Distributed, Collaborative, Knowledge Based Air Campaign Planning

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SUMMARY

This paper addresses existing functional needs and current technical opportunities for intelligent automation to support air campaign and theater level planning. In the context of a changing political, military, and acquisition environment, we describe several advanced automation activities that address key shortfalls in situation assessment, force planning, and legacy systems integration. First we describe a joint Air Force Electronic Systems Center (ESC)/MITRE Corporation effort to deal with the "legacy" problem of integrating intelligence and mission planning systems using a common object request broker architecture to enhance intelligence/operations interactions and support evolvable systems in the field. We then describe results from a joint Advanced Projects Research Agency (ARPA) and Rome Laboratory (RL) initiative aimed at developing the next generation of distributed, collaborative force deployment and force employment planning technology. We then describe another ESC/MITRE effort to develop tools for multisource intelligence integration to support knowledge based, multisensor data fusion and enemy behavior recognition for enhanced situation assessment. Given this context, we then illustrate an integrated vision of a distributed collaborative, knowledge based crisis action planning system, where both machine and human knowledge are utilized synergistically to enhance overall system performance. We summarize lessons learned from these efforts and discuss an evolutionary acquisition process to move the above ideas toward operational realization while minimizing technology transition risk. The article concludes with recommendations for moving forward.

1. INTRODUCTION

United States national security policy states a requirement "in concert with regional allies, to win two nearly simultaneous major regional conflicts" [1]. Supporting this objective requires a revolutionary approach to joint and coalition doctrine as well as significant advances in supporting Command Control Communications and Intelligence (C^4I) infrastructure. Of critical importance to sustain the initiative in warfare is our ability to stay inside the enemy's planning cycle time. While we are increasingly able to work in concert with our allies at a political level to control the proliferation of weapons of mass destruction and to promote stability and democracy, in battle we remain limited in our ability to share information and collaborate using an electronic information infrastructure.

This article highlights recent technology developments and novel acquisition strategies that attempt to address this need. It emphasizes future distributed mission planning and execution infrastructure which can be used to collaboratively plan air campaigns. While the primary focus here is on joint US systems and in particular force deployment and employment, lessons learned may be transferable to coalition activities.

2. PROBLEM

Supporting the US national security strategy of enlarging the global village of free market economies, American troops operated in nearly every country in the world in 1994. For example, in the Air Force:

> We delivered 75,000 tons of relief supplies to Bosnia, 15,000 tons to Rwanda and Zaire; supported major deployments to Haiti and Kuwait; and conducted hundreds of operations in such far-ranging places as Yemen and Johnston Atoll ... We've flown nearly 10,000 sorties in Bosnia. In the Gulf we've launched three times the missions of Desert Storm. Within 10 days of Iraq's provocation this Fall, 160 combat aircraft joined the 140 already deploy there, and we had flown 1,000 sorties ... We've exercised with 50 nations since last December. [2].

These activities underscore the multifaceted nature of modern military operations, spanning tradition roles to defend against, deter, damage/disable, or destroy enemy threat as well as to engage in combat operations other than war, including relief missions and non-combatant evacuation operations.

Desert Storm illustrated the effective application of coalition air power, stealth technology, precision-guided munitions, and C^4I to achieve decisive victory. Despite this success, lessons learned suggest a clear need for a more integrated view of the battlefield to better perform situation assessment, more timely and accurate force deployment and employment, and a more efficient information systems infrastructure to enable rapid plug-and-play of capabilities.

Finally, guidance from Secretary of Defense William Perry emphasizes the use of standards to promote interoperability, Commercial Off the Shelf (COTS) solutions to reduce costs, and joint infrastructure and architecture. Important capabilities are now fielded such as the commercially-based Joint Worldwide Intelligence Communications System (JWICS) which provides interservice video, voice, and data connectivity, and the

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Joint Deployable Intelligence Support System (JDISS), a DODIIS core project which provides the JTF commander with a common UNIX-workstation suite (e.g., e-mail, file transfer, remote access, imagery). While the move toward COTS provides important functional and economic advantages, it is not without risk. In addition to marketplace volatility, experience suggests that effective COTS integration requires detailed knowledge of and access to internal and potentially proprietary source code. Furthermore, there remain functional gaps between desired concepts of operations and government and/or COTS systems as well as serious interoperability problems with existing and projected operational support systems. Crucial to a successful information infrastructure is a well articulated target architecture as we move toward a Global Command and Control System (GCCS).

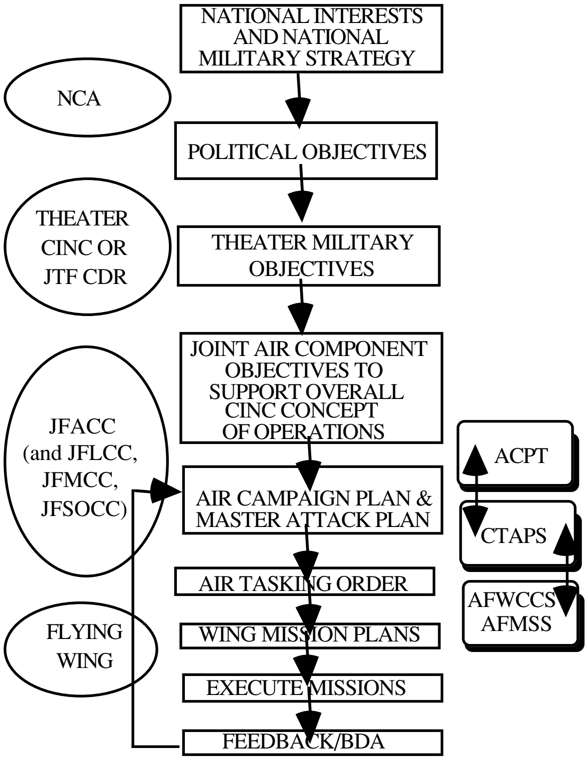


Figure 1. Battle Planning Process

In the remainder of this article we first outline the promise of distributed object computing technology and how this is being exploited to improve future theater level mission planning systems. We then point to innovative joint developments for new distributed, collaborative, knowledge based planning aids at the air campaign level. As Figure 1 illustrates, we focus on current theater level automation systems first, in particular the Air Force's Contingency Theater Automated Planning System (CTAPS). We subsequently turn our attention to future air campaign level automation such as the Air Campaign Planning Tool (ACPT) which produces an overall air campaign plan and a daily Master Attack Plans (MAPs), a potential future input to CTAPs. We do not directly address mission level automation systems such as the Air Force World Wide Command and Control System (AFWWCCS), through which Air Force Wings receive Air Tasking Orders (ATOs) from CTAPS, nor the Air Force Mission Support System (AFMSS), which is used by air crews for tactical mission planning.

3. CTAPS

For many reasons, including changing threats, doctrine, concept of operations, and resources, many large systems are procured to function independently only to discover a future need to interoperate. Figure 1 illustrates CTAPS, a complex, system of systems indicative of the current complexity of theater level infrastructure. For Air Force theater-level battle management, CTAPs is at the heart of the cycle of situation monitoring, diagnosis, plan generation, plan selection, and plan execution, as articulated by NATO AGARD Working Group 11 [3]. CTAPS contains approximately two and one half millions lines of source code encompassing multiple mission functions (from situation assessment to weaponeering to battle planning), software applications (e.g., heterogeneous databases, human computer interfaces), and programming languages (e.g., C, C++, Ada, SQL, Pro C).

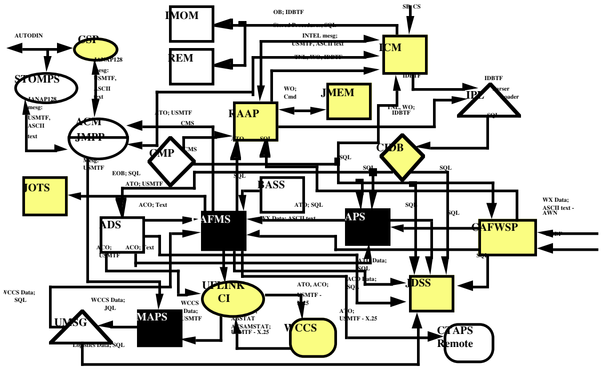


Figure 2. CTAPS Architecture

ESC and The MITRE Corporation in a Mission Oriented Investigation and Experimentation (MOIE) project [4, 5] are examining the integration of legacy CTAPS systems via coarse encapsulation of application objects using the Common Object Request Broker Architecture (CORBA), described below. The motivation is not only to consolidate existing systems in order to reduce cost, increase information consistency, and improve responsiveness. It is also to establish a computational framework which will enable rapid migration to new requirements and systems, including some of the advanced distributed campaign planning tools outlined in the next section.

As highlighted in Figure 2 , MITRE has experimented with the ease and utility of the CORBA integration of three CTAPS subsystems: the Computer Assisted Force Management System (CAFMS), Advanced Planning System (APS), and Joint Message Analysis and Preparation System (JMAPS), together which constitute a half million lines of source code. Currently these applications are coarsely encapsulated using IONA Technologies' Orbix environment as individual application objects, that is there exists a CAFMS object, an APS object, a JMAPS object. Future work will address integrating individual functions and data within these systems, for example, supporting interaction with a mission plan object or an enemy threat object.

3.1 CORBA and CTAPS

The Object Management Group (OMG), formed in 1989, is a consortia of over 500 member companies including the major software system vendors (e.g., Apple, IBM, Digital, Hewlett-Packard, Microsoft, and SunSoft, on whose operating system CTAPS runs) and large end-user organizations which aim to support interoperable software components in heterogeneous environments via the development of standard interfaces and supporting infrastructure. Their resultant reference architecture is based on objects which have associated operations. It further distinguishes object services such as the general management of objects (e.g., their creation, deletion, naming, copying, querying, modification), from common facilities (e.g., object browsers, user interface components, mail, print spoolers, spelling checkers, help facilities) which may be reused in multiple applications, from application objects, which would be custom to a particular domain.

An Object Request Broker (ORB) acts as a communications infrastructure to route messages between objects in a manner independent of the language, platform, and networking protocol local to any object. An Interface Definition Language (IDL) is used by object developers to define the language-independent interface to an object type and an Interface Repository acts as a database of object interface definitions as well as data types, constants, and exceptions. A Dynamic Invocation Interface enables a client, at run-time, to invoke an arbitrary operation on an arbitrary type of object. Inter-ORB protocols were adopted in December 1994, most importantly, the Internet Inter-ORB Protocol for interoperation among ORBs via TCP/IP. Forthcoming extensions will include mappings from IDL to additional languages beyond C, C++, and Smalltalk (e.g., Ada9X, COBOL, LISP, Objective-C).

Figure 3 outlines the Object Request Broker architecture as applied to CTAPS. Object Services are similar to those found in the general CORBA model, however, facilities include both general items (e.g., system administration, e-mail, talk) as well as ones particular to military operations (e.g., message processing, alerting, mapping). In contrast, application objects are unique to theater level mission planning (e.g., theater intelligence, air tasking order planning, weaponeering).

MITRE wrote IDL interfaces and implemented CORBA front-ends for JMAPS, CAFMS, and APS. For example, via ORB invocations, the APS application can be invoked and exited, with or without a map, and the APS data export application can be invoked. Once an Air Tasking Order (ATO) is prepared in CAFMS, the JMAPS ATO Check function can be invoked via the ORB, which passes the ATO message as input to JMAPS and receives an error report as output, also via the ORB. These CORBA front-ends represent encapsulations of applications with command-line (APS and CAFMS) and remote procedure call programming interfaces.

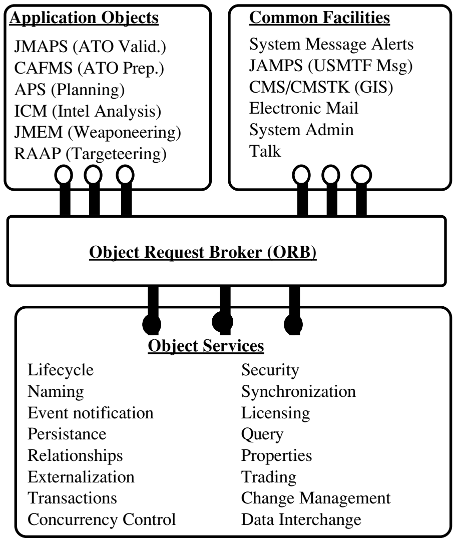


Figure 3. CTAPS ORB Architecture

The ORB also can act as an intermediary not only to applications but also to data. For example, MITRE wrote IDL interfaces and developed a CORBA front-end for relational database management systems. This was specialized to access Oracle. MITRE then developed a front-end based on Mosaic software from the National Center for Supercomputing Applications. This front end supports direct access through an ORB interface to APS and CAFMS databases.

3.2 Lessons Learned

Wrapping existing legacy systems by defining and implementing CORBA interfaces provides a powerful method for systems migration. Coarse encapsulation of legacy systems using CORBA does not require access to the source legacy code, provided sufficient knowledge of high level interfaces. Indeed, it is application architecture knowledge (components, their functions, characteristics, operating assumptions, and interactions) that required the most amount of resources in the above experiment. In fact, the source code to develop the Orbix IDL definitions, servers, human computer interface and utility functions for APS, CAFMS, and JMAPS totaled only 2,617 lines of code (contrast this with the half million lines of code represented by those applications). With object-oriented access to legacy system data and functionality, we have the possibility of moving up the planning systems support hierarchy shown in Figure 1 toward distributed, collaborative planning tools as shown in Figure 1. We turn to these next.

4. AIR CAMPAIGN PLANNING

Figure 4 provides a more detailed view of the levels, inputs, decisions, and activities from campaign planning to execution [3]. Just as the wing and flight level operations require detailed intelligence about terrain, weapons, threats and weather to plan an effective mission, theater and campaign level planners require tools to support situation assessment, course of action development, evaluation, and selection. In this section we will describe several systems that support deployment and employment planning.

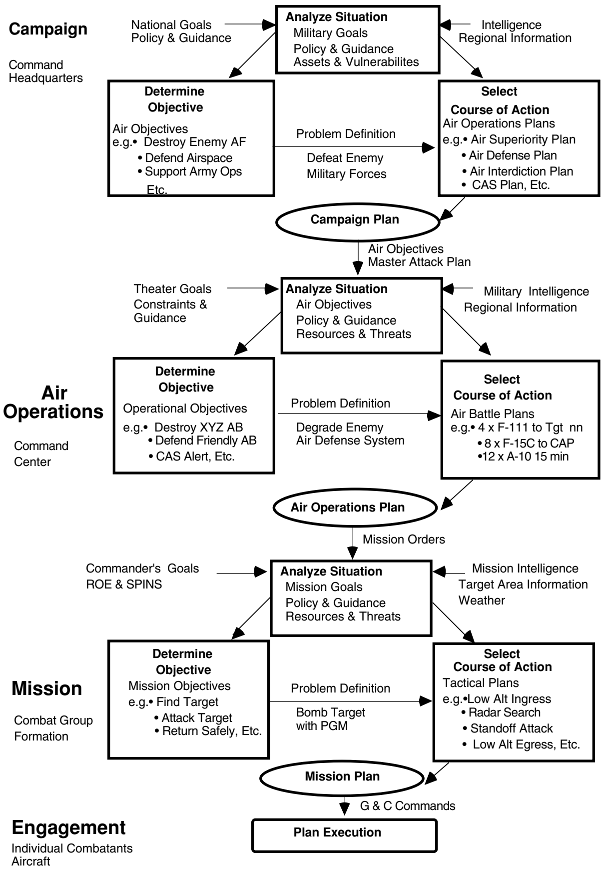


Figure 4. Air Campaign Planning Process [3]

4.1 ARPA/RL Planning Initiative

The joint Advanced Research Program Agency (ARPA) and Rome Laboratory (RL) Knowledge based Planning and Scheduling Initiative (ARPI) is aimed at developing the next generation of distributed, collaborative planning tools [6]. ARPI takes a multi-tiered approach to development via problem focused basic research which flows into Integrated Feasibility Demonstrations (IFD) which then flow into Advanced Capability Technology Demonstrations (ACTDs) which in some instances are fieldable capabilities. Formal “exit” criteria and “final exams” serve as functional evaluations at each step in the process.

IFD-1 consisted of the Dynamic Analysis and Replanning Tool (DART), which was used by transportation planners to manipulate Time Phased Force and Deployment Data (TPFDD). This included the TPFDD Editor (TPEDIT), a temporal constraint-based tool used to construct and edit the elements and temporal aspects of the TPFDD. TPFDDs consist of many unit line number (ULN) records. Figure 5 shows a sample ULN for a US Army air defense artillery battery of Patriot missiles originating from HCRL on C000 (estimated), embarking at NKAK on C010 (estimated), with a destination of JEAH between CO11 and C015 (estimated). Built by a team that integrated end users and technologists, operational folks found DART construction, analysis, and interface showing transportation phasing and feasibility extremely useful. It was claimed a major success in its use for transportation planning during Desert Storm [6].

```
((ULN "U-0AADA  ")
(PROVORG "7") (SERVICE "A")
(UTC "1HM77") (ULC "BTY")
(DESC "ADA BTRY,PATRIOT (MISSLES)")
(FIC "8") (PIC " ") (BULK "0000000")
(OVER "0000450") (OUT "0000000")
(NONAIR "0000000") (ORIGIN "HCRL")
(RLD "C002") (POE "NKAK")
(ALD "C010") (EDD "C000")
(POD "JEAH") (EAD "C011")
(LAD "C015") (PRIORITY "002")
(DEST "JEAH") (RDD "C015")
(SEQNBR "00000") (CEI " "))
```

Figure 5. Sample ULN record from TPFDD database

IFD-2 developed a complex knowledge based planning tool, the SIPE-II Operational Crisis Action Planner (SOCAP). SOCAP consisted of a set of planning operators that specified a taxonomy of military actions (e.g., deploy a unit, perform a mission, allocate a route) each of which achieve particular goals. Each action had associated resource, temporal, and activity constraints. Given a high-level operational objectives, SOCAP could generate an hierarchical plan of air campaign actions.

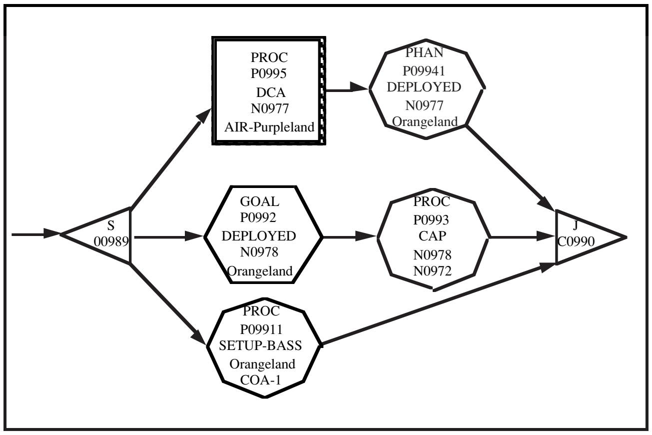


Figure 6. Segment of SOCAP Plan

Figure 6 shows a portion of a partially planned SOCAP course of action to defend territorial integrity. In Figure 6, triangles indicate the start or completion of parallel actions, squares and hexagons indicate processes and goals which require further refinement, and octagons indicate processes (with associated actions, resources, and results). Thus, the partial plan in Figure 6 consists of three parallel steps (from bottom to top):

1. Setting up a base at Orangeland.
2. Deploying tactical fighter forces N0978 (a yet unspecified unit) at Orangeland, followed by a Combat Air Patrol (CAP) performed by N0978 and N0972

3. Deploying tactical fighter forces N0977 for Defensive Counter Air (DCA) in Purpleland, followed by a CAP performed by N0977.

This plan portion could be further refined and/or replanned to achieve higher level goals.

Detailed courses of action are generated by SOCAP by reasoning about goals and detailed action specifications. For example, the tactical airlift operator used to plan moving *force1* from *airfield1* to *airfield2* is:

```
OPERATOR:          move-by-tairlift
 ARGUMENTS:        army1-with-size<10000,
                   airfield1-with-runway>500,
                   airfield2-with-runway>500,
                   tairlift1, tfighter1, air-loc1;
 PRECONDITION:     (route-aloc airfield1 airfield2 air-loc1);
 PURPOSE:          (moved army1 airfield1 airfield2);
 PLOT:
   GOAL:           (located tairlift1 airfield1);
   PROCESS
   ACTION:         move-tairlift;
   ARGUMENTS:      army1, airfield1, airfield2, tairlift1;
   RESOURCES:      tairlift1;
   EFFECTS:        (moved army1 airfield1 airfield2);
 END PLOT
END OPERATOR
```

This detailed plan specifies the context of a successful tactical airlift. For example, the preconditions for successful application of this plan dictate that force1 must be smaller than 10000 tons, *airfield1* and *airfield2* must have runways longer than 500 feet, and there must be an air corridor between *airfield1* and *airfield2*. The purpose of the act is to move *army1* from *airfield1* to *airfield2*. SOCAP demonstrated the feasibility of deliberative planning, although operational users had difficulty understanding PERT-like views of hierarchical plans (as in Figure 6) as opposed to GANTT-chart like views. A more complete library of plan operators needs to be constructed to deal with a variety of operational courses of action.

4.2 TARGET and ForMAT

Theater Analysis, Replanning and Graphical Execution Toolbox (TARGET) was developed and demonstrated during IFD-3. TARGET as well as other ARPI technology was demonstrated daily at the Joint Warrior Interoperability Demonstration (JWID '94), a Joint Staff sponsored annual forum focused on C^4I concepts, technologies, and systems [7]. The demonstration backbone was the Theater Analysis, Replanning and Graphical Execution Toolbox (TARGET) which provides such capabilities as shared plans, video, voice, maps, briefings and pointers. JWID '94 was used to demonstrate collaborative disaster relief planning in Hawaii at US CINCPAC and combat operations at USACOM and the Air Combat Command. TARGET includes a shared set of planning tools which enable users to jointly assess transportation feasibility, cost, casualties, and time associated with alternate courses of action (COA). In the relief scenario, a Combined JTF was simulated from NRaD in San Diego who interacted with surrogate members from Army Materiel Command and Defense Logistics Agency. Logistics, weather, and disaster anchor desks were provided on Oahu. Functionally, the planning tools enable crisis action members to rapidly produce Time Phased Force and Deployment Data (TPFDD), validate feasibility, visualize results on the Geographical Logistics Awareness Display (GLAD), obtain critical situation information from anchor desks, select a final course of action, and transmit this to the theater commander.

A crucial aspect to this process is selecting and supporting feasible courses of action (COAs). The Force Module Analysis and Management Tool (ForMAT) [8] was developed originally for deployment planners at CINCs to build the deployment plans for selected COAs. It is currently being explored for use as an adaptive Force Package editing tool and for supporting Service Components in force generation and selection. ForMAT is currently populated with 322 cases derived from 17 TPFDDs where each case contains elements from 47 possible attribute value pairs.

Using case based reasoning techniques developed for SMARTplan [9], the system is able to index, retrieve, support modification and visualize a database of TPFDDs based on high level specifications of force requirements (e.g., service=Army AND capability=anti-tank). Figure 7 illustrates a joint force created using ForMAT.

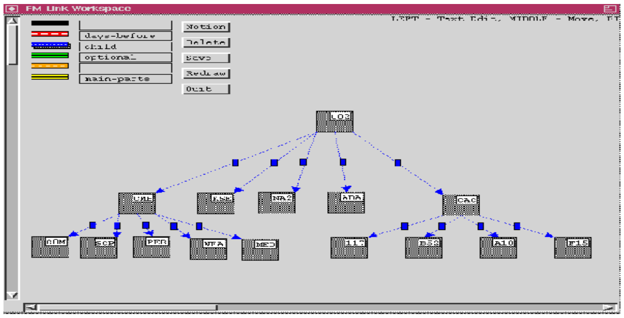


Figure 7. ForMAT Joint Force Structures

ForMAT represents a dramatic improvement both in the quality and speed of developing Operational Plans (OPLANs), which specify where and when forces involved in a mission are to be moved. This previously was a cumbersome process. Significantly, a "small" plan can involve specifying 10,000 distinct force requirements, a large one as many as 200,000, all of which much be scheduled. By matching desired requirements to similar previously stored solutions in the case base, prohibitive computations can be avoided. A user can query for an exact match to a force need (e.g., function=military-police AND service=air-force) and obtain a rank-ordered list or if there are few or no results, then the user can issue a "general" search which walks up a generalization hierarchy associated with search terms to broaden the search (e.g., function=security AND service=air-force). Instead of querying the existing case base, the user can choose from "template force modules" to describe a generic force package (e.g., a small, medium, or large sized Marine Expeditionary Unit).

At JWID-94, ForMAT successfully received force requirements from TARGET and generated lists of satisfying forces. For example, after a mission planning session, TARGET would pass force requirements to ForMAT such as:

MISSION = DESERT-BLAST
THEATER = PACOM
GEOGRAPHICAL-LOCATION = KOREA
FUNCTION = MISSION-AIRCRAFT
SERVICE = AIR-FORCE
DEST-CC = WORLD
UIC = "WALOAA"

ForMAT would then retrieve a set of Force Modules prioritized by the degree to which they satisfied these individual and cumulative requirements. The Force Module functionality of ForMAT will be combined with the creation and editing functionality of TPEDIT and folded into the Global Command and Control System (GCCS). In addition to ensuring transportation feasibility, designing the campaign in the first place is a critical success factor to which we now turn.

4.3 Air Campaign Planning Tool

Current ARPI focus is on tools to support air campaign planning, in part a result of the success of the Air Campaign Planning Tool (ACPT) [10, 11], software developed for the USAF/XO and the "Checkmate" division therein by ARPA and the ISX Corporation. ACPT captures the process utilized during Desert Storm to help the Joint Force Air Component Commander (JFACC) and his staff rapidly build a high quality air campaign plan.

> Led by Lt. General Buster Glosson, a staff of USAF planners developed a strategic plan favoring the application of precision munitions against carefully selected "centers of gravity" to maximize the effect of limited force application, avoiding "mass-on-mass" application of force. [11]

Figure 8 illustrates a high level view of ACPT which indicates inputs, outputs, tools, and existing and envisioned interactions with external systems. ACPT helps the JFACC and his staff to:

- Perform situation assessment
- Specify campaign objectives
- Develop Courses of Action (COAs)
- Identify target Centers of Gravity (COG)
- Allocate resources
- Assess plan feasibility and effectiveness

For example, Figure 9 shows a screen dump in which an air campaign planner is specifying, refining, and satisfying an overall COA by selecting an action (in this case "attack"), an associated effect ("disrupt"), and COG.

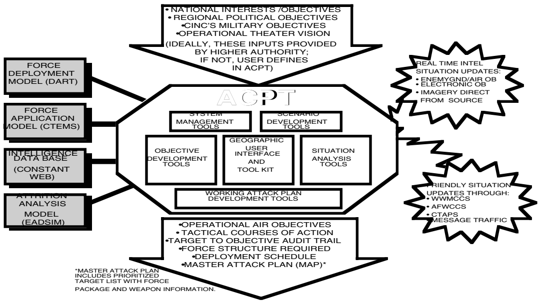
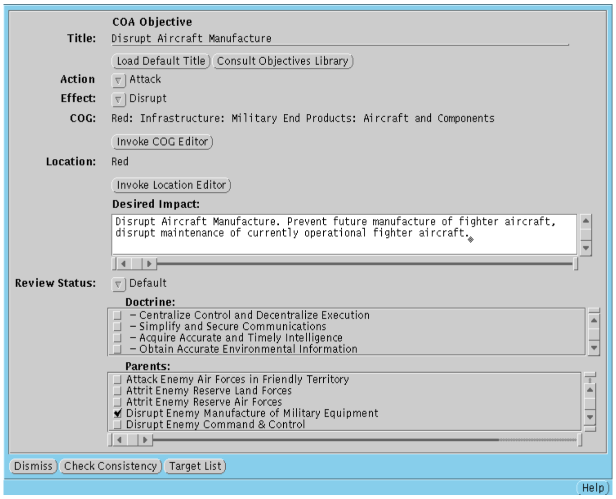


Figure 8. Air Campaign Planning Tool (ACPT) [11]



COA Objective
Title: Disrupt Aircraft Manufacture
Action: Attack
Effect: Disrupt
COG: Red: Infrastructure: Military End Products: Aircraft and Components
Location: Red
Desired Impact: Disrupt Aircraft Manufacture. Prevent future manufacture of fighter aircraft, disrupt maintenance of currently operational fighter aircraft.
Review Status: Default

Doctrine:
☐ – Centralize Control and Decentralize Execution
☐ – Simplify and Secure Communications
☐ – Acquire Accurate and Timely Intelligence
☐ – Obtain Accurate Environmental Information

Parents:
☐ Attack Enemy Air Forces in Friendly Territory
☐ Attrit Enemy Reserve Land Forces
☐ Attrit Enemy Reserve Air Forces
☑ Disrupt Enemy Manufacture of Military Equipment
☐ Disrupt Enemy Command & Control

Figure 9. ACPT Assisting COA/COG Development[11]

Figure 10 shows the planner then selecting a target (e.g., all radar within 50 miles of a location) and exploring force requirements for particular COAs.

ACPT has the advantage that planners can build campaign plans during peacetime as well as during crisis, thus training with what they will fight. The high value application and access to a core set of experts were crucial to the success and continued daily use of ACPT.

Air campaign planning functions may be integrated into future versions of CTAPS for use at the Air Operations Center (AOC) level. Links between ACPT and CTAPS functions, as well as databases adequate to serve all applications, are challenges yet to be resolved.

4.4 Conclusion

JWID evaluations [7] of the above tools showed primary problems to be network capacity and reliability as opposed to functionality. Tools that are to effectively support the complex cognitive functions of analysis and planning need not only be intuitive, they also require detailed knowledge of war fighting, a rich taxonomy of courses of action, and an ability to intelligently guide and support the planner. "Building in" knowledge acquisition to the process of campaign planning or force module retrieval/modification can ease the brittleness and cost of these tools, although capturing and representing situation/political context will remain difficult.

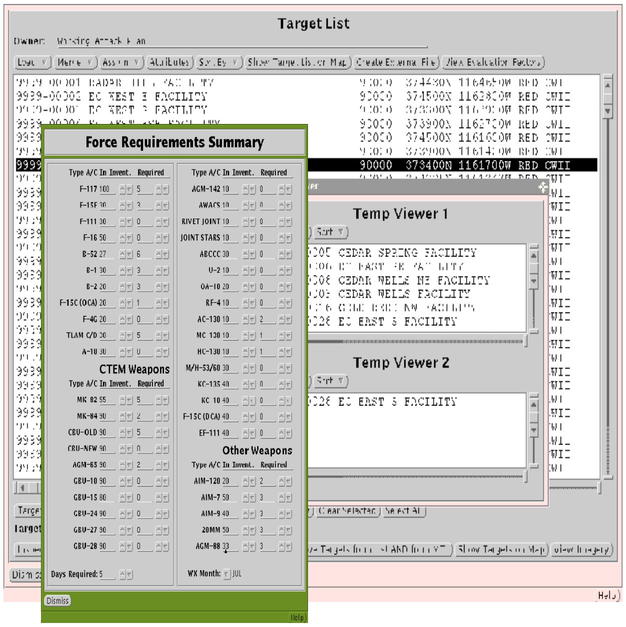


Figure 10. Target Selection and Force Requirements [11]

Finally, experience in ARPI underscores the power of user driven software development. Users are more likely to take a personal stake in the resulting systems they have influence over, and there is a higher likelihood of real increases in operational performance resulting in reduced costs and improved readiness given strong focus on actual problem areas.

5. INFORMATION FUSION

Knowledge of what you can do is only as good as knowledge of what you should do. Understanding the enemy or threat is crucial to plan selection. Often commanders have either too many minute pieces of information or too much general information from which crucial nuggets could be mined (e.g., open source). Moreover, as in the CTAPs system, multiple, separately developed systems can yield incomplete, inconsistent or even an incorrect view of the battlefield. In a separate MOIE effort called Multisource Intelligence Integration and Analysis (MSIIA) [12], The MITRE Corporation in concert with ESC has been investigating tools to assist the intelligence analyst in culling out a cohesive tactical picture of the battlefield.

The Joint Directors of Laboratories Data Fusion Subpanel [13] have developed a four-level generalized processing model that provides a common reference for discussing data fusion systems. The lowest level, Level 1, is represented by sensor-to-sensor correlation technologies and output products such as an estimate of an object's position and identity. At Level 2, logical processes use object information, order-of-battle, and environmental data to determine patterns and produce an assessment of the current hostile or friendly military situation. Products from Level 3 estimate the threat's capability and intent, and an emerging Level 4 addresses collection management. A number of sensor fusion systems are emerging in the intelligence area; however, they are limited in the number of sensors they process or their level of reasoning. A good example of this is the Extended Intelligence Support Terminal (X-IST) being developed for the Navy. X-IST correlates SIGINT and provides graphical representations of tracks on DMA raster maps. Because of the lack of vector map data, X-IST cannot reason about map features. X-IST has a video window and can manipulate softcopy imagery in another software application. However, the imagery is not linked to the maps or SIGINT. While X-IST is very powerful and innovative, it principally performs Level 1 fusion of a single source (SIGINT). It lacks an underlying database architecture for reasoning across sensors and was not designed to link different data sources within a common context.

5.1 MSIIA

An intelligence analyst who directly supports a decision maker in strategic, tactical, or mission planning, produces a report by assembling information from analysts in imagery, signals, and other areas of intelligence. For each sensor domain, there are specialized intelligence analysts who are experienced in interpreting sensor reports. It is the responsibility of the decision-oriented analyst to determine the impact of the information coming from the different intelligence sources. The MSIIA Project [12] is developing a workstation environment that enables a decision-oriented analyst to view, manage, and analyze these sources of information and, simultaneously, confer with specialized analysts. This system integrates radar sensor intelligence (RADINT), imagery (IMINT), signal intelligence (SIGINT), electronic map products, and intelligence order-of-battle databases. Because of disparate intelligence sources displayed in a common geographic context, the decision-oriented analyst can examine data collected over time and collaborate with specialists about the relationship between events detected by different sensors. Figure 11 presents a view of the MSIIA data space and associated situation assessment functions for integrating JSTARS Moving-Target-Indicator Radar, fused SIGINT, IMINT and Geographic Information Systems Data.

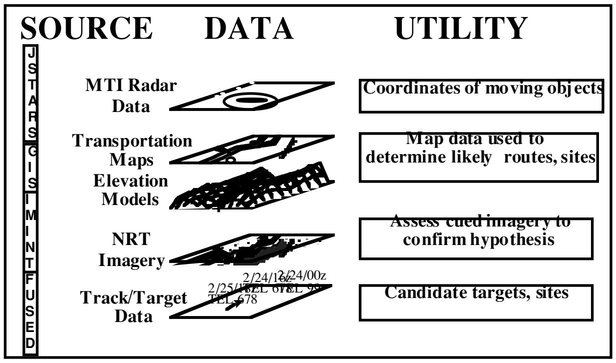


Figure 11. Multisource Information Integration

The MSIIA system combines Joint Surveillance Target Attack Radar System (Joint STARS) Moving Target Indicator Radar (MTI), SIGINT, Defense Mapping Agency (DMA) electronic map products, a variation of the Defense Intelligence Agency's Integrated Database, commercial satellite imagery, and near-real time reconnaissance imagery. A central component of this system is a commercial geographic information system, which is used to manage and display the data in a geographically registered framework.

5.2 Multi-Source Analysis and Fusion

The main goal of any information analysis and fusion system in the domain of military intelligence is to combine the available data on a specified area of interest to achieve the best possible estimate of the objects, their groupings, movements and activities. The ultimate goal of this activity is to enhanced situation understanding that will facilitate a more appropriate utilization of assets (e.g., to prioritize intelligence collection, to guide campaign planning). To exploit disparate sensor and reporting system information over a varied spatial/temporal region, several reasoning mechanisms must be employed, whether by human or machine.

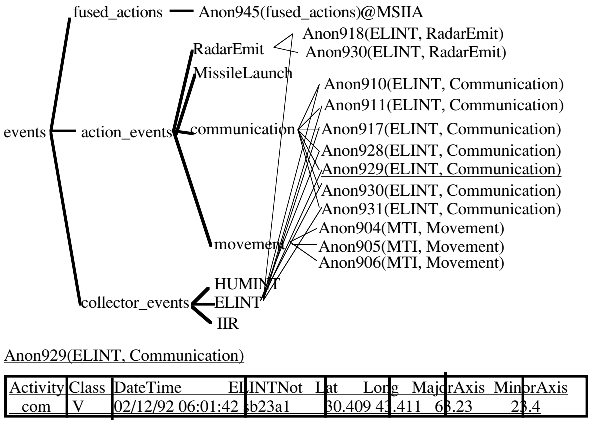
The problem of intelligence analysis and fusion on the MSIIA project is exacerbated by the diversity of sensor and information types brought together in a single, integrated analysis environment. Since there are more sources of information, more information can be gleaned from it, but only if the proper reasoning mechanisms are applied. Data comes in snapshots of a continually changing world. These snapshots contain different pieces of the overall puzzle. Additionally these snapshots are generated at temporally disjoint epochs. What this means is that all the sensor information available on an object is not view able at the same spatial-temporal interval. This is caused by two phenomena. First, sensors (with the exception of Joint STARS) rarely have continuous coverage; therefore, information is gathered at discrete time intervals. The second reason is that most types of information are not being generated continually. Most objects are not going to be communicating, radar or infrared emitting, or moving continually. Thus, in most cases, the only time information is actually gathered is when the sensor is looking and the object is generating the proper signal.

Most data used by the MSIIA workstation will be received as point temporal data or spatial-temporal track data. That is, data pertaining to a specific sensor event will be tagged with a discrete time and geo-spatial location, essentially a snapshot. This information, however, limits the amount of reasoning that can be done since most objects of interest do not stand still. What this implies is that to fuse the various sensor events, reasoning about what is happening between all the snapshots is required.

5.3 Overview of the Fusion Algorithms

The MSIIA fusion mechanisms are implemented on a network of Sun UNIX workstations that house a Sybase relational database, ArcInfo Geographic Information System (GIS), and ProKappa knowledge engineering environment. All reasoning mechanisms are currently implemented in ProKappa and knowledge is represented in frames.

The knowledge based fusion process uses a constraint based reasoning model that mimics the process by which a human analyst would approach the fusion process. This approach has the advantage of allowing for explanation capabilities that can be related to the users reasoning process. There are two distinct sets of constraints that need to be satisfied in order to fuse disparate pieces of sensor information. The first constraint is that of the classification of objects. In order for two pieces of sensor/source information to be fused, they must be about the same type of object. This set of constraint satisfaction is achieved by explicit representation of the possible objects a piece of information could be on the "possible-object" slot of the individual sensor/source objects. Figure 12 presents an illustration of this representation where sensor events are shown inheriting attributes from activity type objects and sensor type objects. The bottom of the figure illustrates a particular instance of a sensor event with associated event type, date, time, location, type of object recognized and so on.



Anon929(ELINT, Communication)

Activity	Class	DateTime	ELINTNot	Lat	Long	MajorAxis	MinorAxis
com	V	02/12/92 06:01:42	sb23a1	30.409	43.411	63.23	23.4

Figure 12. Sensor-/Source Object Hierarchy

Classification constraint satisfaction is accomplished by comparing the possible objects that all candidate sensor/source events can be with all other candidates. The result of this process is a set of objects that can be uniquely related to each other based on classification. With a set of objects that can be related by classification a second set of constraints that related to the relationships on the objects in space and time needs to be satisfied. Spatial-temporal reasoning is the process of analyzing objects in space and time. This is inherently difficult given the complexity of the MSIIA data space combined with the problems with representing temporal data in a two dimensional geographic space. Being able to maintain spatial-temporal relationships is a cognitively demanding task in volatile domains such as MSIIA's. Technically, implementing this type of capability is difficult since conventional relational database technology does not support complex spatial or temporal information analysis. Spatial-temporal constraint satisfaction is achieved in MSIIA by having an explicit temporal model in the fusion algorithms and spatial representation in the GIS. This provides the functionality required to analyze the relationships between sensor/source events in space and time. The following explains how spatial-temporal constraint satisfaction is achieved.

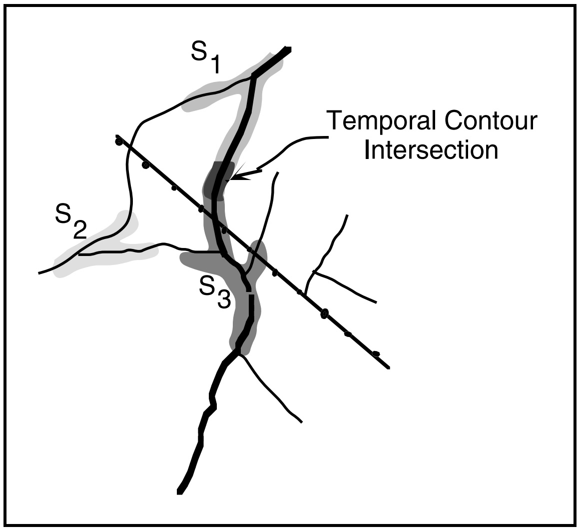


Figure 13. Mobility Contour Intersection

Given a number of sensor events that occur at different times and that can potentially be fused (i.e., they satisfy classification constraints), mobility contours for the time difference between the events are constructed. These mobility contours (generated in the GIS) represent where an object could be based on the time difference to other objects. These mobility contours are generated as a function of the "mobility characteristics" of the object in question. For example a SCUD TEL will only move on improved hard surface roads. The possible fusion occurs when there is an intersection of the mobility contours. Figure 13 presents a graphical example of a possible contour intersection. Here, three sensor events may possibly be combined, but, because of the mobility dynamics of the objects inferred from the sensor events, there is only one possible intersection, namely the intersection of S_1 and S_3. When there is an intersection of two objects a fused "binary track" is created. This becomes a new object in the fusion system and represents the relationship between two pieces of sensor/source data. Binary tracks form the foundation for assembling more complex tracks.

With a set of binary tracks which represent all possible relationships between sensor/source events, addition techniques can be employed to explore the relationship between them. The sensor/source pre-processing portion of the fusion algorithms, which are responsible for taking intelligence information (events) and populating the knowledge base, were modified to facilitate a new reasoning technique for extraction on a minimum set of unique objects and tracks from a set of data. The pre-processor constructs a set of unique one-to-one (binary) relationships between all events. These binary tracks enumerate all the possible relationships that can exist give a set of point sensor/source data under the constrains of classification and spatial-temporal mobility. Given a set of binary tracks it is then possible to construct graphs representing relations between events by using analysis techniques from graph theory to extract unique tracks of objects.

Since the fusion process is based on a model that mimics the analyst's reasoning process, this appears to yield more intuitive and credible explanations of inferences. In particular, since the fusion process is constraint based, MSIIA "justifies" its conclusions by listing the constraints that were satisfied to fuse information together. Figure 14 presents a sample of the explanation of a fused binary track. Here, two events with related classification and meeting spatial-temporal constraints are summarized for the user.

```
Binary track of event 187 and 462

Event  187
classification VAB
location 47.578 28.137
time 02/17/93:13.10.12

Event  462
classification VA
location 47.203 28.134
time 02/17/93:13.57.20

Time difference - 47.08
Distance Difference - 23.47
Average velocity - 29.91
Binary track confirmed by
classification and space-time
```

Figure 14. Sample Fusion Algorithm Explanation

Finally, MSIIA incorporates a natural language front end based on Natural Language Inc.'s COTS tool which enables the analyst to query the system for data and explanations of inferred information. Graphical displays of event sequences over time enable the user to quickly examine the inferred behavior of objects.

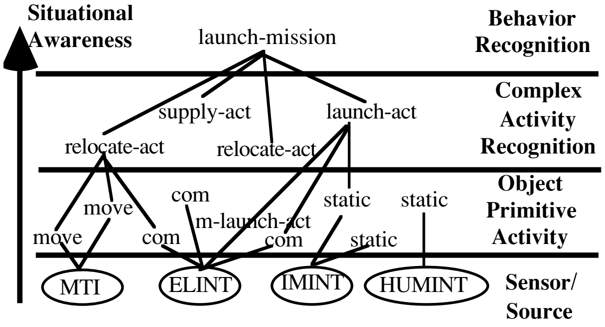


Figure 15. Levels of Recognition

Future investigations are evaluating the ability to interpret information at increasingly higher levels of abstraction. Figure 15 illustrates how sensors can recognize objects and ultimately activities, from which higher level behaviors can be inferred. As information fusion capabilities approach descriptions of enemy behavior levels, opportunities increase for incorporation into high level campaign planning.

6. LESSONS LEARNED

A number of key lessons can be culled from the above experiences. First, Commercial off the Shelf (COTS) hardware and software has assumed strategic importance given the ability to leverage commercial investment, efficiencies, and marketplace competition [14]. This can also dramatically decrease time to field applications and maintenance tails. For example, the intelligence community's Intelink system went from concept to operational in a matter of months by replicating existing Internet functionality on classified networks. What makes COTS truly valuable are standards for information storage, processing, and exchange in order to ensure systems interoperability. This provides the added benefit of vendor independence, which enables the government to take advantage of marketplace competition assuming there is no vendor monopoly. Distributed object management will help further this trend as third party vendors become able to add value to products without having to first develop full-featured offerings.

Finally, unlike traditional multi-year or multi-decade acquisition cycles where a formal process of requirements analysis through acquisition and finally logistical support is rigidly followed, the pace of political, military doctrine, and technology change underscore the importance of a collaborative, evolutionary approach to acquisition. By this we mean that multifunctional teams, from technology providers to end users, are assembled to rapidly deploy, in a phased approach, fielded capabilities which are refined to meet operational requirements through direct interaction with and involvement of end users. In cases where legacy systems are too complex or expensive to re-engineer, object request brokers can serve as an important element in supporting interoperability. Lastly, in any system that will be developed for tasks as complex and involving as many uncertainties as crisis action planning, truly powerful systems will only be possible when we find effective mechanisms that utilize both machine and human knowledge synergistically to enhance overall system performance.

7. A VISION FOR THE FUTURE

Despite formidable mission planning systems such as CTAPS, there exists no current set of collaborative, campaign and theater-level mission planning and battle coordination tools to support joint or international operations. This is exacerbated by the lack of a common information infrastructure at multiple levels (including data element standards, network protocols, security services, and user applications). This has resulted in limited system interoperability which minimizes possible information sharing and real-time coordination of joint and multinational teams. This limits joint coalition forces from effective, real-time resource reallocation and rescheduling and results in decreased resource utilization (increased cost) and increased force risk (e.g., unthwarted enemy threats, fratricide).

Figure 16 shows a vision for knowledge-based, distributed, collaborative planning to support the Joint Task Force Commander, a notional integrated view of capabilities described in this article. These include:

- Knowledge-based planning and scheduling aids, at the campaign and theater level, which exploit techniques such as hierarchical planning, case-based reasoning (e.g., about historical/enemy battles) and knowledge-based simulation of friendly and enemy forces.
- 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
- Collaborative tools that enable not only information sharing but virtual collaboration among users.

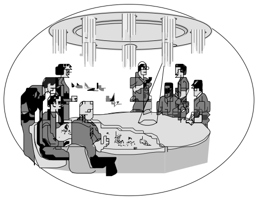


Figure 16. Vision for Intelligent, Distributed, Collaborative Planning

7.1 Capability/Functionality

This vision comprises three key operational facilities: an intelligent and intuitive mission planning interface for joint and multinational use, a set of collaborative, knowledge based mission planning tools, and an information infrastructure that will enable the above.

First, automated multisensor selection and/or multisensor fusion in the context of an intelligent and intuitive display will enable a senior intelligence officer and perhaps even the commander to interactively perform situation assessment. Importantly, the human-machine interface will provide multimedia, multilingual and multiparty interaction to support collaboration with coalition forces. A user-adaptive interface will provide rapidly customizable views for specific task functions, including browsing, search, and visualization of real-time as well as historical information. This will include summary views (e.g., of fused tracks, of overall characteristics of a class of objects) which will allow rapid access to supporting details for further analysis or verification.

Second, the underlying systems will provide a shared set of intelligent mission planning and scheduling tools. These will facilitate decision making through use of multiple capabilities including:

- Access to historical missions/battles to analyze enemy propensities for response/attack
- Intelligent agents to discover and filter critical information and patterns
- Real-time simulation of friendly and enemy forces (using real data mixed with simulated agents) to support rapid what-if analysis

- Knowledge based planning and scheduling tools that take into account factors such as current intelligence, weapons characteristics, logistics constraints, weather conditions, and objectives and strategies, to facilitate decision making through recommendations of alternative courses of action

- Embedded, on-line intelligent trainers for learning advanced system features in non-crisis periods as well as providing on-line task assistance during operations

The aim of all of these facilities will be to increase the cognitive power and efficiency of the decision maker.

To support the above requires a critical third element: mechanisms for bridging the gaps between existing stovepipe systems to support rapid integration of joint and coalition systems in crisis situations. This includes not only access to heterogeneous databases (e.g., intelligence, operations, and logistics data) but also interoperability of higher level application tools (e.g., requirements management, target nominations, force allocation). Modules would be integrated using open systems approaches (e.g., object-request broker standards, messaging and directory services standards) which support evolutionary development of new facilities to facilitate technology transfer.

7.2 Technology Needed

Several technologies are key to enabling the above facilities. First, we require technologies to support adaptive, intuitive user interaction. These include self-adaptive input/output devices, multilingual speech recognition and generation, multimedia presentation planning, natural language dialogue management, information summarization, and virtual displays [15].

To support intelligent decision support, we require a host of technologies such as real-time knowledge based simulation and planning tools. This will result in severe computational challenges, for example, to support large object-oriented and knowledge-intensive simulations (e.g., simulating hundreds of thousands of battlefield objects). The collaborative nature of the tools will require advances in workflow management and intelligent routing (e.g., to support joint and multinational tasking, dissemination of indications and warnings).

Finally, several infrastructure advances are required to facilitate information sharing and collaborative planning. These include scaling up approaches such as the Object Request Broker (ORB) to integrate legacy systems and support rapid integration of and evolution toward new capabilities. Multilevel security will clearly be an issue given the number and types of partners likely to be interacting using such a system and their differing information needs. Communications requirements and complexities will require more sophisticated approaches to network and systems management (e.g., active performance management, knowledge based fault detection, diagnosis, repair). Communicators will demand real-time video teleconferencing as well as application and multimedia information sharing (e.g., maps, imagery) which will likely require gigabit and terabit networking but also advances in compression techniques and wireless technologies to support the soldier, airman, and seaman in the field.

To make progress toward the outlined vision requires not only coordinated technological investment by NATO member nations, but also commitment to more toward common architectures. Action should include:

1. Sharing lessons learned with NATO member nations.
2. Building a common NATO infrastructure by exploiting advances in distributed object technology to set the stage for future systems integration.
3. Establish a working group to forge a common vision for distributed, collaborative planning systems that can foster user pull and international partnering to move in this direction.

8. CONCLUSION

Global geo-political, economic, and military acquisition changes are driving a fundamental questioning of both what is needed to support national and global security and how best to provide that. An increasing trend toward interdependent political, economic, and military systems has focused attention on the need for improved joint service and international systems. We currently lack of a set of collaborative, integrated, interservice and international campaign and theater-level mission planning and battle coordination tools. This is exacerbated by the lack of a common information infrastructure at multiple levels (including data element standards, network protocols, security services, and user applications).

This has resulted in limited system interoperability which minimizes possible information sharing and real-time coordination of joint and multinational efforts. This limits joint coalition forces from effective, real-time resource reallocation and rescheduling and results in decreased resource utilization (increased cost) and increased force risk (e.g., unthwarted enemy threats, fratricide). This article outlines the emerging role of distributed object management, and forthcoming distributed, collaborative force deployment and employment tools that, together with a new approach to procurement and a vision for the future, can help address the serious existing shortfalls in interoperability, functionality, and systems acquisition.

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11. GLOSSARY

ACPT	Air Campaign Planning Tool
AFMSS	Air Force Mission Support System
AOC	Air Operations Center
APS	Advanced Planning System
ARPA	Advanced Research Project Agency
ATO	Air Tasking Order
ATD	Advanced Technology Demonstration
COTS	Commercial Off the Shelf
COA	Courses of Action
CTAPS	Contingency Theater Automated Planning System
CINC	Commander-in-Chief
CAFMS	Computer Assisted Force Management System
C^4I	Command, Control, Communications, Computers, and Intelligence
DART	Dynamic Analysis and Replanning Tool
DMA	Defense Mapping Agency
DODIIS	Department of Defense Intelligence Information System
ESC	US Air Force Electronic Systems Center
ForMAT	Force Module Analysis and Management Tool
GCCS	Global Command and Control System
GIS	Geographic Information System
GLAD	Geographical Logistics Awareness Display
HUMINT	Human Intelligence
IMINT	Imagery Intelligence
IFD	Integrated Feasibility Demonstration
JCS	Joint Chiefs of Staff
JDISS	Joint Deployable Intelligence Support System
JDL	Joint Directors of Laboratories
JFACC	Joint Force Air Component Commander
JFLCC	Joint Force Land Component Commander
JFMCC	Joint Force Maritime Component Commander
JFSOCC	Joint Force Special Operations Component Commander

Joint STARS	Joint Surveillance Target Attack Radar System
JTF	Joint Task Force
JWICS	Joint Worldwide Intelligence Communications System
JWID	Joint Warrior Interoperability Demonstration
JMAPS	Joint Message Analysis and Preparation System
MOIE	Mission Oriented Investigation and Experimentation
MSIIA	Multisource Intelligence Integration and Analysis
MTI	Moving Target Indicator
RL	US Air Force Rome Laboratory
RAAP	Rapid Application of Air Power
SIGINT	Signals Intelligence
SOCAP	SIPE-II Operational Crisis Action Planner
SIGINT	Signals Intelligence
TARGET	Theater Analysis, Replanning and Graphical Execution Toolbox (IFD-3)
TPFDD	Time Phased Force Deployment Data
USTRANSCOM	United States Transportation Command
X-IST	Extended Intelligence Support Terminal