Human Supervisory Control Challenges in Network Centric Operations

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***Abstract*— Network centric warfare (NCW) is a concept of operations that seeks to increase combat power by linking battlespace entities to effectively leverage information superiority. The Department of Defense (DoD) has recognized that a lack of understanding of human decision making relevant to NCW is a significant barrier limiting potential benefits. To this end, this report identifies ten human supervisory control challenges that could significantly impact operator performance in NCW: Information overload, appropriate levels of automation, adaptive automation, distributed decision-making through team coordination, complexity measures, decision biases, attention allocation, supervisory monitoring of operators, trust and reliability, and accountability. Network-centric operations will bring increases in the number of information sources, volume of information, and operational tempo with significant uncertainty, all which will place higher cognitive demands on operators. Thus it is critical that NCW research focus not only on technological innovations, but also the strengths and limitations of human-automation interaction in a complex system.**

***Index Terms*—Human supervisory control, decision support**

I. Introduction

Network Centric Operations (NCO), also known as Network Centric Warfare (NCW), is a concept of operations envisioned to increase combat power by effectively linking or networking knowledgeable entities in a battlespace. Mission success is achieved by leveraging information superiority through a network, rather than through the traditional method of sheer numerical superiority through platforms and weapons. Key components of NCO include information sharing and collaboration which will promote shared situational awareness and overall mission success [1]. To realize NCO, significant improvements will need to be made in areas of communications, sensor design, and intelligent automation. However, while technological advances are important for the successful integration of network centric operations, equally if not more critical is the need to understand how, when, where, and why the technology supports human decision makers and front line soldiers. Command and control domains are complex socio-technical domains in that technology is the means to an end (goal or mission) defined by human intentions. Advanced NCO technologies that are not designed with the express purpose of supporting military personnel in dynamic and uncertain situations with rapidly shifting goals are likely to fail.

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The move from platform-centric warfare to NCW represents a shift in the role of humans both in mission planning and actual operation. As has already been evidenced in the development of fly-by-wire, highly automated aircraft and missile systems (such as Tomahawk and Patriot), military operators are less in direct manual control of systems, but more involved in the higher levels of planning and decision-making. This shift in control from lower level skill-based behaviors to higher level knowledge-based behaviors is known as human supervisory control (HSC). HSC is the process by which a human operator intermittently interacts with a computer, receiving feedback from and providing commands to a controlled process or task environment, which is connected to that computer [2].

HSC in military operations includes mission planning and passive and active intelligence operations, as well as missions involving manned aircraft, and unmanned air, ground, surface, and subsurface vehicles. The use of automated technologies and systems is a fundamental component of NCO; thus in the context of human interaction, NCO is a high level human supervisory control problem. The number and types of human-machine supervisory interfaces will expand accordingly in NCO, but there is little understanding of how functions should be allocated between humans and automation, what level of collaboration is needed, and how these can be supported with actual software and hardware. Given the influx of voluminous information sources in NCO, a particularly acute problem will be how to give operators enough information for well-informed decisions without reaching cognitive saturation. Moreover HSC problems in NCO are further complicated by the dynamic, uncertain, and time-pressured elements typical of command and control environments. Due to the increasing importance of HSC in NCO, the DoD has recognized that a lack of automation reliability and understanding of relevant HSC issues, as experienced both by individuals and teams, are among the primary barriers limiting exploitation of the full potential of NCO [1].

In this paper, ten major human supervisory control issues have been identified as those HSC issues that are likely to cause degraded performance for both the system and the operators/decision-makers in futuristic network centric operations. They are:

- Information Overload
- Appropriate Levels of Automation
- Adaptive Automation

- Distributed Decision-Making and Team Coordination
- Mitigating Complexity
- Decision Biases
- Attention Allocation
- Supervisory Monitoring of Operators
- Trust and Reliability
- Accountability

These ten categories are not in rank order, are not mutually exclusive, and will often overlap theoretically as well as in actual design and testing. The importance of each category will be dependent on the mission context and relevant technological systems. They will now be discussed in turn in the following sections.

II. Ten Human Supervisory Control Challenges

A. *Information Overload*

According to the DoD, the Global Information Grid (GIG), the actual information technology network that will link command and control agents, will be the enabling building block for NCO. The GIG is the end-to-end set of information capabilities, associated processes and personnel for collecting, processing, storing, and disseminating information to those who require it, on the battlefield or otherwise [1]. Metcalf's Law states that the usefulness, or utility, of a network equals the square of the number of users [3]. While this means forces will have access to exponential amounts of information over today's forces, it also means that information intake for the average NCO operator will be higher than ever seen been before in the command and control environment. Even if the information complexity does not increase (which is unlikely), mental workload will increase accordingly. The Yerkes-Dodson Law [4], adapted to workload and performance (Figure 1) illustrates that beyond a task-dependent moderate level of arousal, individuals will become cognitively overloaded and their performance will drop. The problem is predicting when and how this overload will occur for a dynamic decision making environment, so that the amount of information any single person or group is required to process is manageable.

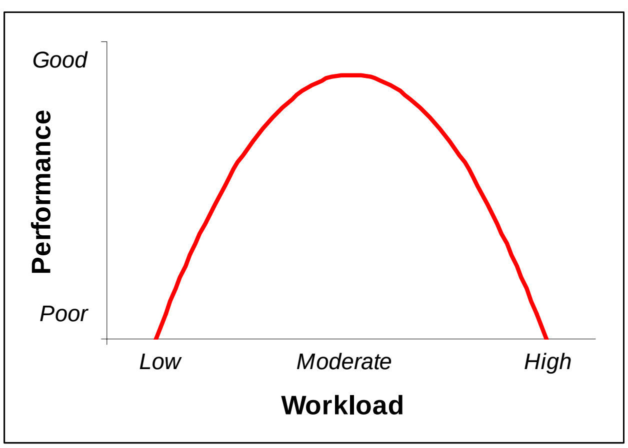

Fig. 1. Performance Adaptation of the Yerkes-Dodson Law

With the voluminous increase in incoming information in NCW, identifying the point or plateau of cognitive saturation is the key to designing systems that operators can effectively manage. Predicting this point of saturation is difficult for NCO systems because it is dependent on task, automation level, operational tempo, training, experience, and a number of other factors. Modeling and simulation can aid in predicting where these points are likely to be which could include cognitive, psychophysiological (to be discussed in a subsequent section), and predictive statistical models based on experimental simulations.

B. *Appropriate Levels of Automation*

While automating significant aspects of NCO is necessary so that information sharing can be both quick and comprehensive, what to automate and to what degree to automate a process/system is a central question in the design of NCO systems. For routine operations, higher levels of automation (LOAs) in general result in lower workload, while the opposite is true for low levels of automation [5].

It is possible to have a LOA too high or too low, each with its own distinct set of problems [6]. For example, HSC problems that could results if LOA is too high include:

- Manual or mental skill degradation.
- Loss of situational awareness due to lack of automation transparency, complexity, and inadequate feedback.
- More advanced automation issues such as brittleness & literalism; in other words, the automated system might not be able to handle novel or unexpected events. Moreover, it may not operate effectively in conditions near or at the edge of the intended operating envelope.
- Time and difficulty to diagnose failures and manually take over.

HSC problems can also occur if the LOA is too low, such as:

- Cognitive and working memory overload in routine tasks under time pressure.
- Human decision biases and heuristics.
- Lack of repeatability and consistency.
- Complacency and boredom.
- Greater human interdependency and chaos when something fails, unless safeguards are in place.

C. *Adaptive Automation*

Military operations are often characterized by long periods of inactivity followed by intense periods of action during which time-critical decisions must be made. At these times performance is most critical, yet it will likely suffer due to the temporary information overload placed on the operator and the need for the operator to cognitively reorient to the new situation. With NCO and the emergence of a robustly networked force, the amount of information available to military personnel at all levels is exponentially greater. Therefore, the problem of information overload, particularly during brief bursts of actions, will become much more common.

One method to alleviate such problems is the use of adaptive automation (AA). Changes in the level of automation can be driven by specific events in the task environment, models of operator performance and task load, physiological methods, or by changes in operator performance [7]. AA has been shown to improve task performance [8, 9], situational awareness [10] and lower workload [9]. Two important questions to answer in deciding how and when to develop an adaptive automation decision support system are 1) when to use adaptive automation to determine under what circumstances the LOA should change, and 2) whether the computer or the human decides to change the LOA.

AA cueing can be accomplished through models of operator performance which can predict the effectiveness of humans during particular processes and behaviors. Thus, the model's forecasted level of operator mental workload or performance on any number of specified tasks can be used to change the LOA. One primary problem with this approach is that the acceptable level of any measure predicted by the model must be carefully defined in advance. Performance models offer the advantage of flexibility in the sense that they can apply to a large range of situations, even unexpected ones, but often are costly and difficult to develop, especially if higher reliabilities are desired.

Psychophysiological measures such as the electroencephalogram (EEG), event-related brain potentials (ERPs), eye movements and electroculography (EOG), electrodermal activity (EDA), heart rate and heart rate variability (HRV), breathing rate and blood pressure have all been correlated with mental workload to varying degrees of success. Experimentally, these methods are advantageous because they are not task specific and they can continuously record data. One significant problem is that often the devices used to take these measurements are obtrusive and physically uncomfortable for subjects, creating a possible anxiety effect. In addition, they are very "noisy" and it is often very difficult to distinguish a true signal from the false ones. While psychophysiological measures have been used to adaptively allocate automation functions in research environments, because of the limitations, transferring experimental AA to operational AA has not yet been demonstrated.

Finally, AA may be based upon performance-based measures, whereupon some performance metric such as reaction time or task accuracy is used to determine mental workload. While generally easier to measure and quantify than physiological measures, performance measures are generally task-specific (and thus not generalizable to other tasks) and often require the subjects to modify their natural task behavior to accommodate the experimental objectives. Moreover, performance-based measures also may only give the experimenter discrete samplings of operator workload at specific intervals instead of a constant measurement. This could be inappropriate for some applications characterized by rapid changes in the environment like what will likely occur in high operational tempo settings in NCW, necessitating quick switches between automation modes.

D. *Distributed Decision Making*

Platform-centric command and control (C^2) in past military operations often avoided distributed decision-making and minimized team coordination in favor of a clear hierarchy for both information flow and decision making. Many decisions were made by a select few at the top level of command, and pains were taken to decompose various factions of the military into small, specialized niches that had little direct contact between one another (a hierarchical waterfall approach). This has begun to change in recent times, and a fully realized vision of NCW will require that both local and global teams of distributed decision makers, not a few people at the top of a hierarchy, make decisions under time-pressure. Therefore, understanding the issues unique to team-based coordination and decision-making take on new importance in the context of NCW. The question is how to make effective decisions between and within distributed teams, particularly in the complex, data-rich, and time-compressed situations often seen in military C^2 and NCW scenarios.

There has been extensive work in the computer-supported cooperative work (CSCW) community that examines how different types of technologies, to include both software and hardware, support effective team decision making. Developing technologies that promote collaboration both locally and remotely in space as well as synchronous and asynchronous in time is highly relevant to NCW. For example, Navy personnel are assigned to different watch sections for a ship's power plant, thus share a space but communicate across different times. One collaborative technology they use to pass knowledge is a log book. Logs are used by watchstanders to record significant events, time they occurred, who was notified, what actions were taken, etc. While they have existed on paper for hundreds of years on ships, written logs are now giving way to electronic logs, with added benefit of an easier search space and automated reminders.

However, while many technologies developed for corporate settings show promise for NCW applications (e.g., electronic whiteboards [11], table top displays [12], more research is needed into both the promised benefits, as well as unintended consequences. For example, chat, a popular and ubiquitous synchronous communication tool for remotely distributed military individuals and teams, can have unintended consequences in terms of degraded human and system performance [13]. In a study focusing on the benefits of shared displays between co-located team members, the shared displays unexpectedly contributed to degraded performance due to an increase in workload [14]. Given the high risk and uncertainty of military time sensitive operations, more investigation into the impact of new collaborative technologies is warranted.

While difficult to capture, Cooke et al. [15] measured distributed cognition in a command and control setting through team knowledge and succeeded in predicting subsequent team performance. However, distributed cognition across large scale time sensitive operations with multiple entities, both human and automated, is not well understood as well as how the introduction of new technologies supports or detracts from team situation awareness in NCW. Boiney [16] echoes this sentiment and in terms of time sensitive targeting, highlights the need for better understanding of collaborative sensemaking, the establishment of trust, distributed team situation awareness, and appropriate information sharing to include communications and awareness cueing.

Lastly, design of team architectures to include role allocation, team geographic distributions, communication, and team sizes is critical to successful NCW distributed decision making and team coordination. Research has shown that organizations operate most efficiently when their structures and processes match their mission environments [17], but it is not always clear whether traditional top-down hierarchies or more lateral heterarchies provide the most efficient structure [18]. Moreover, sensor quality and operational tempo can drive the need for distributed versus centralized control [19], thus further complicating the team architecture problem by adding a technological artifacts.

E. Complexity

Information complexity is a growing problem in many domains, with particular applicability to NCW. Complexity will be impacted by both the amount and sources of information, and will be further exacerbated in the future as sensor technologies improve and the volume of available data continues to grow. NCW operators will be required to understand resultant critical relationships and behaviors of that data at the same or higher level than today. Increased complexity will usually manifest in increased workload and/or unpredictability of the system, to include the human, which will have a negative effect on human and system performance [20]. There are also well known limitations to human performance that are likely to be encountered as workload increases. Therefore, it is important that the interfaces NCW operators interact with help to reduce and manage this increased level of data complexity.

Complexity, as defined by Merriam-Webster, is “the quality or state of being hard to separate, analyze, or solve”. The use of the term ‘hard’ implies that complexity is relative, which was captured by Miller [20] when he described the difference between actual and perceived complexity. Perceived complexity results from those elements of a task or situation that make it hard to deal with, or in other words, what makes a system seem difficult. Actual complexity implies the use of more objective criteria for complexity, and does not take into account humans’ perceptions of a task or situation.

In human supervisory control domains, displays are nominally designed to reduce complexity by representing the environment so that a correct mental model can be formed and correct interactions can take place [21]. Thus displays should reduce complexity and hence workload through transforming high-workload cognitive tasks such as mental computations into lower workload tasks through direct perception, i.e. visually [20]. In addition, displays should promote effective cognitive strategies such as grouping and rule formation to further reduce perceived complexity. However, one drawback to new display technology is that in complex and dynamic human supervisory control domains such as ATC and NCW, it is not always clear whether a decision support interface actually alleviates or contributes to the problem of complexity. While preliminary research indicates that elements of complexity can be measured as separate constructs and that display elements can add to cognitive complexity [22, 23], a more principled approach is needed in the development of metrics for display and organizational complexity.

One other potential problematic area for cognitive complexity that has emerged from recent display technological advances is the aesthetic seductiveness of compelling visual, aural, and haptic displays, otherwise termed as the “cool factor.” While displays that use advanced technologies such as 3D, holographic images, virtual reality, and layering invariably elicit a “that’s cool” response, emerging trends in research show that not only are these technologies often not helpful, they can also be harmful. For example, 3D displays are gaining in popularity, yet in recent command and control studies, realistic 3D perspective views produced poor performance for precise relative position and distance judgments. Furthermore, despite the fact that operators preferred 3-D icons, conventional 2D symbols produced superior performance [24]. Smallman et al., [25] attribute this disparity between operators’ preference for 3D displays and their sub par performance to a concept they term “Naïve Realism.” Operators naïvely prefer displays that mimic realistic scenes over representations that are flawed and imprecise, which could lead to poor performance.

F. Decision Biases

A defining characteristic of NCW is the expected increased information-sharing tempo over platform-centric forces of the past, which will require rapid decision-making with imperfect information. Humans in general, and especially under time pressure, do not make decisions according to rational decision theories. Rather, they act in a naturalistic decision-making (NDM) setting in which experience, intuition, and heuristics play a dominant role [26]. Humans generally employ heuristics in order to reduce cognitive load [27, 28], which will likely be the case in NCW settings. However, while heuristics can be useful, powerful tools, they can also introduce bias in decision making, especially when coupled with large amounts of information under time pressure.

While humans can be effective in naturalistic decision making scenarios in which they leverage experience to solve real world ill-structured problems under stress [29], they are prone to fallible heuristics and various decision biases that are heavily influenced by experience, framing of cues, and presentation of information. For example, confirmation bias takes place when people seek out information to confirm a prior belief and discount information that does not support this belief [30]. Another decision bias, assimilation bias, occurs when a person who is presented with new information that contradicts a preexisting mental model, assimilates the new information to fit into that mental model [31]. Of particular concern in the design of intelligent decision support systems that will support NCO processes is the human tendency toward automation bias, which occurs when a human decision maker disregards or does not search for contradictory information in light of a computer-generated solution which is accepted as correct [32, 33]. Operators are likely to turn over decision processes to automation as much as possible due to a cognitive conservation phenomenon [34], and teams of people, as well as individuals, are susceptible to automation bias [35].

Many studies have demonstrated evidence of automation bias in laboratory settings. Layton, Smith, and McCoy [36] examined commercial pilot interaction with automation in an enroute flight planning tool, and found that pilots, when given a computer-generated plan, exhibited significant automation over-reliance causing them to accept flight plans that were significantly sub-optimal. Skitka, Mosier, and Burdick [37] found that when automated monitoring aids operated reliably, they led to improved human performance and fewer errors as opposed to not having an aid. However, when the automation failed to detect and notify operators of an event, or incorrectly recommended action despite the availability of reliable confirmatory evidence, human error rates increased significantly. More directly related to NCW processes, in a Tomahawk strike planning and execution task, Cummings [38] found evidence of automation bias when an intelligent decision aid recommended a single course of action for retargeting missiles to emergent targets.

G. Attention Allocation

An important task in supervisory control is often one of how to allocate attention between a set of dynamic tasks. In deciding on an optimal allocation strategy, the operator acts to balance time constraints with relative importance of the required tasks. Due to the expected increases in the number of available information sources, volume of information and operational tempo in NCO, greater attentional demands will be placed on operators. This is a fundamental and critical HSC problem in NCO. There are two general areas where attention allocation issues are likely to occur in NCW: Preview times and primary task interruption.

In NCW, the problem of attention allocation issues and preview times occurs when an operator expects sensor information at established time intervals to accomplish some task, and must act on this information, whether complete or not, before a deadline. A central issue with the concept of preview times is how to maintain task priority when additional information is expected in the future, and how emergent situations influence an operator’s ability to assimilate this preview information. Tulga and Sheridan [39] investigated some aspects of this in a generic multi-task supervisory control paradigm. They found that at high workloads, the time subjects planned ahead was inversely proportional to the inter-arrival rate of new tasks. Using a similar paradigm, Moray et al. [40] found that even if subjects were given an optimal scheduling rule, they were unable to implement it under enough time pressure, resorting instead to significantly non-optimal heuristic rules. However, it was not possible to gain new information about specific tasks that would influence planning, nor were there unexpected events that significantly changed the nature of the task. In recent work examining intelligent agent predictions for future periods of high workload in order to aid operators controlling multiple UAVs, results revealed that subjects fixated on attempts to globally optimize an uncertain future schedule to the detriment of solving certain, local problems [41].

Another area of concern is that of primary task disruption by secondary tasks. In time-pressured scenarios, interruptions of a primary task caused by secondary tasks can increase mental processing time and induce errors in the primary task [42]. For supervisory control tasks in command and control that include monitoring of displays which may or may not be changing rapidly, operators will periodically engage in interactive control tasks such as changing the course of UAVs or launching a missile. When task engagement occurs, operators must both concentrate attention on the primary task, but also be prepared for alerts for external events. This need to concentrate on a task, yet maintain a level of attention for alerts, causes operators to have a conflict in mental information processing. Concentration on a task requires “task-driven processing” which is likely to cause decreased sensitivity or attention to external events. Interrupt-driven processing, needed for monitoring alerts, occurs when people are sensitized and expecting distraction. The conflict between focusing on tasks and switching attention to interruptions is a fundamental problem for operators attempting to supervise a complex system which requires dedicated attention but also requires operators to respond to secondary tasks, such as communications or alerts from non-critical sub-systems.

H. Supervisory Monitoring of Operators

A common operating structure in the military is one where a single supervisor oversees several human subordinates for the purpose of managing performance and relaying commands to the appropriate team members. Under information age C^2 structures, the need for this second function will be reduced (even eliminated in some cases), but performance monitoring will still be required. Frequently, these operators will be engaged in HSC tasks, so it will be the job of a supervisor to observe and diagnose HSC issues in one or more teams.

HSC problems can sometimes be subtle in nature, and thus tend to be more difficult to detect than during many other types of operations. Most HSC tasks are primarily cognitive in nature, so the supervisor cannot easily infer accurate performance from physical actions of operators. Rather than being able to directly observe task completion by a human, the supervisor can only evaluate how an operator is interacting with automation that completes that same task, and once it is done, evaluate the results of that effort. Physical actions taken by operators are limited to activities like typing, button pushing, and body movements to position themselves for better screen viewing. Furthermore, the effects of operators’ actions can occur in remote locations from both the supervisor and subordinates. This physical separation means that all people involved with the process must form mental abstractions to envision a complete picture of the situation. Complicating this is that interaction is usually done through artifacts with inherent limitations, such as voice communication, data links, and 2-dimensional screens. While this is clearly a problem with individual operators (it is one of the primary considerations when designing automation of this type), it is an even larger one for supervisors, who must try to synthesize information from multiple operators at once. Furthermore, isolating a single cause for poor performance of an entire team can be difficult, especially in time-pressured scenarios characteristic of NCW environments. Lastly, decreases in performance may be the result of automation degradation and have nothing to do with the human. Supervisors may have difficulty separating the two.

The main problem is then how to support supervisors of HSC tasks so that they are better able to understand what their subordinates are doing. Many of the issues previously discussed in this chapter factor into this discussion. In order to quickly observe and diagnose HSC problems, supervisors must have a high level of SA, both for individuals and teams. Even more so than their subordinates, it is critical that HSC supervisors have a clear picture of the team's *overall* situation. The building block to achieving this superior level of SA is access to and absorption of all relevant data. Therefore, information overload will be a particularly acute problem, as a supervisor could be responsible for any or all of the information available to their numerous subordinates. Additionally, due to the greater range of information types received by HSC supervisors as compared to a single operator, the number of possible relationships and behaviors of this data is higher, thus increasing situation complexity.

I. Trust and Reliability

Anecdotal reports from soldiers in Afghanistan using unmanned ground vehicles reveal that soldiers are underutilizing the robots because they inherently distrust the robots, and this inherent distrust in autonomous systems is reflected in the above case study. Distrusting automation when it is perfectly capable has been shown to lead to disuse or misinterpretation of results in order to fit an operator's mental model, even if the subsequent workload caused by the distrust is very demanding and/or time consuming [32, 43-45]. In process control, operators' trust in automation has been shown to be primarily based on their perception of the automation's competence [46], which is likely the case for the soldiers in Afghanistan.

In contrast, other studies have found that pilots tend to trust automation even when it was failing [47, 48]. In time-pressured scenarios with high stakes and uncertainty, operators can trust automated systems too much, to the detriment of the overall mission. Thus designers of NCW systems are faced with a conundrum – how to design a system that is trusted and utilized to its fullest extent, yet not overly trusted such that humans become complacent.

Trust is dynamic in that it changes with exposure to and time between system failures. For example, after an initial system failure, there is a sharp decrease in trust, but it rebounds with consistently correct automation. If the automation fails subsequent to this initial failure, trust decreases but it is regained more quickly [46, 49, 50]. Relevant to NCW, recent research in trust and automation reliability in UAV military reconnaissance missions demonstrated that while reliable automation aids operators, unreliable automation can significantly degrade performance [51]. Specifically, automation that caused a high rate of false alarms for system failures was far more disruptive than automation that failed to alert operators of a failure (otherwise known as a miss). As a result, Dixon et al. [51] recommended that any automated decision support system that operates below 70% would generate unacceptable costs.

Calibrating an operator's trust level to the automated system's actual trustworthiness or reliability is the solution to the problem of too little or too much trust [44, 50]. However, this is still not well understood in the field of human supervisory control. Automation feedback in terms of self-evaluation and interaction with automated decision aids have been suggested as potential strategies for appropriate trust calibration [44, 45]. Displaying the automation's confidence may facilitate better calibration of trust, however, displaying uncertainty and confidence information about an automated recommendation or solution is not a straightforward matter. Humans are not intuitive statisticians and tend to introduce biases in probabilistic reasoning [28]. Thus presenting probabilistic confidence information to operators so they can make unbiased decisions is not a trivial design problem.

McGuirl and Sarter [52] demonstrated that a categorical trend display of a computer's confidence in its recommendations was superior to a probabilistic static representation for in-flight icing interventions. Uncertainty in information has also been successfully conveyed through degraded images using blended color icons, and the addition of numeric probabilities provided no additional advantage [53]. Once an operator's trust has been properly calibrated, Xu et al. [54] have demonstrated that even with imperfect automation, human operators can still properly execute their tasking. Given the significant uncertainty that will exist within the actual NCW environment as well as the uncertainty introduced by imperfect automation, more research is needed in trust calibration techniques, especially as they apply to time-pressured decisions.

J. Accountability

In addition to the myriad of technical issues that surround NCW human supervisory control problems, there are also social and ethical considerations, especially for weapon systems that impact humans in such a dramatic fashion. What might seem to be the most effective design from a technical viewpoint may not be the most responsible. In one of the few references in the technical literature on humans and automation that considers the relationship between automation and moral responsibility, Sheridan [55] is wary of individuals "blissfully trusting the technology and abandoning responsibility for one's own actions."

While many technical design issues can be resolved through modeling and testing, degradation of accountability and abandonment of responsibility when using automated systems is a much more difficult question to address. Automated tools are designed to improve decision effectiveness and reduce human error, but they can cause operators to relinquish a sense of responsibility and subsequently accountability because of a perception that the automation is in charge. Sheridan [56] maintains that even in the information processing role, "individuals using the system may feel that the machine is in complete control, disclaiming personal accountability for any error or performance degradation."

How then could systems be designed to promote accountability, especially in the context of NCW? One tangible system architecture consideration for accountability is the number of people required to interact with a given decision support system. Research indicates that responsibility for tasks is diffused when people work in collective groups as opposed to working alone. This concept is known as "social loafing" (see [57] for a review). This is of particular concern in distributed systems like those expected in NCW systems since task responsibility will often be delegated to many. While research indicates that people experience degraded task responsibility through collective action, the potential loss of a sense of moral responsibility and agency for operators interacting collectively through human-computer interfaces is not as clearly understood. It is likely that the computer interface becomes another entity in the collective group so that responsibility, and hence accountability, can be cognitively offloaded not only to the group, but also to the computer. This is one area in human-computer interaction and accountability research that deserves significantly more attention.

III. Conclusion

Military forces in the 21st century face complex and subversive threats that often cannot be defeated by conventional tactics. Thus, it is critical that the military be able to leverage all of its available information, and to have sufficient agility to apply relevant resources to bear on emerging situations. This is the driving force behind the US military's transformation into the Information Age and NCW. However, the primary advantage of operations based upon the tenets of NCW, that of rapid access to information across the network, will likely be a major bottleneck and possible point of failure for those humans who must synthesize voluminous data from the network and execute decisions in real-time, often with high-risk consequences under significant uncertainty. Network-centric operations will bring increases in the number of available information sources, volume of information and operational tempo, all which place higher cognitive demands on operators.

The 10 HSC NCW challenges identified here are not mutually exclusive and apply to other domains such as business and civilian command and control entities such as air traffic control and first response systems. Specifically the adoption of NCW principles will be problematic for human decision makers who need to execute supervisory control across complex, distributed networked systems with a high degree of uncertainty. The implementation of NCW will exponentially add to the number of available information sources as well as the volume of information flow. Without measures to mediate this volume, *information overload* will be problematic. To manage the increase in information across the network, increased *levels of automation* will be needed but often introduce additional human performance problems. One potential design strategy is the use of *adaptive automation*, which has been shown in certain cases to lower workload, but is beset with many technical and mission-critical limitations. Workload mitigation strategies such as increased automation and multimodal displays will increase *complexity*, which can cause a loss of situation awareness or an unexpected and unmanageable increase in mental workload. It is therefore essential that designers be able to measure whether or not interfaces with which NCW operators interact actually reduce complexity instead of add to it.

A more fundamental issue associated with the increase in the number of available information sources, volume of information, and operational tempo under NCW are operator *attention allocation* strategies. NCW hinges on successful information sharing, so knowledge of the relationship between perceived and actual high priority tasks and associated time management strategies, as well as the impact of task disruptions is critical. As a result of NCW information sharing, command and control structures will change significantly. Traditional hierarchical command will be partially replaced by *distributed decision-making* and low-level *team coordination*. Therefore, understanding how to make effective, time-pressured decisions within these organizational structures takes on greater importance in NCW. Moreover, leveraging automation to aid in *supervisory monitoring of operators* is another significant area of concern since NCW will contain embedded HSC systems.

NCW will drive an increase in information-sharing tempo and rapid decision-making. Under these time pressures, the use of heuristics and other naturalistic decision-making methods may be subject to undesirable *decision biases*, both for individuals and groups. Often these decision biases will result in complacent behavior such that operators overly *trust* a complex automated system, but there is also significant distrust of automated systems, which is particularly linked to that system's *reliability*. Lastly, this potentially displaced trust in automation and complacency can lead to a loss of *accountability* and erosion of moral responsibility.

Unfortunately, despite the fact that NCW exists to support human intentions, technological determinism is pervasive in that the primary thrust of NCW research is directed toward improvements and innovations in technology [58]. The typical but naïve assumption is that advancements in automated systems will naturally improve both system and human performance. Without dedicated focus on the impact of NCW technology for both individual and team cognitive processes, as identified in these 10 areas, the DoD vision of a network with shared situational awareness, increased speed of command, self-synchronization, and higher operational tempo, lethality and survivability will be replaced with a problematic, sub-optimal, and reactive network with significantly increased risk for warfighters.

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