4.0 Coordination, Planning, and Execution in an Information-Rich World

Dr. Harold W. Sorenson *and* **Mr. Ronald D. Haggarty**

Overview: What Can We Have?

Information systems technology, developing primarily in the commercial marketplace, has already achieved astonishing capabilities and there appears to be no end in sight for its continued growth. Successful application of information technology enables people from widely distributed geographic areas to work as an effective team, while simultaneously speeding up operations and reducing the number of people required to complete many diverse but necessary functions. As a result, businesses around the world are changing the way they operate to become more efficient, responsive, profitable and competitive. Within this commercially dominated, information-dependent world, the Air Force must evolve highly integrated, geographically distributed, collaborative information systems that work across both commercial and military information transport infrastructures to coordinate, plan, and execute the missions that it will be called upon to accomplish during the decades ahead. For convenience, the coordination, planning, and execution system described in this monograph shall be referred to as CPES.

In the future, the traditional coordination process through which combat planning, operations and related intelligence activities are accomplished will be replaced by virtual meetings of participants who, though geographically widely distributed, share common information data bases and are supported by an automatic real-time set of planning and scheduling services. The services will deal with operations options as they relate to logistic and support aspects of the engagement. For example, as decisions are made by the distributed participants, a three-dimensional *"spreadsheet"*-like calculator will execute all the support planning, scheduling and tasking actions (e.g., sensor tasking, air refueling, special EC support, airlift coordination, or emergency support) and issue the appropriate request and task order messages. The "spread-sheet" will update all related elements of the data bases as changes occur. This will contribute to the ability to wage continuous operations. Thus, it will be possible for new combatants to come upon the scene as the current ones pull back to refurbish their weapons—all in a smooth and continuous manner.

The traditional, centrally located "batch processing" method of command and control will have been replaced by a distributed, collaborative and real-time interactive process that utilizes automated computer-aided decision processes. Its key features will be flexibility, adaptability, and quick response. In the long-term, the information infra-structure and its automated decision support services will dramatically reduce the number of support staff required by decision makers at every command level. Using a sports analogy, it will be like shifting from football to soccer—no huddle with everyone on our side having a common view of the action. There will be a superb means of real-time communication between the command staff (the coaching staff), the shooters and sensors (the players), and the supporters (the trainers and equipment managers)—no time outs needed! Additionally, the shared view of the battle space will be augmented by covert means of communicating intentions between the shooters, an advantage not available on the soccer field!

This view of a possible 2025 capability is depicted in Figure 16 and is the subject of the remainder of the monograph. In Section I, *A Guide To The System Of The Future*, an overview of the system is presented that is intended to be a conceptual guide for the discussion in Section II, *Information System Enablers;* Section III, *The Military Information Infrastructure;* and Section IV, *The Coordination, Planning, and Execution System.* The reader concerned primarily with the basic features and characteristics of the system is encouraged, after reading Section I, to skip to Section V, *General Conclusions*; Section VI, *Basic Recommendation;* and Section VII, *Epilogue.*

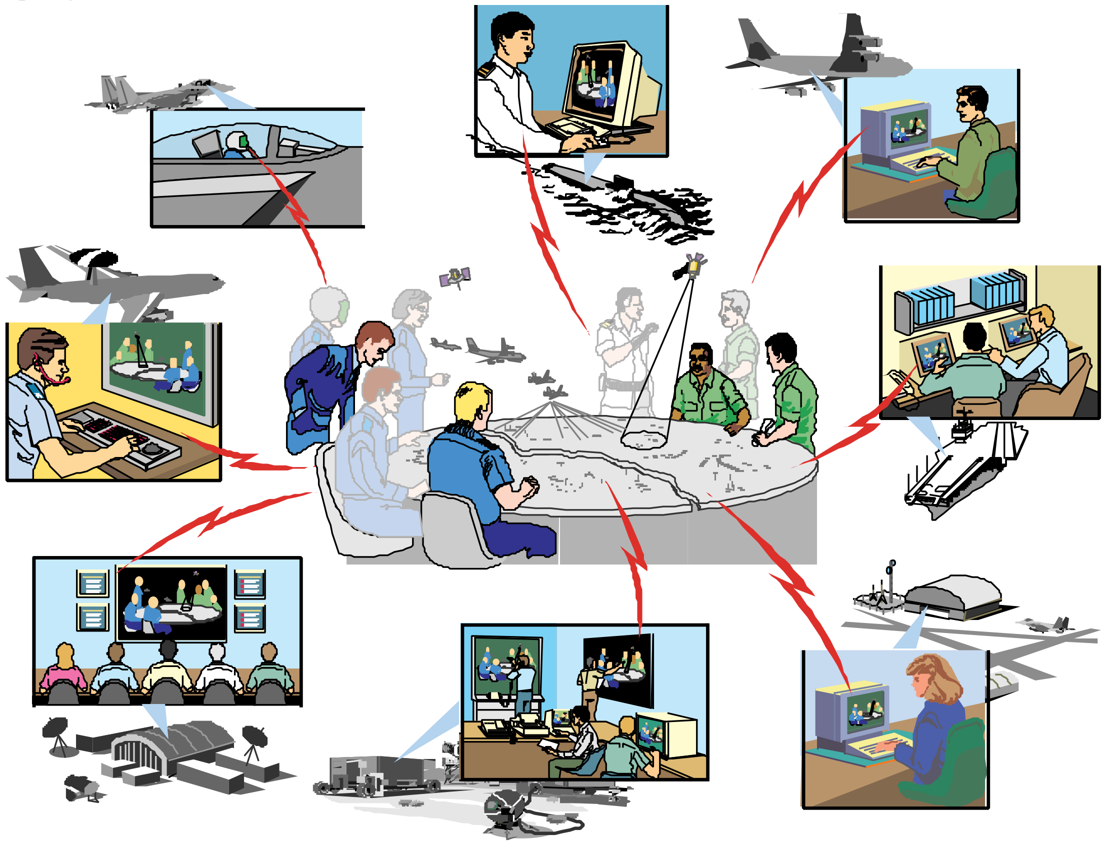

Figure 16. The C⁴I System of the Future

A Guide To The System of The Future

Given our understanding of technology and forecasts of future developments, the achievable capability may be limited primarily by our imaginations and our will to change to a radically new way for conducting command and control. The new structure should provide empowerment to lower levels and implicitly points toward a more horizontally-structured, heterarchical organization.

The operation of the CPES will be perceived by its users primarily through its interfaces and the collaborative interactions among geographically-dispersed participants that it enables.

These interactions will be facilitated through voice, including language translation/generation, and gesture understanding. It will allow dispersed individuals to work together in an "ordinary" manner, even while using languages in addition to English. The system will possess adaptive and intuitive human/computer interfaces that enable the user to access and utilize the distributed, heterogeneous data bases that underpin it.

In the world of 2025, processing, communication, sensing and positioning systems will provide widespread knowledge of everyone's location at precisely measured and synchronized times. Resources and objects will also be located and tracked with precision and this information will be available to all users of the system. Since any location can be characterized by its existing conditions (e.g., weather, man-made objects, terrain, ...), this information will be included in the data base. Thus, it is possible to envision people, vehicles, and resources being described in a geospatial reference grid that also indicates conditions at the location. Within this reference system, decision-makers and mission executors will have a temporal understanding of the situation that far exceeds any capabilities existing in 1995.

Planning will be accomplished in a continuous and interactive manner by drawing from information obtained from a variety of sources and sensors and contained in distributed, heterogeneous, object-oriented and relational databases. Participants can be geographically dispersed but brought together in "virtual meeting facilities". Planning tools that marry the methods of artificial intelligence and operations research will support the activity and facilitate the formulation of alternative courses of action. Then, simulation tools with high-definition video displays or 3-dimensional virtual reality presentations will be used to provide better temporal understanding of a situation and, thereby, aid the decision-makers in choosing the most appropriate course of action. Top-level direction will be transformed into specific mission plans at the appropriate organizational units and will be able to draw from the system all required information about the environment, particularly in the target area, and the vehicles, weapons, and support needs.

Mission executors will also have planning tools, including rehearsal capabilities. The simulation tools used to rehearse a specific mission will be available to all elements of the organization. When a plan is executed, information from the operational systems will be captured in the data bases of the CPES for rapid and reasoned assessments of mission effectiveness. The derived information will be available quickly to planners at all levels to enable them to press the appropriate actions in a near-continuous manner. The system capabilities should also incorporate on-line training. This will permit a higher quality of training with better feedback and less requirement for training personnel with associated reductions in cost.

In this environment, there will be a large fixed base of data and information. It is anticipated this information, suitably tailored to the situation, will be widely distributed and even carried by a user. Consequently, only the important changes that occur as the situation evolves will need to be communicated. By only communicating changes or immediate alert/warning messages, bandwidth requirements will be reduced substantially; there will be an automatic focus on changing events; and there will be an implicit autonomy for warriors when communications are disrupted.

The implementation of the CPES will be accomplished on a robust, highly-interconnected, flexible, and evolvable Military Information Infrastructure (MII). The MII will use existing and evolving commercial components, standards, and specifications to transport military-specific information between designated locations. Since the commercial marketplace is defining and implementing the standards and specifications for object-oriented, open systems information infrastructures, the DoD and the Air Force must be active and aware participants with the national and international organizations that are doing the work.

The development of the MII and the CPES will benefit from research in several areas. The concepts that shape the vision of the system are becoming available now. The maturity, robustness, and performance of many of the tools leaves something to be desired, but research on some current limitations should produce substantial improvements during the next few years. It is anticipated that there will be very powerful capabilities by the year 2025. The system needs to have an architecture that accommodates realistic growth in capability. The complexity and the related dimensionality of the system defines an overarching concern in all aspects of the development and imposes a particularly important constraint on the definition and design of the system architecture.

There is one major threat to the concept. An integrated system of the type that is envisioned must be secure by detecting attacks and responding as appropriate. Certainly, the system must be designed to degrade gracefully and must provide assured access to information that has maximal integrity with minimal chance of disruption, spoofing, or disinformation. The topic of information protection is a fundamentally important consideration for the envisioned system. The virtual environment provided by the MII feeds into the C^4I functions (i.e., CPES) which supports the organization and it ability to conduct operations. The fact that the loss of information security in MII or CPES will have a direct impact on the ability of a commander to conduct operations is depicted in Figure 17.

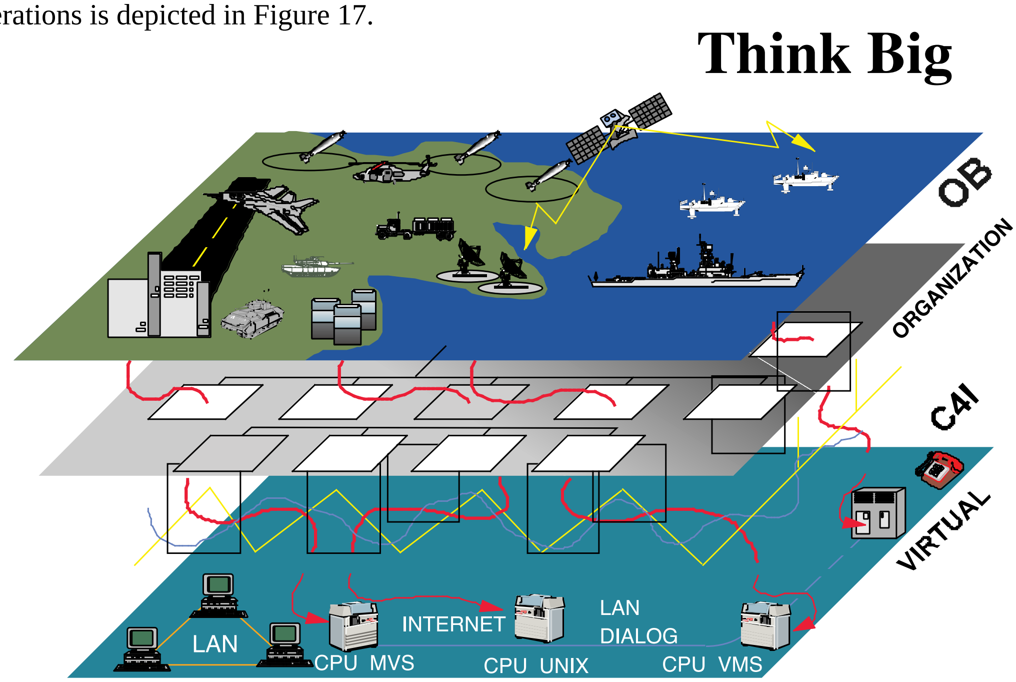

Figure 17, C4I Security Is Critical to Operations

Information System Enablers

Information systems technology will enable the realization of a coordination, planning, and execution system that allows continuous, simultaneous, horizontal and vertical interaction throughout the organization. One can envision the system as a "utility" into which any individual in the organization can "plug" an "appliance" to gain the information that will enable them to accomplish their mission/task. The utility will connect the highest command levels of the organization (i.e., commanders) to the individuals charged with accomplishing specific tasks (e.g., shooters, sensors, logisticians, maintainers). Underpinning the top to bottom command relationship between the commander-operator are the lateral and parallel commander-sensor/ logistician/maintainer relationships that provide supporting resources that enable the shooter to execute his mission/task effectively.

There are several systems and technologies that must be available to realize the coordination system that is postulated below.

Computers: The reduction in feature size is projected to continue at an exponential rate for an extended period Thus, one can envision the availability of computing capability in all endeavors with enormous throughput for computationally intensive activities. The only computational limit may be in human imagination and in the willingness to change the paradigms which have been utilized in the past.

Memory and Storage: Memory and storage devices of all types continue to grow in capability, matching the growth of computer speed and throughput. This technology encompasses the development of database concepts that support massive amounts of data and information. Concern changes from the technologies to the integrity and security of the information and to the methods for extracting appropriate information from the system.

Displays: Increasing computational power enables the consideration of displays that beggar our current capabilities. Flat panel displays with (n,000) x (n,000) pixels are possible. HDTV, "virtual reality", and dynamic holography promise to provide visual interfaces that enable "virtual meetings" and "virtual situation displays" that support human interaction and understanding in substantial and meaningful ways.

Communications: The communication capability envisioned for the future enables one to assume that any two points on the globe can be connected with high band-width links. The combination of fiber optic and wireless systems will permit robust connections that are already being manifested in commercially available products. While there may be choke points in the system (e.g., fighters), there should be sufficient band width to support most of the needs of the DoD. It is worth noting that the increased demand for video and imagery may continue to cause the communication system to be stressed. Thus, there will probably always be a requirement to conserve bandwidth by minimizing the information to be transmitted to that which is really needed. There may be problems in having militarily-reserved frequency bands, but these issues must be worked beginning now if command and control elements are to support national security objectives with commercially-developed information technologies and infrastructure.

Positioning: GPS and its successors will provide the capability of having a universally-accurate and available time standard that enables time alignment between geographically disparate activities. Everyone will know their location to within fractions of meters. Then, the communication systems of the period will inform any other person or activity of this position information. Thus, one can postulate that in 2025, the organization will know “where everyone is at all times and in all places.” Further, there will be a complete description of all conditions at a specific location to assist in achieving the greatest possible situational awareness. Any vulnerabilities of GPS and its successors to jamming will have to be considered in the overall system design.

With the computer, memory, display, communications, and positioning capabilities, the traditional compartmentation of “command, control, communications, computers, and intelligence” (C^4I) will undergo a major revolution. The C^4I function must become focused on providing the infrastructure, or information utility, that permits the “plug and play” environment within which the coordination, planning and execution functions can be accomplished. Implicit in this discussion is the dependence of the system on the utilization of a broad array of *sophisticated software products*. The classes of these products that are fundamental to the system concept are defined and described, briefly, below. For this discussion, the information utility that constitutes the infrastructure for the new C^4I system will be referred to as the Military Information Infrastructure (MII).

The Military Information Infrastructure

The military information infrastructure (MII) must have several key features that can be viewed from several complementary perspectives.

Different Views of the MII

Adaptability, Flexibility, and Timeliness: It is not realistic to consider building a rigid and highly detailed MII architecture that incorporates all possible alternatives if, for no other reason than the components, standards, and specifications that underpin the MII will be determined by commercial marketplace decisions. Therefore, the MII must be able to adapt to unforeseen circumstances, whether induced by the military or by the commercial world.

The commercial market place is driving the information systems of the present and future. The military is a relatively small market force that can try to influence commercial developments, but will follow more frequently than it will lead. However, the commercial world has very similar needs for information and similar coordination challenges; so the military needs to be knowledgeable and proactive with commercial developers about the tools with which it will be provided. By being involved and by making solid technical contributions, the DoD can still be influential in the process.

In this commercially-dominated environment there is an emerging need for a new or strengthened role for the technical community within the Air Force. *It becomes more important to learn to use existing and emerging capabilities in the domain of military applications than it is to develop the capabilities themselves.* However, shortfalls in the existing and emerging products must be identified. These assessments can serve to focus emphasis on important research topics, either for the military or for commercial industry. This point will be discussed further in later sections.

The ability of the military to respond quickly and effectively to a wide variety of crises that may arise concurrently is of paramount importance. The requirement for rapid response into areas having a high potential for armed conflicts with uncertain outcomes may distinguish the military from most, if not all, civilian situations. Thus, a fundamental consideration in the MII is the simultaneous performance of the system across a wide range of missions at numerous global locations having variable capabilities for the indigenous support of operations. This means that there must be, in addition to being flexible and adaptable, a strong emphasis on system-wide performance. Tools and agents that cannot meet the timelines of a situation will have to be improved or replaced. Thus, another thrust of the military's technical community will be to develop specific tools that support the time-critical missions/tasks faced by the DoD.

"Push" and "Pull" Architectures: The need for information takes a variety of forms. In many cases, there is a large community that needs to have a specific piece of information. This information needs to be broadcast, or "pushed", so that it is available to anyone, possibly undefined, who needs it.

But not all situations are accommodated most aptly by a broadcast. If everything is pushed, individuals may suffer information overload and their ability to perform is degraded rather than enhanced. In fact, there is a large amount of information that is location, situation, or function-specific that has limited utility for a broad community. Information filters that limit the data accepted by a site provides some control over the amount of information that is received. However, there are many instances in which the user will be served better if he can "pull" desired information from appropriate data bases in a timely and assured manner.

The MII must be structured to accommodate both push and pull requirements. The push of information can have many advantages. For example, it does not require a attacking aircraft to radiate and, thereby, disclose information about his location to the enemy. In either case, there are fundamental advantages and disadvantages and these considerations must be included in defining the architecture for the system. The general topic of information management constitutes a fundamental challenge for this or any other large-scale information system.

Integrity: The information must be accurate, timely, and available. If a user has no confidence in the information, the system will have failed its mission, and will not be used Accordingly, considerable attention must be given to the quality of information, including confidence estimates, whenever possible, in databases or in broadcasts.

Security: The information that is communicated must be assured in several dimensions. Broadcast information must be protected against jamming or interference that jeopardizes the link or the quality of information. Information extracted from databases must be unaffected by any transmission problems caused by enemy actions. Furthermore, the information that is received must be validated; no spoofing or deception from an enemy can be tolerated.

To emphasize, the MII and its operation must be "invulnerable" to the hostile acts of any enemy in the sense that it must be able to detect attacks, reconfigure, and operate in a degraded mode.. The integrity and security of the information in the MII has to be assured or the entire concept must be reexamined. It is asserted that the advantages of the MII merit the implementation of the vision. But *information warfare* considerations need to drive the development of the MII. A scheme for actively *managing* security must be developed in parallel with the development of the system.

Coordination, Planning and Execution Characteristics: The MII must support three characteristics that define the overall coordination, planning and execution function.

Resources: The databases that comprise the core of the coordination system are many and varied in nature. These databases contain information that relates to sensors, intelligence sources, geodesy and mapping, vehicles, weapons, and support of all types. Every function performed by the military has need for data and information. The MII will accommodate all of these needs. The massive database system of systems that results places unique demands on the methods for maintaining, accessing, interrogating, and retrieving the information contained throughout the MII.

Actions: The resources are used to achieve global situational awareness. Awareness is hollow unless it permits timely and effective actions. Thus, information must be available on demand to the commanders who direct actions and to the sensors and shooters who execute them. The MII must support the planning process and the direction must be communicated and executed by the shooters. The directions and the manner in which the execution is accomplished become part of the database as well.

The coordination, planning, and execution system is the centerpiece of the banquet table of information provided by the MII. In general, the CPES supports activities at all levels of the hierarchy. It represents the mechanism by which the users of the system interact with the MII to accomplish their goals and objectives. Because of its importance, the planning system is discussed in some detail in a later section.

Outcomes: The result of the actions taken by commanders and shooters must be measured and assessed, with the information being incorporated into the system. The “battle damage assessment” (BDA) is accomplished using resources controlled by the operation of the MII. The feedback from the BDA closes the loop on the commander’s decisions and shooter’s actions. As such, it is another key feature of the planning system that must be accommodated in a timely and flexible manner.

A Concept for Data Management in the MII

The concatenation of Resources, Actions, and Outcomes introduces the paradigm that is fundamental to the coordination, planning, and execution system. The importance of these three characteristics is captured by envisioning the linkages and couplings that are implicit. For example, a commander makes a decision to send a flight of F-16s against a ground target. Before they can be sent, the availability of specific aircraft, the appropriate weapons, the crew, the fuel, etc., must be established and the facts must be factored into the plan (hopefully, as automatically as possible). Before the launch, events may occur that force the plan to be changed. After the attack, results, including damage to the enemy as well as our own situation, must be introduced into the databases.

Many of the elements of the databases are tightly linked. The coordination, planning, and execution system needs to be aware of these linkages so that all relevant elements can be modified appropriately, automatically, and quickly. The model of this feature can be captured in the context of current computer tools by representing the desired actions as a *“three-dimensional spread* *sheet.*" The basic variables are provided through the resource database. The other two dimensions are defined in terms of the planning/action activities and of the BDA process and results.

The paradigm is intended to provide the impression that when a cell in the 3-D spread sheet is changed, changes appear automatically in every related cell. Thus, the updates from new information are incorporated with a single entry, no matter where it is located in this three-dimensional space, and the fidelity of the entire database system is retained.

To implement the 3-D spread sheet, there are many hurdles to be surmounted. The biggest challenge may be posed by the "dimensionality" and complexity of the problem. This speaks to the need to define an architecture that uses well-defined and reasonably focused objects that have minimal coupling to other objects. This is only one aspect of the architectural requirements for the system. Figure 18 depicts the different realms that must be considered when we refer to "architectures" and all must be considered as the MII and the CPES are designed.

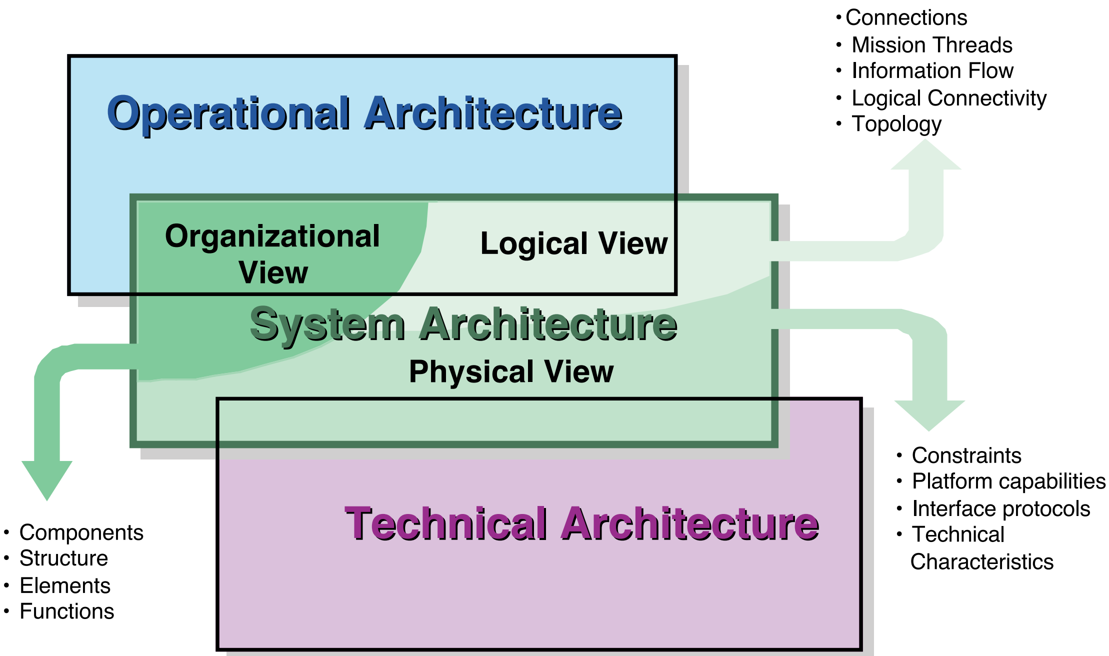

Figure 18. The Many Faces of Architectures

Coupling among data elements is an obvious type of linkage that must be controlled by the 3-D spread sheet. A very different type of coupling that must be accommodated comes from the change and updates that will occur in the commercial products that are used to build the system. As we experience regularly, new versions of software products are not always compatible with older versions. Software that is widely used in the system may exhibit incompatible linkages unless the system developer/maintainer controls the migration in a sensible manner. Management tools that monitor the product versions used throughout the system will be important accessories.

Architectural Concerns For The MII

The Coordination, Planning, and Execution System (CPES) can be envisioned as having desired characteristics that will drive the architectural design of the MII and the applications that ride on it.

Standards and Specifications: The MII should be flexible to accommodate new missions as well as enable the steady evolution of information systems technology, both hardware and software. The architectural paradigms currently being posited by the information systems community are based on the use of "object-oriented, open systems." There is an emphasis on standards that define an "open system." The commercial world is defining standards for most aspects of the information systems world. The DoD has decided to use commercial standards as the norm and to use military standards only in special, well-justified instances. The dynamic nature of the marketplace is reflected by the changing world of standards and specifications. They evolve with the technology and, therefore, add another dimension to the challenge that must be faced.

Object Request Brokers: Further, fourth- and fifth-generation software languages are utilizing the general concepts of "objects". Characteristics and standards for object-oriented implementations are being defined and implemented. A particularly interesting approach to deal with existing or "legacy" systems is the Common Object Request Broker Architecture (CORBA). Tools and specifications for CORBA are emerging from a large, industrial consortium. The approach, simply stated, provides the open system standards and specifications for which "wrappers" can be built around existing software objects. These "wrapped objects" can then be used, even modified, while living in a larger world of new and developing objects and systems. This approach needs to be exploited in evolving existing C^4I systems into the MII.

To provide further illumination about the approach, CORBA is providing common facilities that deal with:

- User interfaces
- Information management
- System management
- Task management

These facilities use object services that provide for concurrency, persistence, transactions, queries, security, time, data interchange, and several other characteristics. If allowed to mature and be used as industry standards, CORBA provides the vehicle for building an MII that allows for the evolution of current capabilities to the system that is envisioned here.

Commercial standards/specifications cover more aspects than software. Network protocols, communication standards, and security services represent only a few of the areas that underpin the development of the MII. Implicit in all subsequent discussion is the presumption that commercial standards will provide the underpinnings for the MII. The topic will not be discussed further.

A Geospatial Reference Grid

The MII will have to support the concept that the position of everyone and everything will be available within databases accessed by the CPES at all times. While this feature requires a robust GPS-like system, coupled with the required communication mechanisms and infrastructure, it also implies the need for a "geospatial reference grid." Every individual or object needs to be tagged with a location indicator that provides for immediate and automatic synchronization and alignment of the objects of interest. Recent studies by the Defense Mapping Agency and the Defense Science Board have many useful insights as to the means for developing and implementing the architecture and the processes for realizing the geospatial reference grid. This is fundamental to the definition of the MII. Figure 19 depicts the vision for a "geospatial foundation" that has been proposed by the Defense Science Board Mapping Task Force.

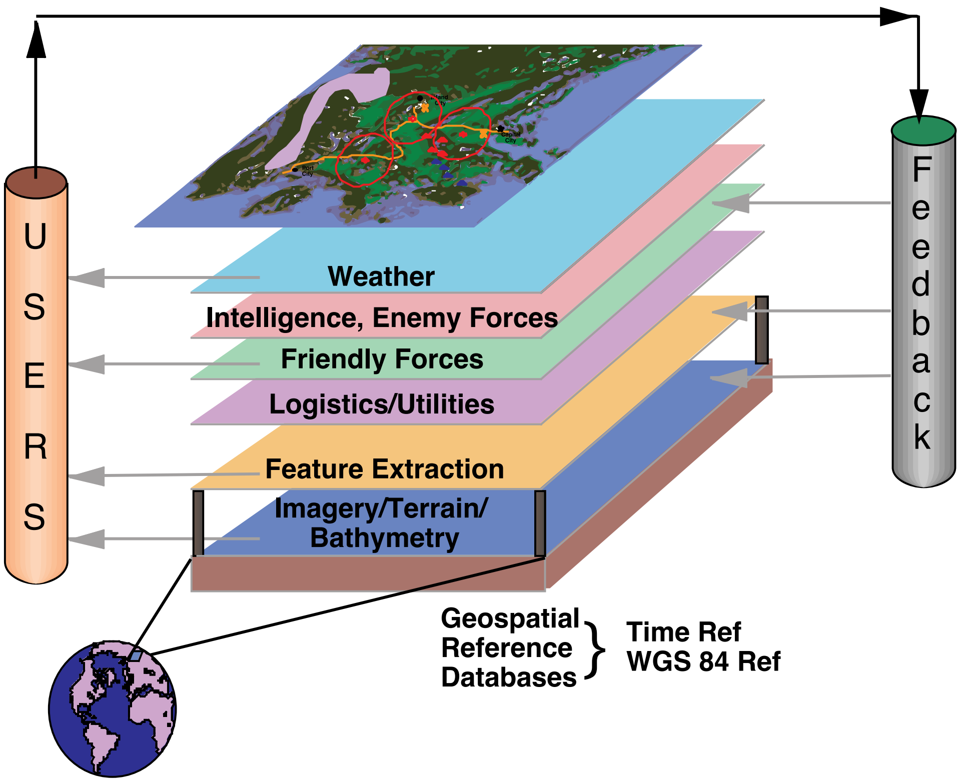

Figure 19. The Geospatial Reference Grid

Storage technology will evolve to the point where each war fighter will carry a high fidelity world model with all data in a geospatial information database management system. This system will be a segment of the world-wide database that is extracted and loaded prior to deployment to the specific geographical theater. The model master database will contain an up-to-date compendium of precise co-referenced information about earth: features, elevation, material type, density, gravity, temperature, velocity, infrastructures, structures, images, etc., plus the requisite client application tools and agents to support: measurement, monitoring, modeling, terrain evaluation, mapping, visualization, etc. The selection and down loading will also be limited to selected data types and tools appropriate for the user mission set and application interface. During the mission, the management system will update and register all new entries automatically and issue alerts to the user agents as indicated.

The Coordination, Planning, and Execution System

With the aim of increasing the cognitive capabilities and efficiency of the decision-maker, the collaborative planning system, operating from the distributed databases that are assumed to be available, will be based on several key elements.

- Knowledge-based planning and scheduling aids, at the campaign and theater levels, which exploit techniques such as hierarchical planning, case-based reasoning, and knowledge-based simulation of friendly and enemy forces
- Embedded, on-line intelligent trainers for learning advanced system features in non-crisis periods as well as providing on-line task assistance during crises
- Collaborative tools that enable not only information sharing but virtual collaboration among users
- Multisource correlation/fusion and enemy behavior learning, recognition and prediction using statistical, pattern recognition, and knowledge-based techniques
- Highly interactive, intuitive, and intelligent human/computer interfaces that support multidimensional situation analysis and course of action visualization

The system characteristics described above are depicted in Figure 20 which illustrates the closed-loop nature of the collaborative planning function.

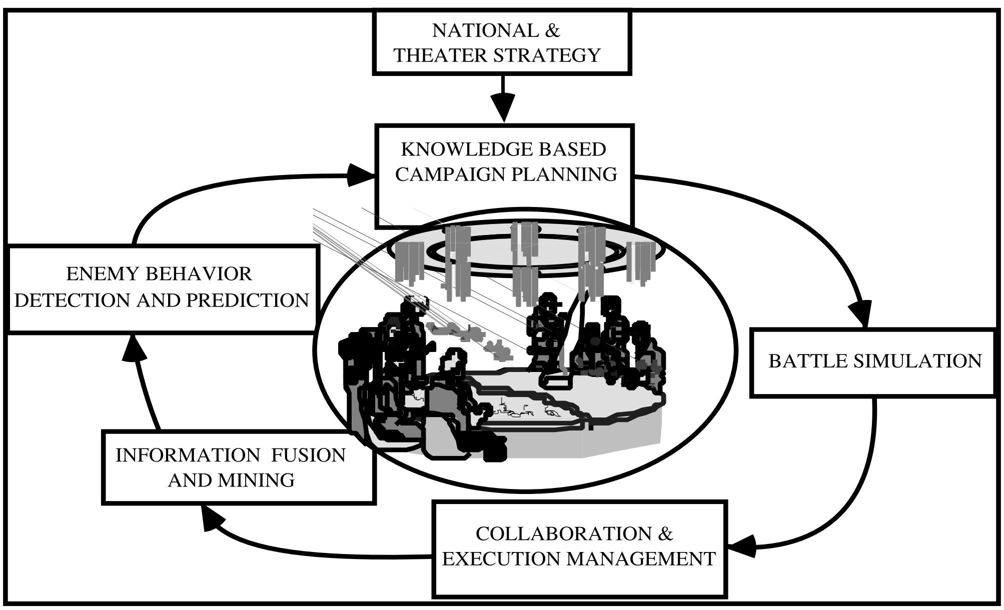

Figure 20. Intelligent, Distributed, Collaborative Planning

CPES flexibility and availability of information should be provided by the MII, the databases that it supports, and by the communications architecture and system. The CPES will have to provide the applications and tools for human/computer interactions that support the requirements for timely responses and effective decision-making. Each topic will be discussed in the following paragraphs.

Human/Computer Interactions (HCI)

The interaction devices between computers and their human users will change dramatically from the keyboard, mouse, track ball, and other tactile devices of current computer systems. They will be augmented, possibly even replaced in many instances, by other, more human-like, input-output mechanisms. There are several research threads whose maturity and capability can be recognized as having fundamental importance for realizing the system capabilities that are desired. These subject areas are highlighted during the following discussion with little supporting explanation.

Fundamental to the interactions will be *speech recognition and generation* devices *and natural language dialogue management*. Steady progress in these areas has been made and substantial further progress is anticipated. Because the future appears to call for even larger involvement with coalition efforts, *near-real-time language translation and generation* also will be an important feature of the system.

Other interaction capabilities will certainly appear and become available. Smart displays that *recognize and respond to gestures* are emerging. These “smart displays” will support the computer in adapting through its interface to the personal characteristics of the human operator, rather than requiring the operator to adapt to the interface. Virtual reality concepts offer the potential for the human/computer interaction to take place in an abstract domain where the computer and its human operator can associate objects through common virtual icons instead of application translations. Common icons expressed in a virtual domain will enable real-time, multinational and global participation in information collection and distribution without language translation. CPES must enable real-time international participation to support effectively coalition operations.

Today, the planning of a complex mission requires the involvement of many people who generally are brought together into a common facility and location. In the future, the MII will support *distributed, collaborative planning* in which participants, although geographically separated, can be “teleported” into a virtual conference facility (e.g., as depicted earlier in Figure 1). The *virtual displays* used for this purpose must be able to support multi-party interactions that contribute to the development of plans for action. These interactions will facilitate conversations and respond to gestures, voice, and tactile inputs. *Multi-media (i.e., voice, video, imagery, data) presentations* must be planned and distributed as part of the interaction.

An aspect that can and should be incorporated in the system is a *smart user-adaptive interface.* Supported by appropriate software agents and display technologies, the interactive system can learn from *user modeling* assessments and past behavioral tastes and patterns to facilitate the use of the system by the operator. As an intrinsic part of the interface, an *embedded on-line training* system should be built that helps the operator learn to use advanced features of the system during quiet times. This training component serves to assist the smart interface to adapt the system to the traits of the individual user.

Support to Decision-Making

User satisfaction with the CPES will be driven by the friendliness of the HCI and the utility and timeliness of the information that is accessed using the 3-D spread sheet. However, effectiveness of the system is determined ultimately by the automated decision support that is provided by planning and rehearsal tools. Many of these tools will be enabled by the use of a class of software products that have come to be called intelligent agents.

Intelligent Agents: A central need of the CPES is the location and retrieval of information that is appropriate for the task at hand. The emerging technology of *"intelligent agents"* provides some capabilities at the present time and there are active research efforts to extend and improve the existing capabilities. Because of the importance of these methods and tools in the constructions of the CPES, a modestly expanded discussion of the topic appears warranted.

An "intelligent agent" is a robust software program that communicates with other entities to gather information and make decisions. There are several classes of intelligent agents that have been defined.

Information filter agents: Agents that provide an interface between a user and broadcast information sources (e.g., e-mail, news services) based on learned user needs and interests.

Information acquisition agents: Agents that query and access various information sources for information relevant to user-specified or anticipated information needs (e.g., automated network surfing).

Network interface agents: Agents that deliberate on how best to fulfill user information requests (e.g., complete partially specified requests).

Programming Agents: Agents that interact with a user to develop programs (e.g., programming assistant).

Cooperative scheduling agents: Agents that communicate with other agents to schedule the allocation of resources in their individual purviews (e.g., meeting scheduler).

Multitask execution agents: Agents that execute a series of tasks at different sites (e.g., electronic shopping).

Cooperative problem solving agents: Agents that work together to solve a complex problem-solving task (e.g., collaborative design).

Information fusion agents: Agents that enable the exploitation of diverse but synergistic intelligence and sensor reporting systems in order to improve situational awareness.

Cybercop agents: Agents that look for degenerate or subversive forms of agent interactions and either neutralize them or report them.

Other taxonomies are possible. We have chosen to define the agents in terms of functions that are directed toward the tasks that can be envisioned for the CPES. Agents will provide the tools for dealing with massive data bases, with smart user interfaces, and with a variety of planning and network management activities.

Scheduling: The scheduling process certainly will involve thousands, even hundreds-of-thousands, of variables. The tools used to solve the scheduling problems must be robust and able to provide automated directions to all participating military units with near-simultaneous timing to ensure synchronized actions by all operations and support elements. *The marriage of artificial intelligence methods with the tools of operations research* is an important need for the system. There is a growing body of knowledge in this subject area and useful tools are emerging. Further progress is needed.

Coordinated Planning: Decision-makers will need to have access to situation-dependent information. It has been implied, but not stated explicitly, *that network and system management of large networks and peta-byte size databases* are required. It is in this area that the dimensionality of the system emerges as a primary concern. As noted above, a concern that significantly complicates the network and database management problem is *the security of the system.* The defense of such a system against hostile attack requires continuing and strong emphasis. Cybercop agents, for example, need to have an understanding of the proper functioning of the legitimate agents described above as well as actions that might suggest subversive activity. They can rein in errant good agents (network management) as well as police malicious agents and suspicious activity. An example of suspicious activity might be over dependence of a decision-making agent on a single source of input. This could suggest spoofing by an enemy agent.

Given that decision-makers have the information they need, the planning function will be distributed to appropriate elements of the organization. Distributed planning will be facilitated through the use of *work flow management and intelligent routing* tools.

Data and information about a specific object or activity can be obtained from several, very disparate sources. The information retrieval system should assist decision-makers in integrating information about each object/activity through a generalized *correlation/fusion* process. Information types vary from sensor measurements to intelligence sources to orders of battle to geographic and terrain data. These disparate types of information need to be merged in an intelligent manner that depicts to the user an answer with the attendant uncertainties and caveats. Using temporal and geospatial reasoning, information fusion agents will aggregate multiple sensor events related to the same object over time to produce object movement histories. They will then select the most battle critical entities, perhaps using case-based reasoning, and predict higher level enemy behaviors and intent. The use of the geospatial reference grid is expected to facilitate the correlation/fusion function.

The system must have the capability to “roam” and “zoom” to support the decision-makers understanding of the situation. It seems reasonable to assume that high-level decision makers (e.g., the JTF commander) will want to have information that allows him to define strategies and tactics that respond to the general situation. Wing commanders will need different and more specific views of the battlespace. To illustrate the general point which can apply to all types of information, consider the roaming and zooming capabilities offered by different types of sensors. Space-based platforms provide swaths of information at a particular resolution. The information is obtained during intervals that are discrete and may be separated by tens or hundreds of minutes.

A unmanned air vehicle (UAV) can survey an area continuously and with greater resolution in selected areas. The UAV can roam or fix upon specific areas. The two sensor systems provide overlapping and complementary capabilities that have utility that depends on the role of the decision maker. The preceding discussion raises the important topic of *collection management*. The manner in which sensors are tasked to achieve improved situational awareness for a specific situation becomes an important feedback loop within the CPES system.

The planning process often identifies more than one course of action. Decision-makers can be supported in making the ultimate choice of a plan through the use *of faster than real-time simulation tools* that permit the meaningful assessment and comparison of alternative courses of action. The output of the simulations using two-dimensional (e.g., *HDTV*) or three-dimensional (e.g., *virtual reality*) displays will provide a much sharpened intuition and understanding of the situation that is being faced. The development of appropriately fast and accurate simulation tools, including the intelligent display of the results, is an objective which is becoming more and more realizable.

General Conclusions

The implementation of the Military Information Infrastructure (MII) and the Coordination, Planning, and Execution System (CPES) can be supported by the information system applications and technologies that are emerging at the present time. There seem to be no major inventions required to realize the MII and CPES. The greatest limitation may be our imagination or perhaps a reluctance to leave the paradigms and cultures of the present for a very different future reality.

There should be no confusion about the difficulty of the task. A great deal of effort will be required to achieve the desired vision. The approach is based on an assessment of current capabilities and a projection of the possibilities for the future. Even if the exponential growth in processing power is not realized and the ideal system outlined here is unachievable, the capability that is fielded should be “good enough”, particularly when compared with the “stove-piped” systems of the present time

Success in this endeavor will produce a military organization that can operate effectively with the reduced force and command structure that is predicted. It will be able to respond to a broad range of missions, from regional conflicts to humanitarian support. The ability to respond rapidly, deploy quickly, conduct surgical operations, etc., will be enabled.

The MII/CPES can provide the means to achieve global situational awareness and to take actions in the timely manner required to be effective. Obviously, sensors that provide the “eyes” for the system are required as are the platforms and weapons that provide the arms, legs, and muscle for accomplishing the desired actions. However, the coordination, planning, and execution system that has been outlined here can provide the US with an insurmountable advantage in any situation. Since the technologies are available through the commercial market place, the investment by DoD must be concentrated on the application of the technology to military missions. More than anything else, this is a requirement to integrate information system components into a system of systems that will support the goals, objectives, and missions of the armed forces.

Basic Recommendation

The development of the MII and CPES will be challenging. The history of information systems technology provides some lessons that may guide us in planning for the MII and CPES. One highly successful distributed information system is the Internet. It is now being used for purposes that its original developers never envisioned. It has undergone revisions to its naming system over the years, is growing steadily, and is now hosting a series of new hypermedia applications (e.g., Mosaic, Netscape, and the World Wide Web), giving access to millions of new users. This suggests that a bottom-up, evolutionary approach to large systems may work well, as opposed to a top-down approach working from a formal specification of the objective system.

We do *not* believe that the development of the system can be achieved using an entirely "top-down" approach. As is said in many situations, "the devil is in the details." We must learn from past experience and capitalize on new trends in the information systems marketplace. Thus, we recommend the following approach.

The Development Approach: The Air Force must make a *long-term* commitment to the vision of the MII and the CPES. This necessitates a continuing commitment of resources for an extended period of time, analogous to the development and acquisition of major weapon systems like the F-22. The emphasis on "long-term" is deliberate. The commitment must reflect the following attitude, "If the system stinks; fix it." It cannot be allowed to reflect the attitude, "If the system stinks; kill it."

There are two aspects to the commitment:

(a) There needs to be a top-level architectural effort that clearly describes the overall "vision" or objective system. It must delineate the desired capabilities of the system, define the architectural approach (e.g., standards, tools), and institutionalize the process through which the developing system is confirmed to satisfy the architectural requirements. This cannot be done just once because important lessons will be learned along the way. New technologies and standards will probably emerge and could require changes to the architecture. Therefore, reference models, standards, guidelines and well-defined processes are needed to manage the overall evolutionary development.

(b) The MII and CPES should be procured in a series of small increments, each more elaborate than the previous one. Each increment should be developed in a relatively short time and should satisfy the current formulation of standards, guidelines, and procurement strategies for future increments. For any and all of these increments, risk mitigation strategies (such as competitive design phases) can be employed. Should an increment run into significant development trouble, it should be possible to "cut one's losses", cancel that increment and redirect the overall MII/CPES program. The developers of each increment should be incentivized toward contributing to the success of the total MII/CPES system, not only to the success of any individual increment. In this way the MII and the CPES can evolve toward the ultimate objective system.

The system architects, engineers, and technologists who develop and maintain the documents defining the objective system and its processes will serve as the knowledge keeper that guides the architectural evolution and assures the fidelity to the vision of developing system

Operator-Engineer Interactions: A distributed prototype of the MII/CPES must be built that involves users from across the Air Force directly with the engineers charged with constructing the system. This has several advantages. Obviously, the use of a development increment by end users may reveal flaws, or areas for improvements. Second, it is advantageous that end users have visibility into the kinds of information technologies they will employ routinely in the future. We believe that just as the MII and the CPES will evolve over time, so must military war fighting doctrines and military organizations evolve to take full advantage of the MII and CPES. Exposing Air Force users as early as possible will foster discussion of the issues that emerge. Finally, actual field use is the best way to judge progress. The prototype should be used in war gaming and exercises to the extent possible in a way that permits comparisons between the new version and earlier, fielded capabilities.

The prototype must be planned to evolve within the architectural guidelines to achieve the general vision for the system. By building the system from an "embryo" and guiding its maturation, the difficult problems that require concentrated efforts for their solution can be unearthed and investigated in the "real" world rather than in the "abstract." A consequence of the activity may be a structured, even an automated, process for identifying mission deficiencies and defining requirements.

The visionary system is too complex to anticipate where the stickiest problems will emerge. By expecting the unanticipated, failure is certain on the short-term (i.e., "the system stinks"). By committing to the long-term goal, the solution of important problems will occur within the context of the operational system (i.e., "fix it").

There is an attendant advantage to the proposed approach. The system must from the outset link as many organizational elements as possible. An important goal of the prototype development would appear to be that every unit of the Air Force should be connected to the system as soon as possible. Certainly, it should be used in conjunction with exercises to gain some realistic assessments of its performance and deficiencies. It is even easy to imagine that this system can be used for some contingencies at a relatively early time during its development.

By linking operational units, the ultimate users of the system become intimately involved from the start. Their emphasis must focus on getting their operational job done. The engineers who build the system must deal with the most satisfactory ways to implement the real needs of the users. A constructive dialogue must be established and maintained throughout the life of the development.

Air Force Link to the Commercial Marketplace: The Air Force must be more than a passive consumer of evolving COTS and other information systems technology. As stated earlier, the Air Force has many needs in common with other consumers of real-time, distributed information systems. The Air Force should attempt to influence the direction of future information systems technology, leveraging its influence by working closely with other consumers to keep vendors aware of Air Force needs and priorities. The experience gained by Air Force engineers from the development of the MII/CPES should make them a knowledgeable and influential member of the information systems community. There must be a strong effort to establish this link between the Air Force and this community.

Epilogue

The implementation of the Coordination, Planning, and Execution System (CPES) has significant implications for the Air Force of 2025. The access to large amounts of information at even the lowest level of the organization empowers units and individuals to achieve near real-time responses that some situations may require. A more horizontal organizational structure seems natural with a greater emphasis on the leadership role of the commanders. For example, the Air Tasking Order may provide the top level strategy that is executed by the rest of the organization but not include the immense amount of detail included at the present time.

To repeat the sports analogy used earlier, the change will be like shifting from football to soccer. There will be no pauses in the action to huddle and to define the next play. so that everyone has a common view of the anticipated action. Instead, actions are continuous within the strategies set before the start of play. In addition, there will be superb real-time communication at all times between the command staff (the coaching staff), the shooters and sensors (the players), and the supporters (the trainers and equipment managers). They will share a common view of the battle space including covert means of communicating intentions between the shooters, an advantage not available on the soccer field! Assuming the opponent does not have an equivalent awareness, dominance in the game should follow.

To close, the fact that most of the information system technologies and products are being provided by commercial industry implies the DoD does not have to bear large development costs, but primarily the costs of integration and application. This implies that the creation of the MII and CPES, while manpower-intensive, will involve the educated purchase, but not the development, of information systems. As already stated, a long-term commitment to the effort is mandatory but the costs should be considerably less than generally experienced in the acquisition of large systems. In the end the Air Force will have a system that is more than a force multiplier. It will be the enabler for the capability to respond quickly, effectively, and decisively to situations ranging from regional conflict to operations other than war.