminating the opponent. That said, we proceed to examine a central issue of command and control, situation awareness in the cognitive domain.

Hierarchically-Layered Model of SA

Our analysis is based on the notion that Situation Awareness can be measured and quantified [ENDSLEY95_2]. The existence of a metric for situation awareness, even if in a case-by-case format [PEW00], would help in the eventual evaluation of ways to process SA in the cognitive domain. A general description of the measurement function is $M : SA \mapsto R$ where the set R can be either a number or a categorical value. Since it is the individual that makes decisions, human situation awareness and tactical decision-making research has necessarily been focused on the individual. SA has been classified into Level 1 Perception, Level 2 Comprehension, and Level 3 Projection [ENDSLEY95_1]. This definition is analogous to a layered intelligent agent architecture, as described by Wooldridge [WOOLDRIDGE02], where environmental precepts and system actions go through a two-pass vertical layered architecture. In that case, the three layers are defined by as Behavior, Plan, and Cooperation layers.

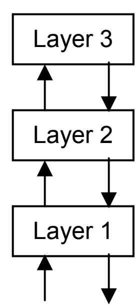

Diagram 1: Vertical Layered Two-Pass Architecture

While Endsley has classified SA by its purpose as perceptive, comprehensive, or projective, SA can also be classified by the type of physical entities that owns the particular SA. Internal entities interact only with other entities within the organization while peripheral entities also interact with the environment. The two types of SAs are correspondingly internal and peripheral SA.

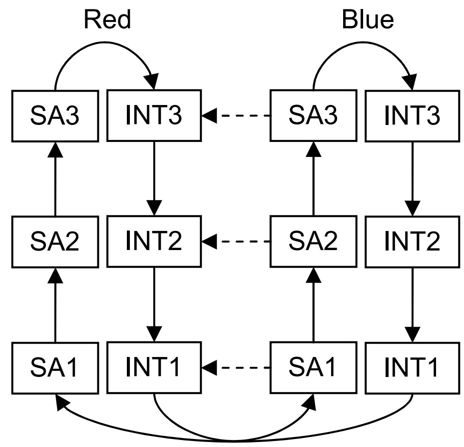

Diagram 2: Modified joint OODA Loop model in the Cognitive Domain

Diagram 2 is based on a two-pass vertically layered architecture by Müller [MULLER95] it describes the relationship between an entity and its opponent. They are connected mutually though action and perception processes at level 1. The actions are perceived by layer 1 entities and higher levels of situation awareness are formed from lower level of awareness. Actions are generated by instantiation of higher layer intentions to lower layers. The dashed line from Blue entity's situation awareness layer to Red's intention layers indicates that the goal of SA is to understand an opponent's intention. The interactions are through the information and physical domains between lower levels of the entities; actions are transmitted to the physical domain as a result of intention that flows down the intention chain, which is perceived by level 1 of the opponent's SA.

Each level of situation awareness depends on the lower level, and level 1 SA receives inputs directly from the environment. Ideally, each of these SA should be relevant to the opponent's intentions at that equivalent level for the purpose of generating reactive responses to the existing situation, and could also initiate proactive actions to control the situation, described graphically as

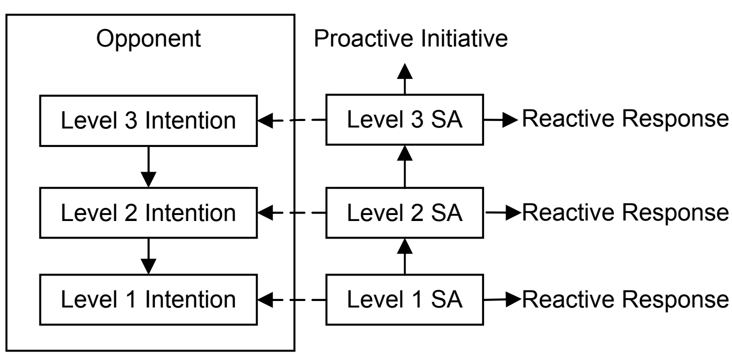

Diagram 4: The Purpose of Being Situational Aware

Processed information is moved up the SA chain, where formation of higher level SA become the basis for decisions. Intention forms the background of the OODA loop, which generates and executes actions. Both situation awareness and intentions are divided into 3 levels that correspond to Strategic, Operational, and Tactical functions of an entity. In Diagram 2, the dashed line from the Blue's situation awareness process is connected to the Red's intentions. While situation awareness operationally emits an action based on identification of a situation, in a deeper sense situation awareness is trying to identify the opponent's intention that led to the present situation, and upon which future actions will be based. Knowing the intention reduces reaction time by priming the sensors for expected situations. We have divided intention into 3 levels corresponding to the 3 levels of SA. For example, a lower level intention might be the completion of a flanking maneuver, and a higher level intention could be "Identify an entry point to a building." Higher level intention could be more difficult for a situation assessment process to clarify because actions span over wider space and time.

The Joint OODA loop is a cognitive domain artifact [ALBERTS02]. SA-capable entities are distributed throughout the physical domain, and more importantly, operate within the organizational structure and policies. Network Centeric Warfare can significantly affect the cognitive domain, as well as both the physical domain and the mediating information domain.

An organization contains many entities that are capable of being situationally aware. These individual islands of situation awareness need to be connected to fully realize an organization's situation awareness potential:

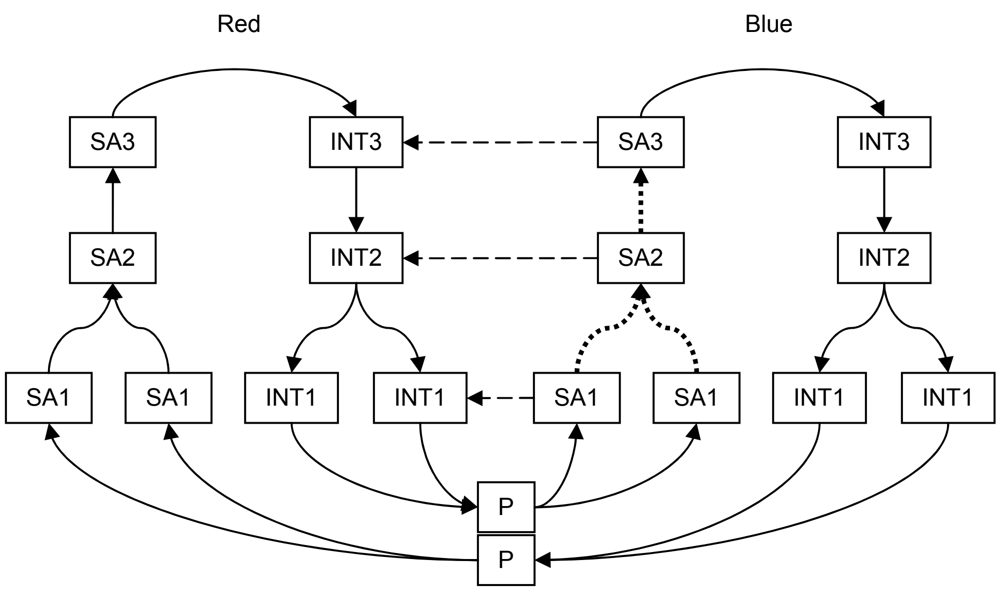

Diagram 3: A Cognition-Centric Model of Interaction of Distributed Situation Awareness

Diagram 3 is an expanded cognitive model of organization situation awareness. In this view, the physical domain has been reduced to the boxes labeled 'P' at the bottom of the diagram. Their function is to connect the actions and perceptions between the two entities. The information domain is instantiated as arrows between boxes that represent situation awareness and intentions. Starting with the perception of actions from the Red entity, level 1 entities are combined to form higher-level situation awareness SA2 and

SA3. High-level intention, INT3, is generated and passed down to entities that generate actions. The instantiated actions in the physical domain are then perceived by Blue's level 1 SA entities, which migrate up the cognitive model and result in high-level intentions. The intentions are instantiated as actions in the physical domain by externally connected entities, at which time the cycle repeats. The dashed line from Blue's situation awareness box to Red's intention box indicates that the goal of situation awareness is to understand the opponent's intention. The above description is an interpretation of the OODA loop; each entity's goal is to increase its relative cycle speed for the realization and control of possible future situations.

Modal Logic Representation

Diagram 3 is a representation of distributed situation awareness in the cognitive domain. Each individual's situation awareness is processed by the entity or communicated to form higher-level situation awareness. We propose using the SALMA (Situation Awareness Language for Military Application) protocol for modeling distributed situation awareness. SALMA is a modal logic-based language that is able to represent full situation awareness states such as belief, intention, possibilities, and self-knowledge. For example, when a level 1 entity is aware of some fact ϕ and a level 2 entity has knowledge $\phi \Rightarrow \psi$, then connecting these two SAs will result in knowing both ϕ and ψ. More importantly, a modal logic based protocol would be rich enough to describe concepts such as *necessarily* and *possibly*. Situational knowledge such as "it is possible that a destructive device is on an inbound cargo container from Cape Town" or "to eliminate the possibility of the smuggled destructive device, it is necessary to check every cargo originated from Cape Town." Both sentences are legitimate and possible situation awareness states, and both can be represented in SALMA and communicated to other entities in the cognitive domain. In addition, modal logic is able to represent important situation awareness concepts such as self-knowledge, e.g. "If the information that can identify the target cargo container is in an email message within the last 48 hours, then I know I have the means to find the targeted container." That knowledge is represented as $K\phi \Rightarrow KK\phi$, where K is the modal operator meaning "knows." (This axiom is known as the axiom of "positive introspection" in the S5 system, the epistemic logic most often used to model knowledge. [BLACKBURN92]) This SALMA notation embodies Sun Tzu's concept of "know yourself" and "what the people know and are aware they know." [ALBERTS02_2].

Quantifying the Quality of Situation Awareness

Organization Situation Awareness (OSA) is the war-fighting organization's total situation awareness, which is composed of SA from all SA-capable entities including the commander and all resources available to him:

$$OSA = \bigcup_{i \in WFO} SA(e_i) \qquad (1)$$

OSA changes with time as it is continuously updated by SAs throughout the physical domain. We have described distributed situation awareness in the cognitive domain and its role in conjunction with the opponent's OODA loop. We now focus on an individual entity's state of awareness using a simplified binary approximation. Specifically in this example, situation awareness is defined by an entity's ability to recognize members from a set of situations in the environment. From that definition, we can develop a more concrete definition of organization situation awareness as follows: let $S = \{s_i\}$ be a set of situations and define $SA(e_i): S \mapsto \{0,1\}$ as the characteristic function that maps to 1 for a recognized situation or a 0 for unrecognized situation. For example,

$$SA(e_3) = <0 \quad 1 \quad 1 \quad 0 \quad 0>$$

indicates that entity e_3 recognizes the occurrence of situation s_2 and s_3, and e_3's SA is $<0 \quad 1 \quad 1 \quad 0 \quad 0>$. OSA is a disjunction of a set of characteristic functions, $SA(e_i)$, where each function describes an entity's existing situation awareness. Equation 1 is displayed in tabular format as

Time = t_i	s_1	s_2	s_3	$\cdots$	s_n
$SA(e_1)$	0	0	0	…	0
$SA(e_2)$	0	0	1	…	0
$SA(e_3)$	0	1	1	…	0
$\vdots$	$\vdots$	$\vdots$	$\vdots$		$\vdots$
$SA(e_m)$	0	0	0	…	0
$OSA(\{e_1 \cdots e_m\})$	0	1	1	…	0

Table 1. Tabular Representation of Organizational Situation Awareness

where the bottom row of the table is a list of situations that the organization recognizes as a whole. The following equation shows that total situation awareness of an entity can be partitioned into Endsley's 3 levels,

$$SA(e_i) = SA^1(e_i) \cup SA^2(e_i) \cup SA^3(e_i)$$

It can also be partitioned by location of the entity within the organization,

$$SA(e_i) = SA^{external}(e_i) \cup SA^{internal}(e_i)$$

In preparation for the analysis of how changing the organizational structure in the physical domain can affect situation awareness in the cognitive domain, we define a utility function $U(\cdot)$ to measure the effectiveness of a SA, which should be grounded on the goodness of the final outcome. The utility of SA is being developed by the emerging field of SA measurement [ENDSLEY00]. At this point, we carry out our analysis based on a measurement of SA that is a function of a particular task. A SA's utility, $U(\cdot)$, is a measure grounded on the goodness of the final state of a task in which the entity was involved.

We assert that the utility of *OSA* is greater than the sum of the utilities of the individual SAs in the organization,

$$U(OSA) > \sum_{i \in WFO} U(SA(e_i))$$

This can be demonstrated with an example, if entity e_1 knows the fact ϕ and entity e_3 knows the fact $\phi \Rightarrow \psi$ then individually their awareness is $\{\phi, \phi \Rightarrow \psi, \cdots\}$. However, by connecting their separate awareness, the combined awareness becomes $\{\phi, \psi, \phi \Rightarrow \psi, \cdots\}$, and the utility of the combined awareness is greater than the sum of individual awareness.

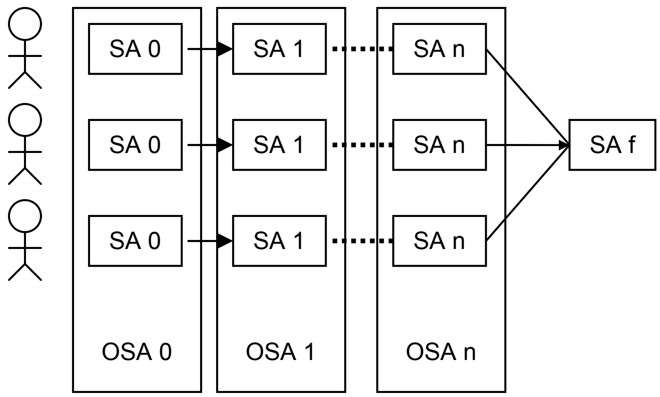

Diagram 4: Individual Situation Awareness and Organization SA in Time

Diagram 4 illustrates a retrospective view of a three-person task that has been completed. The final state is "SA f". The utility of each of the situation awareness states should necessarily depend on the quality of the final state "SA f". That is, the quality of a particular situational state is a function of the quality of the final outcome. At this point, it might be useful to relate this sequence of measurements to the generally accepted battle process, the OODA loop. The Observe and Orient phases of OODA require SA. The next two phases are Decision and Action. The output from decision and action are actions, finally the effectiveness of an action should be measured based on how that action contributes to achieving the goal, and the situation awareness should also be measured by how the particular awareness state contributes to the goal.

We have placed situation awareness within the cognitive domain and also within a task process. As a result of the interaction with the external environment, situation awareness can be qualified by frequency, duration, volume, and history,

$$SA_{f,d,v,h}$$

where frequency is the shortest interval the entity is able to process input, duration is the time period for which the entity will consider events relevant to form SA, volume is the physical space this process is involved with, and history is how long the entity will remember the experience. For example, if the SA measurement maps SA to {None, Some, Average, Good, Full}, the measurement may be presented as

$$M(SA_{0.05Sec.,0.5Sec,Person,1Minute}) = Full$$

this measurement could be how a person becomes aware that the person who sold her the coffee forgot to put a cup insulator on the hot cup of coffee. In this case, she might very well take an effective action of setting the coffee on the counter immediately. For another example, if the instrumentation of an entity's SA maps to $[0\ldots100]$, the measurement might be presented as

$M(SA_{1hour,6month,Country,15year}) = 80$

where the smallest frequency of input to the process being assessed is one hour, the SA is being formed with a moving window of 6 month worth of events, the scope of the process involves the size of a country, and the SA is being remembered for no less than fifteen years. The process being measured could be a long-term project such as a national campaign.

We give an example where organization situation awareness has higher utility than an individual's utility:

> Event 1: General Tsao's army stops at the sight of Lord Jeang's castle. The castle's gate is open with no significant activities seen within. Tsao's observer reports seeing Lord Jeang playing non-chalantly with his pet parakeet in the observation tower.

The state of situation awareness of General Tsao at this point is not certain enough for him to give the attack order. Which can be described using SALMA as $\{K(\overline{Trap}) \Rightarrow Attack\}$. This is due to fuzzy situation awareness that cannot rule out the possibility of a trap in waiting. However, by combining SA from another part of his organization, an observer of Event 2, General Tsao is able to elevate the quality of his situation awareness,

> Event 2: General Tsao receives a report from an intercepted messenger returning to Lord Jeang's castle. The message says, "The deal has been accepted; reinforcements will arrive within a day's time."

Knowing that Lord Jeang believes he needs support (through Event 2) enables General Tsao to conclude that the existing situation is merely a charade. Thus he orders his men to enter the castle and quickly capture Lord Jeang. By adding SA from the second observer, General Tsao was able to increase his SA from:

$M(SA^{t1}_{5\min.,1week,WFO,year}) = Some$ at time t_1 to $M(SA^{t2}_{5\min.,1week,WFO,year}) = Good$ at t_2 .

In the above example, the set {None, Some, Average, Good, Full} was selected to describe the quality of SA.

Impact of Information Technology on Distributed SA

As an integral part of the OODA loop, the commander assesses the situation, makes a decision, and assures his organization carries out commands effectively. With experience, he will be able to automate repetitive tasks of the OODA loop into an integrated and continuous process. With knowledge, management skill and leadership, he assures that his organization executes the OODA loop in the most practical manner to defeat the opponent. It is paramount that he possesses situation awareness to assure OODA efficiency. Information domain advancement has imparted changes to the infrastructure that supports OODA. Technology advancement can be divided into four categories: perception (sensors), infrastructure, decision support, and force projection. Sensors and force projection advancement such as satellite imagery, autonomous vehicles, and precision weaponry clearly improve the battle organization's capabilities. However, management of these new capabilities can become a concern for the commander, especially of voluminous information channels made available by new technology and making sense of a larger amount of rich data that can flow through the channels. This is in addition to the possibility of new control channels available to the commander; in analogy, it is interesting that some yogi have the ability to directly control their body's autonomous functions such as the heart rate, but deconstructing that automaticity might not necessarily be desirable for most of us.

In response to changing types of conflicts from planned wars to guerilla battles, new organizational theory suggests changes to the infrastructure on which the OODA process has been based. It is expected that integration of newer technology and implementation of new organizational theory will lift OODA to a new level of efficiency at the organizational level.

Network Centeric Warfare (NCW) proposes a C2 organizational structure that could prepare the military organization to deal more effectively with guerilla tactics. The main points of NCW include the re-distribution of military objectives amongst the commander and subordinate commanders. An extension of the NCW concept alludes to the disassociation of the C2 functions from the commander; in other words, the construct of the war fighting organization will be able to facilitate the C2 process, based on the nature of the C2 functions [ALBERTS03] (p. 17). It is a fact that a commander's personality plays a significant role in the focus and productivity of his organization. It is uncertain how the delegation of the traditional command responsibilities will affect his ability to project his resolve and will to the battle organization.

We know the war of today is fought differently simply because no opponent is willing to face the U.S. Forces head-on. Guerilla maneuvers are becoming the prevalent strategy used against our troops. This fact necessitates a review of our post-Korea war-fighting infrastructure, which has been improving via the Vietnam, Panama, Yugoslavia, Afghanistan, and Iraq experiences. However, advanced technology can cause wider asymmetric information needs when faced with less technology-dependent opponents.
Network Centric Warfare gives many restructuring possibilities due to information technology innovations. Using the horse and buggy analogy, war doctrine and policy is the horse and information domain innovation is the buggy. In the civilian world, technology adoption is a bottom-up process. As the critical mass that uses an innovation has been reached, it is inevitable that an organization has to accept the new technology. A caveat to the above statement is that what has been said takes place in the context of a peaceful environment, and the motivation that drives an organization is to assure its customers will continue to purchase its products and services. It is unclear who the analog of the customer is in a war fighting context. In contrast, war technology is integrated in a top-down manner, based on the time-tested war-fighting knowledge in the

cognitive domain. In other words, each adaptation of a technology should have its purpose, which is to improve the tried-and-true war process model in the cognitive domain, which itself is being improved by researchers. Uncontrolled bottom-up technology consumption will cause uncertainty and C2 difficulty; the horse should always lead the buggy. Moreover, it is necessary to clarify the role of each new technology being integrated into the war organization. Unlike civilian business processes, there is no room to insert nebulous-purposed innovations in the critical war fighting value chain. Moreover, the promise of automatic control through war-fighting information infrastructure where humans merely supervise the process is both far-fetched and can result in the loss of control during war time.

Many of the information technology innovations from the Dot Com era were designed for the business domain, where the majority of the processes are accounting related and the measure of success is profit, which interestingly, is also a product of the accounting process. War is different than business, the fog of war is different than the fog of business, and technology that reduces the fog of business might not necessarily reduce the fog of war. Case in point, it might be very comforting for a snack food company executive to know how many bags of potato chips are being delivered to a grocery store via secure wireless link from the delivery truck to the corporate database. A straight transference of that technology can give the commander the number of rounds being fired by each of the soldier, perhaps even expected time to depletion; that is obviously an over application of innovative technology. Dot Com era information technology was targeted to clear the fog of business at the Endsley SA level 1, record keeping and accurate transmission of information, but Clausewitz's fog is an Endsley SA level 3 object. Level 3 SA assesses the opponent's intention and projects future status. Its achievement would satisfy Sun Tzu's advice of "know the enemy and know yourself". However, no remarkable Level 3 decision tools have been developed that can be applied to the military C2 process. At the beginning of the 21st Century, significant business command and control decisions such as merger & acquisition, product identification, and negotiation are still being decided within the executive's brain. It is unfortunate that the business development of intelligent support systems is not as advanced as it could be. The promise of intelligent decision support technologies such as artificial intelligence and neural networks has been over-sold by eager marketers. Moreover, even the existence of a proven business decision support system might not be easily adaptable for war-fighting purposes; business competition is fought through the customer intermediary in a highly regulated fashion; it is like a tennis match. In contrast, war is literally becoming a street brawl in a dark corner. While excelling at record keeping and information transmission, the paradigm and technology that supports the business process needs to be evaluated to assure its built-in assumptions are identified and adaptable to war fighting command and control scenarios, such as the ramification of using well known technology, robustness, speed, etc. In general, the critical question is the technology's ability to augment SA and enhance decision-making under the stress of battle.

Technology is a process that increases the value of products or services [CHRISTENSEN03]. As changes are being applied to the technology domain to improve the command and control process, it implies that inserted technology can add value to the command and control process. What is the definition of *value* in command and control in the war-fighting domain? We assert that SA is an essential component of command and control, and improvement of SA results in improved C2 performance, thus technology that improves SA performance adds value to the command and control process, and SA performance can be improved by improving the acquisition of distributed situation awareness.

Conclusion

Advancement of human cognitive knowledge, organization theory, and information technology necessitates the evaluation of a possible paradigm-shift in the existing war fighting infrastructure. Considering the likelihood of a continued increase of guerrilla tactics by the opponents, it is paramount to assure that new paradigms will improve the Information Need asymmetry. Nevertheless, the Network Centric Warfare model holds the potential for material improvement of the command and control decision process by achieving better situation awareness. Obviously, the improvement of shared awareness does not mean the re-introduction of the corporate central database in the physical domain; it is fragile and prone to information contamination. Improvement of shared awareness requires improvement in how SA is organized and shared in the cognitive domain. We introduced the hierarchical representation of SA objects in the cognitive domain and the notion of Organization Situation Awareness (OSA). Examples were given that showed how OSA improves the overall situation awareness. In addition, we gave a rich modal logic-based language (SALMA) that can be used to communicate distributed SA in the physical domain to form OSA in the cognitive domain.

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