Special Feature

The world has changed since the Air Force structured its logistics support organization and processes. In the future, Joint warfighting will place extraordinary demands on the Air Force's ability to execute superior logistics support decisions.

logistics

Combat Support

Sense and Respond Combat Support: Command and Control-Based Approach
Beyond Authorized Versus Assigned: Aircraft Maintenance Personnel Capacity

This edition of the Journal presents two featured articles: "Sense and Respond Combat Support: Command and Control-Based Approach" and "Beyond Authorized Versus Assigned: Aircraft Maintenance Personnel Capacity."

In "Sense and Respond Combat Support: Command and Control-Based Approach" the authors examine a new approach to combat support. In the past, prediction and responsiveness have been viewed as competing concepts. The authors argue that both are necessary and can be integrated within a command and control system to create military sense and respond capabilities.

The second featured article examines total not mission capable maintenance (TNMCM) rates for the C-5 fleet. To address the root cause factor of aligning maintenance capacity with demand, a method of determining available maintenance capacity was needed. To meet this need, a new factor designated as net effective personnel (NEP) was developed by the authors. The NEP calculations were ultimately used in conjunction with historical demand to propose base-level maintenance capacity realignments resulting in projected improvements in the C-5 TNMCM rate. This article is the first in a three-part series.

Sense and Respond Combat Support

Command and Control-Based Approach

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This article is dedicated to the memory of Dr C. Robert Roll, a great friend and a scholar.

Nothing is too wonderful to be true.

—Kay Redfield Jamison

Introduction

Special Feature

Modern warfare has evolved from conflicts dominated by massed manpower, the so-called *first generation* of modern (post-Westphalian) war, to a warfare that has integrated political, social, economical, and technological issues. A recent National Defense University study maps this evolution from first generation warfare, culminating in the Napoleonic Wars, to second-generation wars dominated by firepower. Third generation war was the new maneuver tactics developed by the Germans in World War II. Unconventional enemy, in terms of insurgencies and counter-insurgencies, dominates the fourth generation.[1] In fourth generation warfare, the nation-states no longer hold a monopoly on weapon systems and may be involved in long conflicts with stateless enemies. Although insurgency is not new (dating back over two millennium)[2] the political features of insurgency have become a predominate character of modern insurgents. Advances in information technology also have had a revolutionary impact in these types of warfare.

A constant throughout the history of warfare has been the central role of logistics in the successful prosecution of any conflict. However, the 20th century logistical system lagged behind rapidly changing technology and tremendous efforts were put into the scientific study of logistics. Most of the early supply systems operated on a *push* concept rather than in response to actual needs and changes. It was thought that having an abundance of resources in theater ensured that combat support (CS) elements would be able to provide everything needed to achieve the desired operational effects. In practice, the presence of *mountains of supplies* did not always ensure warfighters' demands were met. In fact, the backlog of war materiel congested the CS system because of inefficiencies in the transportation system and the prioritization processes. It was evident that a more comprehensive capability was needed for matching CS assets to warfighter needs. In the past, prediction and responsiveness have been viewed as competing concepts. However, in this article, we argue that both are necessary and can be integrated within a command and control system to create military sense and respond capabilities.

Military logistics planning grew even more difficult with the collapse of the Soviet Union and the dissolution of the associated threat to United States interests in Europe. The shift in global power exposed the inefficiencies of legacy CS systems that had been hidden under a static and focused, albeit immense, threat. The geopolitical divide that once defined US military policy was replaced by a temporary rise of regional hegemons, which in turn slowly evolved (and continues to evolve) into a geopolitical environment that is defined not only by regional powers, but also by nontraditional security threats. The uncertainty associated with planning for military operations was thus extended to include uncertainty about the *locations* and *purpose* of operations.

Article Highlights

Unless significant improvements are made to last-mile transportation in theater, S&RL will have only a limited effect on operations. A robust, assured transportation network is the foundation on which expeditionary operations, as well as S&RL implementation, rests. The complete integration of transportation into the CSC2 architecture is essential.

Most of the early supply systems operated on a *push* concept rather than in response to actual needs and changes. It was thought that having an abundance of resources in theater ensured that combat support (CS) elements would be able to provide everything needed to achieve the desired operational effects. In practice, the presence of *mountains of supplies* did not always ensure warfighters' demands were met. In fact, the backlog of war materiel congested the CS system because of inefficiencies in the transportation system and the prioritization processes. It was evident that a more comprehensive capability was needed for matching CS assets to warfighter needs. In the past, prediction and responsiveness have been viewed as competing concepts. In "Sense and Respond Combat Support: Command and Control-Based Approach," the authors argue that both are necessary and can be integrated within a command and control system to create military sense and respond capabilities. In the course of the article they outline how this may be accomplished.

The authors conclude by noting that significant challenges remain before the Air Force can realize a sense and respond combat support (S&RCS) capability. To develop effective tools that accurately link logistics levels and rates to

The Air Force, in response to the changing military environment, designed and developed a transformational construct called the Air and Space Expeditionary Force (AEF).[3] The implementation of the AEF changed the Air Force's mindset from a threat-based, forward-deployed force designed to fight the Cold War to a primarily continental United States-positioned, rotational, and effects-based force able to rapidly respond to a variety of threats while accommodating a high operations tempo in the face of the uncertainties inherent in today's contingency environment. The AEF prompted a fundamental rethinking and restructuring of logistics. This modern perspective of CS does not merely consider maintenance, supply, and transportation but is expanded to include civil engineering, services (billeting and messing), force protection, basing, and command, control, communications, and computers.

The shift to a more expeditionary force compelled a movement within the Air Force toward a capability called agile combat support (ACS). One of the Air Force's six distinctive capabilities, ACS includes actions taken to create, effectively deploy, and sustain US military power anywhere—at our initiative, speed, and tempo. ACS capabilities include provision for and protection of air and space personnel, assets, and capabilities throughout the full range of military operations.[4] ACS ensures that responsive expeditionary support for right-sized forces used in Joint operations is achievable within resource constraints. ACS began to emerge as a concept in a series of Air Force and RAND publications,[5] which detailed both micro- and macro-level analyses. One of the key conclusions of these studies has been the need for a robust and responsive combat support command and control (CSC2) architecture.

Combat Support Command and Control: Key to Agile Combat Support and Essential for Sense and Respond Combat Support

Command and control (C2), although often associated with operations, is also a fundamental requirement for effective CS. As warfighting forces become more flexible in operational tasking, the support system must adapt to become equally flexible. The C2 of modern CS assets must be woven thoroughly with operational events—from planning through deployment, employment, retasking, and reconstitution. Additionally, CS goals and objectives must be increasingly linked directly to operational goals and objectives. The traditional distinction between *operations* and *CS* loses relevance in such an environment. CS activities need to be linked to operational tasking with metrics that have relevance to both warfighter and logistician.

In essence, CSC2 sets a framework for the transformation of traditional logistics support into an ACS capability. CSC2 should provide the capabilities to

- Develop plans that take operational scenarios and requirements, and couple them with the CS process performance and resource levels allocated to plan execution to project operational capabilities. This translation of CS performance into operational capabilities requires modeling technology and predicting CS performance.

- Establish control parameters for the CS process performance and resource levels that are needed to achieve the required operational capabilities.
- Determine a feasible plan that incorporates CS and operational realities.
- Execute the plan and track performance against calculated control parameters.
- Signal all appropriate echelons and process owners when performance parameters are out of control.
- Facilitate the development of operational or CS get-well plans to get the processes back in control or develop new ones, given the realities of current performances.

CSC2 is not simply an information system. Rather, it sits on top of functional logistics systems and uses information from them to translate CS process performance and resource levels into operational performance metrics. It also uses information from logistics information systems to track the parameters necessary to control performance. It includes the battlespace management process of planning, directing, coordinating, and controlling forces and operations. Command and control involves the integration of the systems, procedures, organizational structures, personnel, equipment, facilities, information, and communications that enable a commander to exercise C2 across the range of military operations.[6] Previous studies built on this definition of C2 to define CS execution, planning, and control to include the functions of planning, directing, coordinating, and controlling CS resources to meet operational objectives.[7]

The objective of this transformed CSC2 architecture is to integrate operational and CS planning in a closed-loop environment, providing feedback on performance and resources. The new CSC2 components significantly improve planning and control processes, including

- Planning and forecasting (prediction)
  - Joint analysis and planning of CS and operations
  - Determining feasibility, establishing control parameters
- Controlling
  - Monitoring planned versus actual execution—a feedback loop process allowing for tracking, correction, and replanning when parameters are out of control
- Responsiveness
  - Quick pipelines and the ability to respond quickly to change

One of the key elements of planning and execution is the concept of an effective feedback loop that specifies how well the system is expected to perform during planning, and contrasts these expectations with observations of the system performance realized during execution. If actual performance deviates significantly from planned performance, the CSC2 system warns the appropriate CS processes that their performance may jeopardize operational objectives. The system must be able to differentiate small discrepancies that do not warrant C2 notification from substantial ones that might compromise future operations. This requires the identification of *tolerance limits* for all parameters, which is heavily dependent on improved prediction capabilities. This feedback loop process identifies when the CS plan and infrastructure need to be reconfigured to meet dynamic operational requirements and notifies the logistics and installations support planners to take action, during both planning and execution.

Article Highlights

operational effects, the modern Expeditionary Combat Support System must be developed and tested in conjunction with operations and intelligence systems.

Technologies associated with S&RL are still in an early stage of development and may not be fielded for a number of years. Ultimately, the Expeditionary Combat Support System should relate how combat support performance and resource levels affect operations, but current theoretical understanding limits these relationships. The Air Force does not appear to be lagging behind industry in the implementation of S&RL capabilities but should continue to make judicious investments in this field.

The Air Force has recently established the Global Logistics Support Center as the single agent responsible for end-to-end supply chain management. The creation of this entity holds promise for the achievement of S&RCS capabilities. The Global Logistics Support Center should be in a position to advocate for future improvements while exploring ways to provide the capability utilizing current systems.

Article Acronyms

ABM – Agent-Based Models
ACS – Agile Combat Support
AEF – Air and Space Expeditionary Force
C2 – Command and Control
CoAX – Coalition Agent Experiment
CS – Combat Support
CSC2 – Combat Support Command and Control
DARPA – Defense Advanced Research Projects Agency
DoD – Department of Defense
ECSS – Expeditionary Combat Support System
IT – Information Technology
OFT – Office of Force Transformation
RFID – Radio Frequency Identification
S&R – Sense and Respond
S&RCS – Sense and Respond Combat Support
S&RL – Sense and Respond Logistics

A robust CSC2 construct will enable a sense and respond capability that integrates operational and CS planning in a closed-loop environment, providing feedback on performance and resources. Figure 1 illustrates this concept in a process template that can be applied through all phases of an operation from readiness, planning, deployment, employment, and sustainment to redeployment and reconstitution.

This comprehensive transformation of CSC2 doctrine and capabilities blends the benefits of continuously updated analytical prediction with the ongoing monitoring of CS systems, which, given a robust transportation capability, enables the rapid response necessary to produce a sense and respond combat support (S&RCS) model appropriate for military operations in the 21st century.

Defining Sense and Respond Combat Support

The emphasis on the ability to *respond* quickly and appropriately through the command and control function to the broader areas constituting CS is how this article differentiates S&RCS from the traditional definition of sense and respond logistics (S&RL). Implementing S&RL concepts and technologies through the CSC2 architecture is the way to achieve an S&RCS capability.

In an often volatile commercial market, the manufacturer and distributor constantly monitor changes in buying patterns and adapt quickly to maintain market share. By employing S&RL, commercial enterprise has been able to reduce investments in warehouses and stock. Industry now increasingly produces what is desired and required rather than what a planner thinks should be built based on internal production goals. Commercial S&RL, in theory, reduces stock and overhead costs and responds rapidly to change.[8] The key to these improvements is a robust system of information-gathering and analysis or, in military terms, a highly efficient C2 system.

Commercial practices and commercial definitions of S&RL fall short of what is needed to create S&RCS in the Air Force environment. Although there are similarities between some of the issues and constraints of the military and those of a large corporation, the risk of human casualty, the consequences to the international political order, and vastly different military objectives set the Department of Defense (DoD) apart from any corporation of comparable size. The scope of activities included in military CS is also much broader than that of commercial logistics; any reorganizational concept must consider the nuances of military operations. It is interesting to note that firms have designed lean supply chains to be resilient to business disruptions,[9] but it has been shown that resiliency for firms may not translate to resiliency for the entire supply chain and the government provision of pliability and redundancy may be necessary in an era of lean supply chain management.[10] In the military case, the Air Force is the sole user and provider and thus the business notions of resiliency may not be entirely applicable.

Traditionally, ongoing planning and tasking often occur in isolation from those who would subsequently be required to support the levels and rates of tasking. Coordination, if any, occurs after initial planning cycles are completed. Modern, responsive systems demand information-sharing among all partners in the military enterprise. Moreover, tools and technology play a vital role in this enterprise.

A Brief Survey of Sense and Respond Tools and Technology

The DoD Office of Force Transformation (OFT) developed the military sense and respond logistics concept, borrowing heavily from research in the commercial sector (which was in turn indebted to earlier military efforts, such as the observe, orient, decide, and act loop)[11] to describe an adaptive method for maintaining operational availability of units by managing their end-to-end support network. OFT addresses S&RL from a Joint force perspective and as an important component of DoD's focused logistics strategy.

OFT considered architectural development planning that includes the development of an information technology S&RL prototype. One of these architectural concepts is the Integrated Enterprise Domain Architecture, which has the objectives of integrating, accommodating, and employing concepts and components of logistics, operations, and intelligence architectures and of their command, control, communications, computers, intelligence, surveillance, and reconnaissance concepts.[12] Presently, Integrated Enterprise Domain Architecture is in a predevelopment stage, but plans are to eventually link it to other architectures or programs, including Joint Staff J4, Joint Forces Command, US Marine Corps, United States Transportation Command, and possibly certain organizations in the Navy and the Army. Among the in-work project linkages is

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the RAND-Air Force CSC2 Operational Architecture as the Air Force vehicle for coordinating with concepts in S&RL.

Overall, the OFT program for S&RL is in a very early stage, but it has the potential to influence and effect near- to mid-term changes in some current programs using S&RL technologies. OFT suggests that elements of the concept can be employed in an evolutionary development in the very near term and could result in immediate operational gains.[13] OFT has also identified a number of technologies that are essential in an S&RL system, two of which were highlighted as especially important components: radio frequency identification and intelligent (adaptive) software agents.

However, before we discuss these components it is noteworthy to present some of the technical requirements that are essential in supporting sense and respond CS. Although there is great diversity amongst various approaches to sense and respond logistics implementation and its applications, a general theme is best stated by the IBM Sense and Respond Enterprise Team.[14] These criteria are in line with RAND's CSC2 concepts which the Air Force is in the process of implementing.[15] In general, technologies and innovation to support sense and respond (S&R) must have the following:

- The ability to detect, organize, and analyze pertinent information and sense critical business (force) conditions
- The filters for enterprise data to enable stable responses to disturbances in the business or military environment
- The intelligent response agents that analyze global value chain relationships and information and derive the optimal strategy for the best supply chain performance
- Predictive modeling at multiple levels: strategic, tactical, and operational
- Agent coordination mechanisms at multiple levels: strategic, tactical, and operational
- The ability to learn by comparing previously predicted trends with recorded data and information to improve future responses
- A software infrastructure to integrate heterogeneous and collaborative agents implementing critical business policies and making operational decisions

This concept can be contrasted with the OFT perspective. OFT, within its All Views Architecture, lists specific systems architecture components for S&RL, including the following capabilities:[16]

- Passive and active tagging, instruments, and sensors that provide location status, diagnoses, prognoses, and other information relative to operations space entities, especially for conditions and behavior that affect force capabilities management, logistics, and sustainment.
- Intelligent software agents that represent operations space entities, conditions, and behaviors, provide a focus for control of action or behavior, or act as monitors.
- S&RL knowledge bases oriented toward force capabilities management, logistics, and sustainment.
- S&RL reference data, again focused on force capabilities, assets, and resources related to force capabilities management, logistics, and sustainment.
- S&RL rule sets, which govern the operations and organization of S&RL functions, activities, and transactions.
- S&RL cognitive decision support tools uniquely supporting force capabilities management, logistics, and sustainment.
- Unique S&RL processes, applications, portals, and interfaces not provided either by Distributed Adaptive Operations

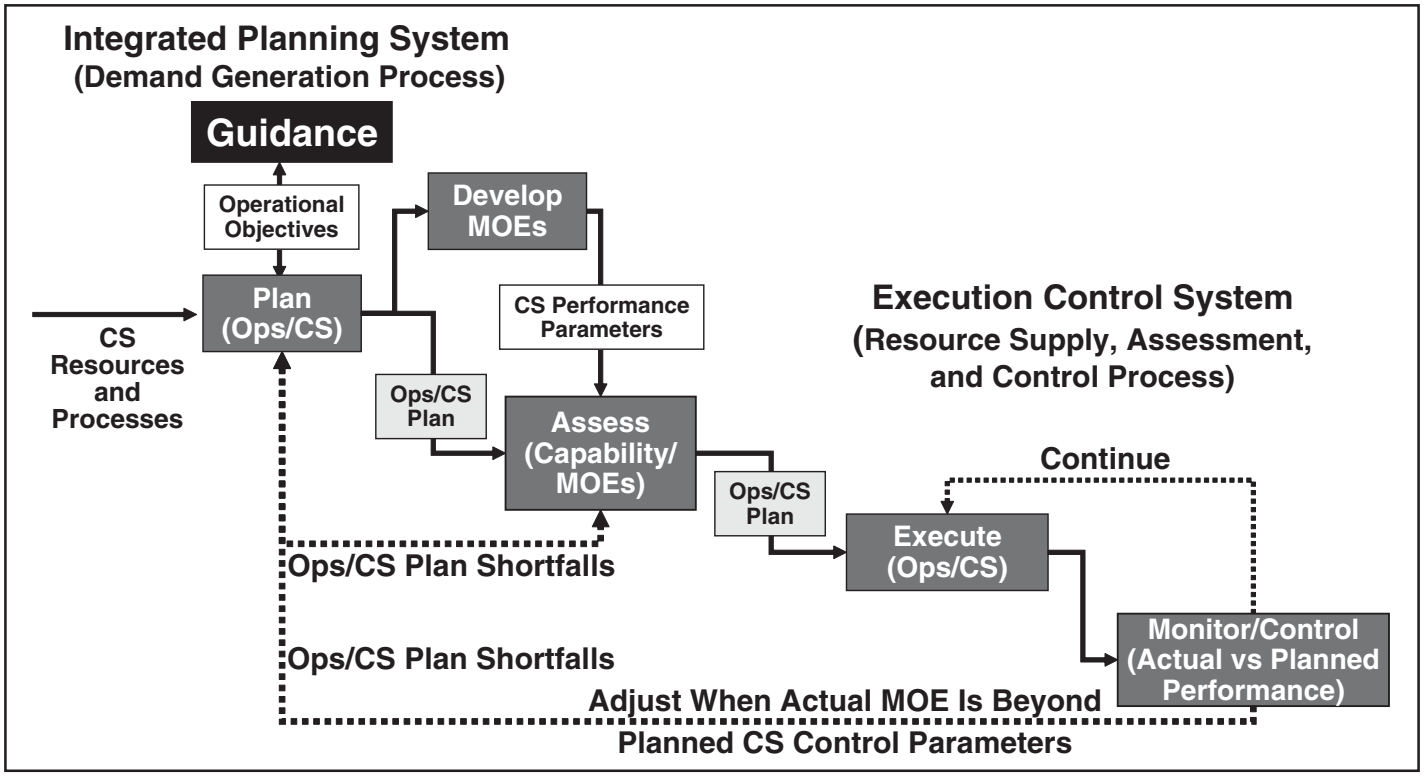

Figure 1. Feedback Loop Process

Command and Control or the Network-Centric Operations and Warfare infrastructure.

These are representative of the technologies and innovations that have been identified with military and commercial S&RL initiatives. In the next section, we discuss two important technologies needed to enable an ultimate S&RCS capability: radio frequency identification (RFID) and intelligent (adaptive) software agents.[17]

Radio Frequency Identification. RFID is an automatic identification technology that provides location and status information for items in the CS system. RFID technologies are fairly mature and have been fielded in both commercial and military arenas. Technically, RFID offers a way to identify unique items using radio waves. Typically, a reader communicates with a tag, which holds digital information in a microchip. However, some chipless forms of RFID tags use material to reflect back a portion of the radio waves beamed at them. This technology is of equal interest to military and commercial enterprises.

There are several examples of real-time information-gathering and distribution. For example, in Iraq, some Marine units had active tags not just on pallets but also on vehicles. RFID readers were set up at a distribution center in Kuwait, at the Iraq-Kuwait border, and at checkpoints along the main arteries in Iraq. When trucks passed the readers, the location of the goods they were carrying was updated in the DoD's in-transit visibility network database. This enabled commanders on the ground to see the precise location of the replenishments needed to sustain operations. RFID implementation is limited, but the DoD goal is to minimize human involvement when collecting data on shipments and their movements.

The Application of Agent Technology. The application of agent technology in S&RL research has become pervasive both in military and nonmilitary programs. Agent-based modeling (ABM) allows a more robust simulation of CS operations.[18] Agent-based models are already in wide use within the DoD for force-on-force simulations but have only recently been adapted for military logistics use. The logistics domain is distributed and involves decentralized (autonomous) organizations. These organizations are also

- Intentional entities, with goals, functions, roles, and beliefs, using processes and expertise to achieve their goals
- Reactive, and thus responsive to changes that occur in their environment
- Social, so they interact with other organizations to achieve their goals, where the social interaction is typically complex, such as negotiation, rather than just action requests

The similarity in characteristics between agents and organizations makes agents an appropriate choice for modeling organizations. This also explains agent functionality in carrying out organizational or human processes in S&RL applications. Moreover, robust distributed C2 strategies can also be tested using ABMs.[19] Although some simple supply chain simulations have been done for logistics, almost none have modeled actual organizations with the requisite detail and calibration necessary to compare alternative policies and gain insight.

Although individual automated software agents are already employed commercially for particular tasks, intelligent multi-agent systems are still in early development.[20] Consequently, ABMs have only had a limited effect on practical decisionmaking. Only in recent years have academic researchers explored the use of intelligent agents for supply chain management.[21] Although ABMs are properly understood as multi-agent systems, not all agents or multi-agent systems are employed for modeling and simulation purposes. Several researchers, including some under DoD contracts, have developed applications of ABMs for supply chain management.[22]

Agents have been used in telecommunications, e-commerce, transportation, electric power networks, and manufacturing processes. Within telecommunications, software agents bear the responsibility for error-checking (such as dropped packets), routing and retransmission, and load-balancing over the network. Web-search robots are agents that traverse Web sites collecting information and cataloging their results. When a customer searches for an item on a Web site, say Amazon.com, at the bottom of the page there is a list of similar products that other customers interested in the item also viewed. Similar agents assemble customized news reports and filter spam from e-mail. Data-mining agents seek trends and patterns in an abundance of information from varying sources and are of particular interest for all-source intelligence analysis.[23]

A World of Initiatives

The following discussion represents recent and current initiatives, both public and private, to develop sense and respond capabilities.

- The Defense Advanced Research Projects Agency (DARPA) has been working on an end-to-end logistics system under the Advanced Logistics Project.[24] Under this project, DARPA developed an advanced agent architecture with applications to logistics. As follow-on to Advanced Logistics Project, DARPA initiated a program called Ultra-Log that attempted to introduce robust, secure, and scalable logistics agents into the architecture. Ultimately, ultra-Log is seeking valid applications to DoD problems (such as Defense Logistics Institute applications) while adopting commercial open-source models.
- DARPA led another experiment called Coalition Agent eXperiment (CoAX), which was an example of the utility of agent technology for military logistics planning. A multi-agent logistics tool, implemented within CoAX, was developed using agent technology to have agents represent organizations within the logistics domain and model their logistics functions, processes, expertise, and interactions with other organizations. The project generated important lessons for S&RL, identifying two types of issues that need to be overcome for agents to be effectively used for military logistics planning—technological and social (human acceptability). RAND believes the issues are the same for use in executing logistics functions. Under technology, the identified issues include logistics business process modeling, protocols, ontologies, automated information-gathering, and security. We found some of these being addressed in DARPA's work. Under social acceptability, the following were important: trusting agents to do business for you, accountability and the law, humans and agents working together, efficiency metrics, ease of use, adjustable autonomy, adjustable visibility, and social acceptability versus optimality.

- The Air Force Research Laboratory, Logistics Readiness Branch (AFRL/HEAL) has focused its attention on human factor issues in S&RL, with a concentration on cognitive decision support.[25] AFRL proposes to focus on the human aspects of distributed operations by researching and developing enhanced or novel methodologies and measures to evaluate the effect of collaboration technologies on human performance from an individual, team, and organizational perspective. This group suggests that human performance metrics should be created along with other performance metrics for S&RL functions and activities in the military enterprise, although such considerations are currently not being called for in the requirements.

In addition to the multiple DoD-led initiatives, a number of commercial sector and university initiatives have developed some of the technologies needed to enable an S&RCS capability and presents a number of industrial applications of fielded S&R systems. These included an IBM Sense and Respond Blue program, which was a major influence on the military OFT enterprise definition and emphasized the employment of careful planning as well as intelligence, flexibility, and responsiveness in execution in order to achieve high levels of distributed efficiency.[26] In addition, General Electric Transportation Systems developed and fielded an autonomic logistics capability for its locomotive engine business. This capability is enabled through an onboard computing and communications unit that hosts software applications, continuously monitors locomotive parameters, and provides communications to General Electric's Monitoring and Diagnostics Service Center.[27]

Based on this technology review of both military and commercial activities and initiatives (and a more thorough review detailed in the RAND monograph[28]), we concluded that although current technology has enabled a limited set of sense and respond capabilities, a full implementation of S&RL concepts remains dependent on substantial future technological development. The largest challenge ahead for implementing a broader S&RCS capability is the development of an understanding of the interactions between CS system performance and combat operational metrics. Without the proper metrics for measuring the agent (and other) technologies used in S&RCS implementation, it is difficult to project where or when CSC2 effectiveness best stands to gain from this technology insertion. This is an important subject to address through information technology prototyping for CSC2 because it should drive information technology investments among S&RL technologies.

Air Force Combat Support Command and Control Implementation Effort

The Air Force has taken initial steps to implement the CS command and control operational architecture. Its efforts are designed to help enable AEF operational goals. Implementation actions to date include changes in C2 doctrine, organizations, processes, and training. Although progress has been steady, the area of information systems and technology requires increasing application of modern capabilities. The emerging modernized logistics information systems emphasize mostly business process improvements, with little focus on CS challenges and requirements. Additionally, CS systems are not being coordinated and tested in an integrated way with operations and intelligence systems. The architecture and requirements for peacetime and wartime logistics and CS information systems will need to be more closely coordinated.

The Air Force has begun evaluating the effectiveness of CSC2 concepts in exercises. Improving CSC2 organizations, processes, and information systems hardware, software, and architecture will require several years of active involvement by US Air Force Headquarters as well as Air Force initiatives to restructure a system that was previously organized around fixed-base, fight-in-place air assets. However, there are active efforts to structure CSC2 activity and policy in a way that should effectively support forces throughout the 21st century. Below is a summary of the status of Air Force implementation actions.

C2 Doctrine. The Air Force initiated a review of its doctrine and policy and began revisions to reflect the robust AEF CSC2 operational architecture. Such actual and planned changes to Air Force doctrine and policy are on the right track. As doctrine is changed, procedures, policies, organizations, and systems can then be changed to align with the changing concepts of warfare. Perhaps the most significant opportunity for improvement is the integration of CS and operational planning. Currently, there are no standard processes for operational planners to communicate operational parameters to CS planners. This deficiency greatly hinders timely, accurate CS planning. Creating a framework, reinforced in doctrine, to delineate specifically what information operations planners provide, in what format, and to whom could

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address this shortfall. Solidifying this linkage between operations and logistics in crisis action planning would enable a step forward in the coordination, timeliness, and accuracy of CS planning.

Organizations and Processes. The Air Force has made progress in establishing standing CS organizations with clear C2 responsibilities and developing processes and procedures for centralized management of CS support resources and capabilities.

Training. The Air Force has made much progress in improving CSC2 training, including the formation of an education working group, to address the development and enhancement of formal education programs. The group will also address the implementation of significant new C2 instruction at the Air Force Advanced Maintenance and Munitions Officers School at Nellis Air Force Base, Nevada,[29] and the development of the Support Group Commanders Course and the new CS Executive Warrior Program, which will provide training for support group commanders, who are potential expeditionary support group commanders and A4s.

Information Systems. This area needs the most change. These changes should include the following:

- Relate operational plans to CS requirements
- Convert CS resource levels to operational capabilities
- Conduct capability assessments and aggregate on a theater or global scale
- Conduct tradeoff analyses of operational, support, and strategy options
- Focus integration efforts on global implementation of a few selected tools
- Standardize tools and systems for consistent integration

Most of the logistics information systems' modernization efforts are linked to improving information technology solutions, which support day-to-day business processes. Modernization of the peacetime systems will certainly yield some improved CSC2 information ability. However, the requirements for a more robust S&RCS capability need to be considered within the wartime CSC2 architecture. CS system modernization will need to assess both peacetime and deployment requirements and produce tools and capabilities that will satisfy business processes as well as CSC2 needs.

Enterprise-Wide Systems and Combat Support Command and Control. CSC2 analytical and presentation tools will need to augment typical data processing with increasingly modern sense and respond capabilities. Batch processing and analysis, a proven rate and methodology for most of the Air Force's 60 years of experience, will not effectively support agile combat operations and effects-based metrics. To respond to continuously changing desired effects, enemy actions, rates of consumption, and other controlling inputs, the 21st century logistics warfighter will need to accumulate, correlate, and display information rapidly and in graphic formats that will be equally understandable for operators and logisticians. Data will need to be refreshed much more rapidly than the former monthly and quarterly cycles. Daily decisions will require daily (if not hourly or possibly continuous) data refresh cycles.

A closed-loop planning and control system is essential to a robust military S&RCS architecture. Currently, information about Air Force resource and process metrics is organized by commodity or end item and located on disparate information systems. Creating a single system accessible to a wide audience would enhance leadership visibility over these resources. Such a system needs to have enough automation to translate lower-level process and data into aggregated metrics, which can be related in most cases to operational requirements.

Significant challenges remain before the Air Force can realize an S&RCS capability. To develop effective tools that accurately link logistics levels and rates to operational effects, the modern Expeditionary Combat Support System must be developed and tested in conjunction with operations and intelligence systems. Only through integrated testing can the CSC2 architecture be properly developed and implemented.

The greatest change required in modernized logistics systems is to reorient existing logistics systems toward combat-oriented ones. The peacetime-only materiel management systems need to be structured to participate in the enterprise-wide sharing of data and culling of information.

Stand-alone, single-function systems need to be replaced with systems that serve several functions for CS leaders at all echelons. Finally, modern CSC2 systems need to provide information useful in both peacetime and wartime decisionmaking.

Future Work and Challenges

The Air Force has made some progress toward implementing doctrine and policy changes, and plans are in place to continue to close the information technology and analytical tools gaps. An expanded Air Force *to-be* CSC2 execution planning and control architecture system would enable the Air Force to meet its AEF operational goals. New capabilities include the following:

- Enable the CS community to quickly estimate support requirements for force package options and assess the feasibility of operational and support plans
- Facilitate quick determination of beddown needs and capabilities
- Ensure rapid time-phased force and deployment data development
- Support development and configuration of theater distribution networks to meet Air Force employment timelines and resupply needs
- Facilitate the development of resupply plans and monitor performance
- Determine the effects of allocating scarce resources to various combatant commanders
- Indicate when CS performance begins to deviate from desired states and facilitate development and implementation of get-well plans

CS and operations activities must be continuously monitored for changes in performance and regulated to keep within planned objectives. Significant advances must be made in the way planning, directing, coordinating, and controlling functions are performed to move the Air Force toward a robust S&RCS capability. These essential elements of an effective C2 system must be altered to allow them to accomplish the important aspects of sensing and responding to changes in operating parameters when the violation of tolerance becomes evident. These sense and respond activities will need to take place in a nearly real-time environment.

The objective of rapid sensing and response is to alert decisionmakers to initial deviations in the plan, rather than reacting after-the-fact, to situations affecting mission capability. Emphases of metrics in the future need to be on *outcomes*, rather than on *outputs*. The RAND report details necessary adaptations that include (at the minimum) the following improvements in CSC2 architecture and activities.

- **Planning.** With the AEF's short timelines and pipelines, it is critical to be able to add CS information to initial planning, giving planners flexibility and confidence. CS execution planning functions include monitoring theater and global CS resource levels and process performance, estimating resource needs for a dynamic and changing campaign, and assessing plan feasibility. Because capabilities and requirements are constantly changing, these activities must be performed continuously so that accurate data are available for courses of action and ongoing ad hoc operational planning.
- **Directing.** CS-directing activities include configuring and tailoring the CS network, and establishing process performance parameters and resource thresholds.[30] Planning output drives infrastructure configuration direction—there must be an ongoing awareness of CS infrastructure and transportation capabilities to feed into operational planning and execution. Once combat operations commence, the logistics and installations support infrastructure must be regulated to ensure continued support for dynamic operations. The system must monitor actual CS performance against the plan. The performance parameters and resource buffers established during execution planning will provide advance warning of potential system failure.
- **Coordinating.** Coordination ensures a common operating picture for CS personnel. It includes beddown site status, weapon system availability, sortie production capabilities, and other similar functions. Coordination activities should be geared to providing information to higher headquarters to create an advance awareness of issues should one be needed at a later date. Great effort must be made to effectively filter the information flows up the command chain, to avoid overwhelming commanders with information of little utility, but to provide sufficient information to improve battlespace awareness.
- **Controlling.** During the execution of peacetime and contingency operations, CS control tracks CS activities, resource inventories, and process performance worldwide, assessing root causes when performance deteriorates, deviates from what is expected, or otherwise falls out of control. Control modifies the CS infrastructure to return CS performance to the desired state. CS control should evaluate the feasibility of proposed modifications before they are implemented and then direct the appropriate organizations to implement the changes.

Toward a Responsive System

The Air Force has already begun to take steps to implement some of these concepts and technologies with varying degrees of success. Air Force implementation actions include making doctrine changes to recognize the importance of CSC2, as part of S&RCS capabilities, and identifying training and information system improvements.

However, significant challenges remain before the Air Force can realize an S&RCS capability. To develop effective tools that accurately link logistics levels and rates to operational effects, the modern Expeditionary Combat Support System (ECSS) must be developed and tested in conjunction with operations and intelligence systems. Only through integrated testing can the CSC2 architecture be properly developed and implemented.

Technologies associated with S&RL are still in an early stage of development and may not be fielded for a number of years. Ultimately, ECSS should relate how CS performance and resource levels affect operations, but current theoretical understanding limits these relationships. The Air Force does not appear to be lagging behind industry in the implementation of S&RL capabilities but should continue to make judicious investments in this field.

The Air Force has recently established the Global Logistics Support Center (GLSC) as the single agent responsible for end-to-end supply chain management. The creation of this entity holds promise for the achievement of S&RCS capabilities. The GLSC should be in a position to advocate for future improvements while exploring ways to provide the capability utilizing current systems.

Finally, the observations of the Joint Logistics Transformation Forum are worth repeating: Unless significant improvements are made to *last-mile* transportation in theater, S&RL will have only a limited effect on operations. A robust, assured transportation network is the foundation on which expeditionary operations, as well as S&RL implementation, rests. The complete integration of transportation into the CSC2 architecture is essential.

End Notes

1. Thomas X. Hammes, "Insurgency: Modern Warfare Evolves in a Fourth Generation," *Strategic Forum, No 214* January, 2005.
2. Darius the Great, King of Persia (558-486 BC), and Alexander the Great (356-323 BC) both had to deal with insurgents in their respective empires.
3. Early in its development, the term Expeditionary Aerospace Force (EAF) was used to describe the concept of employing Air Force forces rapidly anywhere in the world, in predefined force packages, called Aerospace Expeditionary Forces. The terms have since evolved and the Air Force now uses the term Air and Space Expeditionary Force to describe both the concept and force packages.
4. Air Force Doctrine Document 2-4, *Combat Support*, March 23, 2005.
5. Robert S. Tripp, Lionel A. Galway, Paul S. Killingsworth, Eric Peltz, Timothy L. Ramey, and John G. Drew, *Supporting Expeditionary Aerospace Forces: An Integrated Strategic Agile Combat Support Planning Framework*, Santa Monica, CA: RAND Corporation, MR-1056-AF, 1999.

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6. Air Force Doctrine Document 1, *Air Force Basic Doctrine,* September, 1997.
7. James Leftwich, Robert S. Tripp, Amanda Geller, Patrick H. Mills, Tom LaTourrette, Charles Robert Roll, Cauley Von Hoffman, and David Johansen, *Supporting Expeditionary Aerospace Forces: An Operational Architecture for Combat Support Execution Planning and Control*, Santa Monica, CA: RAND Corporation, MR-1536-AF, 2002.
8. The military readers need to equate the word *customer*, in civilian literature, to *operational effects*.
9. Yosef Sheffi, *The Resilient Enterprise: Overcoming Vulnerability for Competitive Advantage*, Cambridge, MA: MIT Press, 2005.
10. See for example: Henry H. Willis and David Santana Ortiz, *Evaluating the Security of the Global Containerized Supply Chain,* Santa Monica, CA: RAND Corporation, TR-214-RC, 2004.
11. David S. Alberts, John J. Garstka, Richard E. Hayes, and David A. Signori, "Understanding Information Age Warfare," *Department of Defense Command and Control Research Program Publication Series*, Washington DC, 2001.
12. US Department of Defense, *Sense and Respond Logistics: Co-evolution of and Adaptive Enterprise Capability*, Concept Document (long version), Washington, DC, 2004, a.
13. *Ibid.* In conversations with Office of Force Transformation (OFT) staff, the timeframe for identifying and developing specific technologies for full implementation of all elements of operational S&RL is 2010 to 2015.
14. Grace Lin, Steve Buckley, Heng Cao, Nathan Caswell, Markus Ettl, Shubir Kapoor, Lisa Koenig, Kaan Katircioglu, Anil Nigam, Bala Ramachandran, and Ko-Yang Wang, "The Sense-and-Respond Enterprise: IBM Researchers Develop Integrated SAR System of Global Value Chain Optimization," *OR/MS Today*, April 2002.
15. Leftwich.
16. US Department of Defense.
17. This certainly is not an inclusive list because this is an active research area with numerous initiatives around the globe. Although we will examine a few of these in some detail, projecting the availability of these technologies is beyond the scope of our research.
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25. Information on DARPA's research is based on personal communications with Dr. Mark Greaves, the current Ultra-Log program manager; see also DARPA's Web site: www.darpa.gov.
26. Author's communication with Mr. Edward Boyle, Chief, AFRL/HEAL.
27. Lin et al., 2002.
28. See www.getransportation.com/general/locomotives/services/rm_d/lococomm.asp.
29. Tripp, et al.
30. Major General Kevin Sullivan, "Concept to Reality," in James C. Rainey et al., eds., *Combat Support: Shaping Air Force Logistics for the 21st Century*, Montgomery, AL: Air Force Logistics Management Agency, August 2003.
31. Heuristically determined thresholds can be established while more sophisticated expert rules or algorithms are being developed. For instance, Brigadier General Hennessey AMC/LG) uses zero-balance stock positions coupled with forces supporting an engaged combatant commander as a rule to determine when lateral actions should be taken to resupply a unit *at war*. Using this rule, he authorizes the AMC/Regional Supply Squadron (RSS) to reallocate stocks from units with stock to those with zero balances. The idea is to prevent mission degradation by focusing attention on the items that will cause the next mission degradation.

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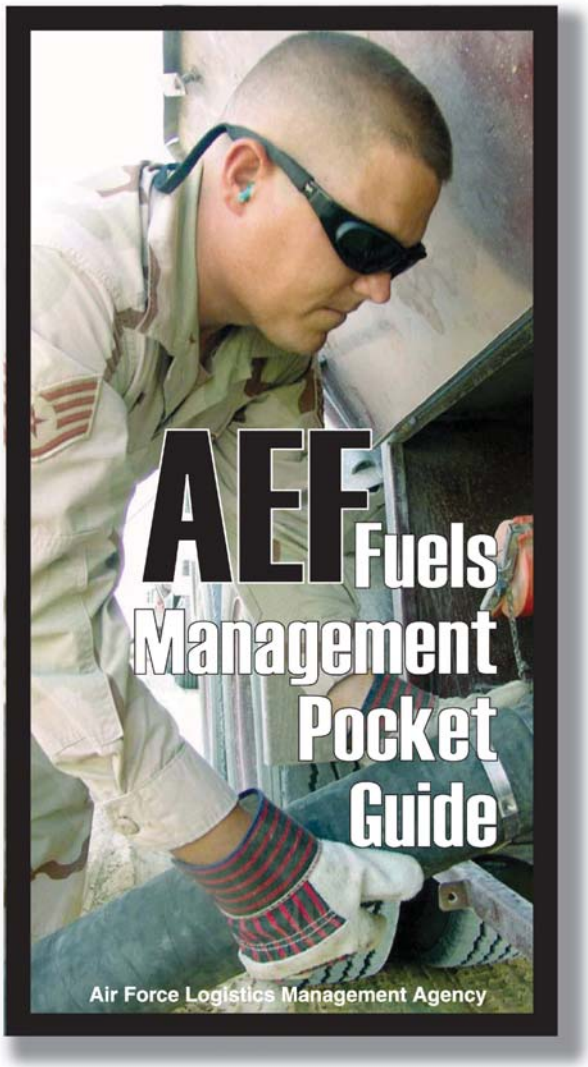

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