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JOINT FIRE SUPPORT IN 2020: Development of a Future Joint Fires Systems Architecture for Immediate, Unplanned Targets

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The United States military has continually strived to develop systems and procedures that attempt to maximize the effectiveness and improve the collaborative effects of fire support across the spectrum of warfare. Despite improvements in the interoperability of the Department of Defense service components, there continue to be difficulties involved with executing emergent Joint Fires in a timely manner in support of the commander. In this context, the Joint Fire Support in 2020 project applied systems engineering procedures and principles to develop functional, physical, and operational architectures that maximize rapid battlefield effects through efficient target-provider pairings. The unplanned, immediate joint fire support requests, and the architectures that enable the rapid pairing and tasking of fire support providers to fulfill those requests, were the emphasis of the study. Through modeling, simulation, and qualitative assessments of existing and planned command and control systems and organizations, a Centralized Joint Fire Support Network that incorporates and consolidates the various cross-service fire support functions, was chosen as the preferred evolutionary development path to a fully Distributed Joint Fire Support Network. The Project Team recommended several doctrinal, organizational, training, tactics, and materiel acquisition (DOTMLPF) solutions and identified areas of continued effort and study.

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ABSTRACT

The United States military has continually strived to develop systems and procedures that attempt to maximize the effectiveness and improve the collaborative effects of fire support across the spectrum of warfare. Despite improvements in the interoperability of the Department of Defense service components, there continue to be difficulties involved with executing emergent Joint Fires in a timely manner in support of the commander. In this context, the Joint Fire Support in 2020 project applied systems engineering procedures and principles to develop functional, physical, and operational architectures that maximize rapid battlefield effects through efficient target-provider pairings. The unplanned, immediate joint fire support requests, and the architectures that enable the rapid pairing and tasking of fire support providers to fulfill those requests, were the emphasis of the study. Through modeling, simulation, and qualitative assessments of existing and planned command and control systems and organizations, a Centralized Joint Fire Support Network that incorporates and consolidates the various cross-service fire support functions, was chosen as the preferred evolutionary development path to a fully Distributed Joint Fire Support Network. The Project Team recommended several doctrinal, organizational, training, tactical, and materiel acquisition (DOTMLPF) solutions and identified areas of continued effort and study.

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LIST OF SYMBOLS, ACRONYMS, AND ABBREVIATIONS

AAWC	Anti Air Warfare Commander
ABCCC	Airborne Battlefield Command and Control
ACE	Aviation Combat Element
ADA	Air Defense Artillery
ADCON	Administrative Control
ADLO	Air Defense Liaison Officer
ADOCS	Automated Deep Operations Coordination System
AFAOC	Air Force Air and Space Operations Center
AFARN	Air Force Air Request Net
AFATDS	Advanced Field Artillery Tactical Data System
AFDD	Air Force Doctrine Document
AFFOR	Air Force Forces
AFIT	Air Force Institute of Technology
AFSOC	Air Force Special Operations Command
ALO	Air Liaison Officer
AME	Air Mobility Element
AMLS	Airspace Management Liaison Section
ANGLICO	Air and Naval Gunfire Liaison Company
ANOVA	Analysis of Variance
AO	Area of Operations
AOA	Amphibious Objective Area
AOC	Air Operations Center
AREC	Air Resource Element Coordinator
ARFOR	Army Forces
ASD/C3I	Assistant Secretary of Defense for Command, Control, Communications and Intelligence
ASOC	Air Support Operations Center
ASUWC	Anti Surface Warfare Commander
ASWC	Anti-Submarine Warfare Commander
ATACMS	Army Tactical Cruise Missile System
ATO	Air Tasking Order
ATWCS	Advanced Tomahawk Weapons Control System
AWACS	Airborne Warning and Control System
AWC	Air Warfare Commander
BAA	Battalion and Above
BCD	Battlefield Coordination Detachment
BDA	Battle Damage Assessment
BDE	Brigade
BN	Battalion
C2	Command and Control
C2PC	Command and Control Personnel Computer
C2WC	Command and Control Warfare Commander
C3	Command, Control, and Communications

C3I	Command, Control, Communications and Intelligence
C4I	Command, Control, Communications, computers, and Intelligence
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CANTCO	Cannot Comply
CAOC	Combined Air Operation Center
CAS	Close Air Support
CATF	Commander Amphibious Task Force
CCT	Combat Control Team
CFF	Call for Fire
CG	Guided Missile Cruiser
CGFOR	Coast Guard Forces
CIs	Configuration Items
CJCS	Chairman of the Joint Chiefs of Staff
CJFSN	Centralized Joint Fire Support Network
CJTF	Commander, Joint Task Force
CLF	Commander, Landing Forces
COCOM	Combatant Commander
COLT	Combat Observation Lasing Team
CONOPS	Concept of Operations
COP	Common Operating Picture
CP	Command Post
CPOF	Command Post of the Future
CRC	Control and Reporting Center
CRE	Control and Reporting Element
CSG	Commander, Carrier Strike Group
CSSE	Combat Service Support Element
CSW	Coordinate Seeking Weapons
CTF	Commander, Task Force
CTP	Common Tactical Picture
CVBG	Carrier Battle Group
CWC	Composite Warfare Commander
DAFS	Dynamic Allocation of Fires and Sensors
DASC	Direct Air Support Center
DD	Spruance Class Destroyer
DDG	Guided Missile Destroyer
DIRMOBFOR	Director of Mobility Forces
DISA	Defense Information Systems Agency
DIV	Division
DJFSN	Distributed Joint Fire Support Network
DOCC	Deep Operations Coordination Cell
DoD	Department of Defense
DOTMLPF	Doctrine, Organization, Tactics and Training, Materiel, Leadership and Education, Personnel and Facilities

EMP	Electro-Magnetic Pulse
EPLRS	Enhanced Position Location and Reporting System
ERGM	Extended Range Guided Munition
EW	Electronic Warfare
F2T2EA	Find, Fix, Track, Target, Engage, Assess
FAC	Forward Air Controller
FAC(A)	Forward Air Controller (Airborne)
FBCB2	Force XXI Battle Command, Brigade-and-Below
FCB	Functional Capabilities Board
FDC	Fire Direction Center
FFCC	Forces Fires Coordination Center
FFE	Fire For Effect
FFJC	Family of Future Joint Concepts
FIST	Fire Support Team
FO	Forward Observer
FOM	Figure of Merit
FS Cell	Fire Support Cell
FSCA	Fire Support Coordination Agencies
FSCC	Fire Support Coordination Center
FSCOORD	Fire Support Coordinator
FSE	Fire Support Element
FSO	Fire Support Officer
GCCS	Global Command and Control System
GCCS(A/AF)	Global Command and Control System, Army and Air Force
GCCS-M	Global Command and Control System-Maritime
GCE	Ground Combat Element
GIG	Global Information Grid
GLO	Ground Liaison Officer
GPS	Global Positioning System
HMMWV	High Mobility, Multi-Purpose Wheeled Vehicle
HQ	Headquarters
ID	Identify/Identification
I-O	Input-Output
IP	Internet Protocol
IPB	Intelligence Preparation of the Battlefield
ISR	Intelligence, Surveillance, Reconnaissance
IW	Information Warfare
JAG	Judge Advocate General
JAOC	Joint Air Operations Center
JAWP	Joint Advanced Warfighting Project
JBMC2	Joint Battle Management Command and Control
JC3IEDM	Joint Consultation Command and Control Information Exchange Data Model
JCIDS	Joint Capability Integration and Development System
JCR	Joint Capabilities Roadmap

JDAM	Joint Direct Attack Munition
JF	Joint Fires
JFA	Joint Fires Area
JFACC	Joint Forces Air Component Commander
JFAO	Joint Force Area of Operation
JFC	Joint Force Commander
JFCOM	Joint Forces Command
JFEO	Joint Forcible Entry Operations
JFIIT	Joint Fires Integration and Interoperability Team
JFIRE	Joint Applications of Fire Power
JFMCC	Joint Forces Maritime Component Commander
JFS	Joint Fire Support
JFSN	Joint Fire Support Network
JFSOCC	Joint Forces Special Operations Component Commander
JHAPL TBM	John Hopkins Applied Physics Laboratory Theater Ballistic Missile
JMCC	Joint Movement Control Center
JMEM	Joint Munitions Effects Manual
JOC	Joint Operation Center
JOCC	Joint Operations Command Center
JPEO	Joint Program Executive Office
JROC	Joint Requirements Oversight Committee
JSOACC	Joint Special Operations Air Component Commander
JSOTF	Joint Special Operations Task Force
JSTARS	Joint Surveillance, Target Attack Radar System
JTAC	Joint Terminal Attack Controller
JTCB	Joint Targeting Coordination Board
JTRS	Joint Tactical Radio System
JUO	Joint Urban Operation
LCC	Amphibious Command Ship
MAGTF	Marine Air-Ground Task Force
MANA	Map Aware Non-Uniform Automata
MARFOR	Marine Forces
MARLO	Marine Liaison Officer
MEF	Marine Expeditionary Force
MIP	Multilateral Interoperability Program
MLE	Marine Liaison Element
MRT	Military Ruggedized Tablet
NALE	Naval and Amphibious Liaison Element
NAVFOR	Navy Forces
NECC	Naval Expeditionary Combat Command
NFCS	Naval Fires Control System
NFS	Naval Fire Support
NGLO	Navy Ground Liaison Officer
NLO	Navy Liaison Officer
NPS	Naval Postgraduate School

NSFS	Naval Surface Fire Support
NSS	National Security Strategy
NSWTG	Naval Special Warfare Task Group
NSWTU	Naval Special Warfare Task Unit
NTDR	Near Term Digital Radio
OA	Operating Area
OMB	Office of Management and Budget
OPCON	Operational Control
OSD	Office of the Secretary of Defense
OTC	Officer in Tactical Command
PDA	Personal Digital Assistant
PGM	Precision Guided Munition
POM	Program Objective Memorandum
PPBE	Planning, Programming, Budgeting and Execution
QDR	Quadrennial Defense Review
RECCE	Reconnaissance
RF	Radio Frequency
ROE	Rules of Engagement
SACC	Supporting Arms Coordination Center
SATCOM	Satellite Communications
SEA	Systems Engineering and Analysis
SEA-10	Systems Engineering and Analysis Cohort 10
SEDP	Systems Engineering Design Process
SF	Special Forces
SFCP	Shore Fire Control Party
SINCGARS	Single Channel Ground and Air Radio System
SO	Special Operations
SOCCE	Special Operations Command and Control Element
SOCOORD	Special Operations Coordination Element
SOF	Special Operations Forces
SOLE	Special Operations Liaison Element
SoS	System of Systems
SPG	Strategic Planning Guidance
SQ+	Status Quo Plus
SSGN	Nuclear Guided Missile Submarine
SSN	Nuclear Fast Attack Submarine
STT	Special Tactics Team
STWC	Strike Warfare Commander
SUWC	Surface Warfare Commander
TAC(A)	Tactical Air Coordinator (Airborne)
TACC	Tactical Air Command Center (USMC)
TACC	Tactical Air Control Center (USN)
TACC	Tanker Airlift Control Center (USAF)
TACON	Tactical Control
TACP	Tactical Air Control Party

TACS	Theater Air Control System
TADC	Tactical Air Direction Center
TALCE	Tanker Airlift Control Element
TAPS	Tomahawk Afloat Planning System
TARN	Tactical Air Request Net
TBMCS	Theater Battle Management Control System
TCP/IP	Transmission Control Protocol/Internet Protocol
TIC	Troops in Contact
TLAM	Tomahawk Land Attack Missile
TLDHS	Target Location, Designation, and Hand-Off System
TOC	Tactical Operations Center
TST	Time Sensitive Targeting
TTP	Tactics, Techniques, and Procedures
UAV	Unmanned Aerial Vehicle
UHF	Ultra High Frequency
USA	United States Army
USAF	United States Air Force
USMC	United States Marine Corps
USN	United States Navy
USWC	Undersea Warfare Commander
VHF	Very High Frequency
VoIP	Voice over Internet Protocol
WCS	Weapons Control System
WMD	Weapons of Mass Destruction
WOC	Wing Operations Center
XML	eXtensible Mark-up Language

GLOSSARY

Analysts: A type of stakeholder. Individuals of groups that evaluate the effective needs which assisted in determining the projected performance of various system alternatives to determine the most efficient and effective alternative.

Area of Operations (AO): An operational area defined by the joint force commander for land and naval forces. Areas of operations do not typically encompass the entire operational area of the joint force commander, but should be large enough for component commanders to accomplish their missions and protect their forces.

Advanced Field Artillery Tactical Data System (AFATDS): AFATDS is an integrated fire support system used by Army and Marine Corps. It processes fire mission and other related information to coordinate the use of fire support assets, including mortars, field artillery, cannon, missile, attack helicopters, air support, and limited naval gunfire.

Advanced Tomahawk Weapons Control System (ATWCS): ATWCS is an upgrade to the initial *Tomahawk* system. The ATWCS improvements include hardware, software, and firmware modifications. The added capabilities include: contingency-strike operations planning, embedded training at all levels, and a simplified man-machine interface. It is used for the planning, execution, and launch of the Tomahawk missile aboard naval ships and submarines.

Airborne Warning and Control System (AWACS): AWACS provides all-weather surveillance, command, control and communications needed by commanders of U.S. and NATO air defense forces.

Applique System: The appliqué system is an experimental battlefield digitization computer system consisting of four basic versions of hardware installed on vehicles and used by individual soldiers, connected by a radio system.

Automated Deep Operations Coordination System (ADOCS): The Automated Deep Operations Coordination System (ADOCS) developed by General Dynamics is a joint mission management software application. It provides a suite of tools and interfaces for horizontal and vertical coordination across battlespace functional areas.

Clients: Agencies or groups of people that will have substantial input as to the development of the solution set or system.

Close Air Support (CAS): Air action by fixed- and rotary-wing aircraft against hostile targets which are in close proximity to friendly forces and which require detailed integration of each air mission with the fire and movement of those forces.

Danger Close: In close air support, artillery, mortar, and naval gunfire support fires, it is the term included in the method of engagement segment of a call for fire which indicates that friendly forces are within close proximity of the target. The close proximity distance is determined by the weapon and munition fired.

Command Post of the Future (CPOF): A system currently deployed at the division level. Enables division and brigade commanders to discuss and collaborate when processing information, share ideas, and attend virtual meetings without assembling at one place.

Decision Makers: A type of stakeholder. Personnel or organizations who have the authority to make impacting and final project decisions.

Electronic Warfare (EW): Any military action involving the use of electromagnetic and directed energy to control the electromagnetic spectrum or to attack the enemy.

Enhanced Position Location and Reporting System (EPLRS): A system that provides secure, jam-resistant, near real-time data communications support for the five Battlefield Functional Areas of the Army Tactical Command and Control System (ATCCS).

Fire Support Coordination: The planning and executing of fire so that targets are adequately covered by a suitable weapon or group of weapons.

Fire Support Coordination Center (FSCC): A single location in which are centralized communications facilities and personnel incident to the coordination of all forms of fire support.

Fires: The effects of lethal or nonlethal weapons.

Force XXI Battle Command, Brigade and Below (FBCB2): The FBCB2 consists of Applique hardware, software and EBC Software integrated into the various platforms at brigade and below, as well as appropriate Division and Corps slices necessary to support brigade operations. It interconnects platforms through a communications infrastructure called the Tactical Internet consisting of existing EPLRS and SINCGARS nets to pass Situation Awareness data and conduct Command and Control. Primary functions are to send out and receive automatic position location reports, and to send and receive command and control message traffic and graphics for display.

Global Command and Control System (GCCS): The Global Command and Control System (GCCS) is an automated information system designed to support deliberate and crisis planning with the use of an integrated set of analytic tools and the flexible data transfer capabilities.

Global Information Grid (GIG): A net-centric system operating in a global context to provide processing, storage, management, and transport of information to support all Department of Defense (DoD), national security, and related intelligence community missions and functions-strategic, operational, tactical, and business-in war, in crisis, and in peace.

Joint: Activities, operations, organizations, etc., in which elements of two or more Military Departments participate.

Joint Battle Management Command and Control (JBMC2): JBMC2 consists of the processes, architectures, systems, standards, and command- and-control operational concepts employed by the joint force commander. The joint force commander executes joint operations by employing the entire array of JBMC2 capabilities during the planning, coordinating, directing, controlling, and assessing of joint force operations from interface with the strategic level through the tactical level.

Joint Fires (JF): Fires produced during the employment of forces from two or more components in coordinated action toward a common objective.

Joint Fire Support (JFS): Joint fires that assist land, maritime, amphibious, and special operations forces to move, maneuver, and control territory, populations, and key waters.

Joint Force Commander (JFC): A general term applied to a combatant commander, subunified commander, or joint task force commander authorized to exercise combatant command (command authority) or operational control over a joint force.

Joint Operations: A general term to describe military actions conducted by joint forces or by Service forces in relationships (e.g., support, coordinating authority) which, of themselves, do not create joint forces.

Joint Surveillance, Target Attack Radar System (JSTARS): Long-range, air-to-ground surveillance system designed to locate, classify and track ground targets in all weather conditions.

Joint Targeting Coordination Board (JTCB): A group formed by the Joint Force Commander to accomplish broad targeting oversight functions that may include but are not limited to coordinating targeting information, providing targeting guidance and priorities, and preparing and/or refining joint target lists. The board is normally comprised of representatives from the joint force staff, all components, and if required, component subordinate units.

Naval Fires Control System (NFCS): NFCS is a battle management system that enables for surface land attack in net-centric warfare. NFCS supports mission planning for 5"/62 - Advanced Gun System and Extended Range Guided Munitions (ERGM).

Rules of Engagement (ROE): Directives issued by competent military authority which delineate the circumstances and limitations under which United States forces will initiate and/or continue combat engagement with other forces encountered.

Single Channel Ground and Air Radio System (SINCGARS): SINCGARS is a family of VHF-FM combat net radios which provides the primary means of command and control for Infantry, Armor and Artillery Units. SINCGARS is designed on a modular basis to achieve maximum commonality among the various ground and airborne system configurations.

Sponsors: A type of stakeholder. Offices or groups of people that provide financial support, which may include technical support or support in the form of special studies or specialized information.

Stakeholders: Stakeholders are a group of people (users, owners, manufacturers, maintainers, trainers, etc.) for whom a system is being built.

Target Location, Designation and Handoff System (TLDHS): A modular, man-portable equipment suite that will provide the ability to quickly acquire targets in day, night, and near-all-weather visibility conditions. Operators will be able to accurately determine their own location as well as that of their targets, digitally transmit (hand-off) data to supporting arms elements, and designate targets for laser-seeking Precision Guided Munitions (PGM) and Laser Spot Trackers (LST).

Theater Air Control System (TACS): The Theater Air Control System (TACS) provides the Air Force Component Commander (AFCC) and the Joint Forces Air Component Commander (JFACC) the capability to plan and conduct theater air operations, including joint US operations and combined operations with allied forces. The TACS supports the Air Force doctrine of centralized control and decentralized execution of theater air support assets.

Theater Battle Management Core System (TBMCS): Provides the Combat Air Forces (CAF) and the Joint/Combined Forces with an automated and integrated capability to plan and execute the air battle plan for operations and intelligence personnel at the force and unit levels.

Troops in Contact (TIC): A close air support situation where the friendly troops are within 1 kilometer of the intended targets unless the ground commander determines otherwise. JTACS and aircrews must carefully weigh the choice of ordinance and delivery profile in relation to the risk of fratricide in a TIC situation.

Users: A type of stakeholder. Agencies or groups of people that will actually use the system that is developed.

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EXECUTIVE SUMMARY

The Joint Fire Support in 2020 project represents a cooperative research study involving the Naval Postgraduate School (NPS) Systems Engineering and Analysis (SEA) curriculum, other student groups on campus, and more than 10 NPS faculty members. The impetus for this undertaking was a request by US Joint Forces Command (JFCOM) to both NPS and the Air Force Institute of Technology (AFIT) to study and analyze possible joint war fighting improvements. Analysis was performed in one of the many study areas described in the Joint Battle Management Command and Control (JBMC2) Roadmap published by JFCOM in 2005. The seven SEA-10 students in the Joint Fires Support Project Team utilized a tailored Systems Engineering Design Process (SEDP), an iterative procedure that facilitated a methodical approach to solve the design problem, composed of three phases: Problem Definition, Design and Analysis, and Decision Making.

During the Problem Definition phase, the Joint Fires Team conducted an extensive analysis of existing and proposed fire support systems. Stakeholders were identified and interviewed and an Effective Need was developed. This Effective Need was to define an operationally feasible Joint Fires request, coordination, and tasking architecture to provide rapid battlefield effects to the Commander. *This type of request system would allow for fire support that is effects-based rather than fire support that is service-centric*.

Metrics were identified to evaluate the performance of the competing alternatives ability to meet the objectives of the Effective Needs statement. These metrics were: average processing time for a request to be serviced, the pairing effects ratio of tasked providers, and the number of systems, decision points, steps, and process gaps involved in the request-to-task process.

Alternative system architectures were developed that would achieve the objectives presented in the Effective Need. After considering current program development and realistic technological advances, three distinct alternatives were evaluated as feasible architectures for a future joint fire support system.

The Status Quo Plus alternative is an expansion of the current “as is” fire support systems. It is based on the growth path of existing programs of record and published fire support related roadmaps. This system will benefit from improvements in both capabilities and materiel during this timeframe, but it retains most of the current fire support system organizations and processes.

The Centralized Joint Fires Support Network (CJFSN) capitalizes on the DoD transformation to a force with improved communications connectivity. A defining component of this alternative is the Joint Fire Cell. It is the key to horizontal and vertical consolidation of functionally-equivalent organizations. The Joint Fires Cell will receive, acknowledge, process, pair, and task joint fire requests to a provider. This will enable a request for fire to be sent to a single decision-making organization that will collectively choose and task the best joint asset available. Overall processing, pairing, and decision making is expected to be faster because the JFS resource owners are organizationally intertwined and combined.

The Distributed Joint Fires Support Network (DJFSN) represents a fully networked force, enabled to share fire requests and tasking information. This alternative assumes common, fully interoperable Command and Control (C2) data at lower echelon units including battalions, ships, and aircraft. In this alternative, the fire support requests are sent to a fire support database via the Global Information Grid (GIG). All participating fire support providers evaluate engagement capabilities with automated algorithms. Commonality of Command Control, Communication, and Intelligence (C3I) and automated pairing algorithms will allow for selection and tasking of an agreed “preferred shooter.” The Joint Force Commander exercises oversight and command by negation as a participating unit throughout the process.

Qualitative and quantitative modeling and simulation were used to assess the complexity and performance of these alternatives. Overall modeling performance convinced the Project Team to rank the DJFSN as the best system and CJFSN as better than Status Quo Plus.

A subjective assessment of the implementation challenges and operational risks of the alternatives with respect to expected missions was conducted. The team rated each alternative's overall risk by assessing the scope of changes required to implement while simultaneously maintaining current operations. The Status Quo Plus was estimated to have the lowest risk, the CJFSN moderate risk, and the DJFSN was estimated to present the highest implementation risk.

Overall, the DJFSN represents the alternative with the greatest risk to implement but most opportunity for operational benefit. Because of the expected performance, the DJFSN was chosen as the preferred architecture. While Status Quo Plus has little risk to implementation, it also has low expected benefit.

The path to implementing the DJFSN can be achieved at a much lower risk to day-to-day operations by transitioning to a CJFSN first. The CJFSN is the logical first evolutionary step towards the DJFSN. This "build a little, test a little" approach will allow gradual development of the required doctrinal, organizational, and procedural changes.

To implement the CJFSN alternative, the team recommends several changes be made immediately to the realm of Joint Fire Support. The functionally equivalent organizations should be consolidated in order to overcome the cumbersome C2 process of the planned joint fire support organization. The joint responsibilities, and explicit command and decision making relationships, should be clearly established. The tactics, training, and procedures for immediate unplanned fire support should be clarified and integrated into widely-disseminated Joint Tactical Doctrine and Procedures.

Tactical decision aides should be developed in support of capability-based operations. The Joint Fires Cell processing time and efficiency would benefit from these automated tactical decision aides. Additionally, they will form the basis for fully automated prioritization, pairing, and deconfliction algorithms required by the DJFSN alternative.

The DJFSN requires a fully joint common operational picture. To achieve commonality and timeliness of the information, the team recommends a single Joint PEO to provide oversight in the design, acquisition, and fielding of a common interoperable C3I system to enable distributed networked decision making.

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The SEA-10 Joint Fire Support in 2020 Project Team would like to express our thanks and deep gratitude for the time, expertise, guidance, and dedication of the faculty and leadership of the Systems Engineering department, the Wayne Meyer Institute, and the entire Naval Postgraduate School. We are also appreciative and grateful for the patience, understanding, and support of our families during the long hours and lost weekends needed to successfully complete this project.

DEDICATION

This project is dedicated to the legacy of CAPT Stephen Starr King, USN (1955 – 2006). As our faculty advisor for this study, CAPT King generously shared the perspectives and the expertise he had learned during his 29-year Navy career as it pertained to joint fire, and to leadership. As an officer, a gentleman, and a friend, he will be surely missed by all who knew him.

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1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this report is to document and detail the conduct and results of the Wayne E. Meyer Institute's cross-campus study entitled *Joint Fire Support in 2020: Development of a Future Joint Fires Systems Architecture for Immediate, Unplanned Targets.* Conducted at the Naval Postgraduate School (NPS) from July through December 2006, this study was led and managed by students in the Systems Engineering and Analysis (SEA) curriculum and includes the academic efforts and intellectual contributions of numerous members of the NPS student and faculty community. The purpose of the study was to provide insight into the theory and execution of Joint Fire Support in order to improve its application in future conflicts. This project fulfills a major portion of the SEA student's academic requirements to be awarded the Masters of Science degree in *Systems Engineering and Analysis*.

1.2 TASKING

Working with their project advisors, students in SEA Cohort Ten (SEA-10), were tasked to lead a six-month systems engineering and analysis study to investigate alternative architectures to improve the US Department of Defense's (DoD) execution of Joint Fire Support (JFS) in 2020. Stemming from background issued in the Joint Battle Management Command and Control (JBMC2) Roadmap, study and analysis was conducted of JFS concepts as they pertain to the current and planned DoD doctrinal, organizational, and equipment constructs. The broad tasking was to "design a conceptual system of systems to enable future Joint Close Air Support, Time Sensitive Targeting, and Joint Fires missions."[1] The scope of the tasking allowed for exploration of a wide variety of topics to determine an area of study with potential for significant impact or

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[1] Frank. E. Shoup, "SEA-10 Capstone Project Objectives," Naval Postgraduate School, Monterey, CA, 3 April 2006.

insight. Focus areas identified in the tasking were: to identify capability gaps; options for the integration of different service air, surface, and subsurface fires; and to address Concepts of Operation (CONOPS), systems capabilities, and training issues as part of a system of systems for the missions and capability gaps identified.[2]

The diverse professional makeup of the SEA-10 Project Team was significant to the selection of Joint Fires Support as the area of study. The team consisted of four US Navy officers, two US Air Force officers, and one US Army officer. Each member of this unique team brought with them extensive operational experience: in USN and USAF tactical aviation, USN surface and undersea warfare, USN and USA communications and networking operations, and USAF acquisition and aircraft maintenance projects.

In addition to conducting the bulk of the project work, the team led and managed the effort, supported by other student and faculty teams from across NPS. Our team employed the project management tools and methodology studied in their course work at NPS.

1.3 PROJECT METHODOLOGY

The Project Team utilized a Systems Engineering Design Process (SEDP) that fused design and methodology elements from several recognized System Engineering experts, including Buede, Blanchard, Fabrycky, and Paulo.[3] The SEDP is an iterative process that facilitates a methodical approach to a design problem. A tailored SEDP was utilized in the Joint Fires project that was composed of three phases: Problem Definition, Design and Analysis, and Decision Making.

The products of each of the SEDP phases combined to form an overall systems architecture for the project. The systems architecture used follows the

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[2] F.E. Shoup, “SEA-10 Capstone Project Objectives,” Naval Postgraduate School, Monterey, CA, 3 April 2006.

[3] E.P. Paulo, “Systems Engineering and Architecture,” (Class Notes), Naval Postgraduate School, Monterey, CA, 2006.

model attributed to Buede.[4] He describes the overall systems architecture as being composed of a functional, physical, and operational architecture. Throughout the process of developing and assessing the proposed system of systems, the team considered each of the three architectures in the framework of the DOTMLPF model (Doctrine, Organization, Tactics and Training, Materiel, Leadership and Education, Personnel and Facilities).

The purpose of a functional architecture is to provide a framework for all of the interactions within a system and within the environment in which the system will exist. It identifies the connections between all of the functional parts of the system. According to Buede,

> The functional architecture defines what the system must do, that is, the system's functions and the data that flows between those functions. The functional architecture of a system contains a hierarchical model of the functions performed by the system,…a data model of the system's items; and a tracing of input/output requirements to both the system's functions and items.[5]

A physical architecture defines the resources and components which comprise the system identified in the functional architecture. These resources are identified in a "top-down" manner that creates a hierarchical architecture. Buede states,

> The physical architecture of a system is a hierarchical description of the resources that comprise the system. This hierarchy begins with the system and the system's top-level components and progresses down to the configuration items (CIs) that comprise each intermediate component. The CIs can be hardware or software elements or combinations of hardware and software, people, facilities, procedures, and document's. The physical architecture provides resources for every function identified in the functional architecture.[6]

The last architecture to be developed is the operational architecture. The operational architecture combines the elements of the functional and physical

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[4] D.M. Buede, *The Engineering Design of Systems*, John Wiley & Sons, Inc., 2000, p. 175.

[5] Ibid.

[6] Ibid., pp. 215-216.

architectures to completely describe the system design. This architecture is specific enough to begin modeling and conducting analysis of alternatives. Buede describes the operational architecture as follows:

> The development process for the operational architecture is the activity during which the entire design comes together. The operational architecture integrates the requirements decomposition with the functional and physical architectures.[7]

The process of developing these architectures, described in detail in Chapters 2, 3, and 4, enabled us to propose alternative solutions and analyze them during the Design and Analysis Phase. Several alternative system designs were assessed and comparisons included analysis of modeling and simulation results. Details of this process and the modeling performed are described in Chapter 4 of this report. Cost, risk, and reliability assessments are discussed in Chapters 5 and 6. The Decision-Making Phase was the final step in this project, and the rationale and analysis for those decisions are described in the Chapter 7 of this report.

1.4 JOINT FIRES EXPLORATION

Joint Fire Support (JFS) can be most simply described as coordinated fire support from more than one service component. Because of the challenges involved in coordination between services, JFS has historically been an area where the reality of joint operations performance falls short of expectations. According to the Defense Science Board,

> To take advantage of the full potential for joint fires and close air support in a future characterized by non-linear battlespace operations, zero tolerance for fratricide and collateral damage and emerging expanded capabilities in coordinate-seeking weapons (CSW), there must be a commensurate improvement in the

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[7] D.M. Buede, *The Engineering Design of Systems*, John Wiley & Sons, Inc., 2000, pp. 245-246.

> approach that our forces employ in command and control for fires, both within the Services and in joint fire support across Services.[8]

The potential benefits of truly “joint” fire support where all services can potentially interoperate with all other service are enticing. By applying a methodical study process based on a top-down view of this area of opportunity, the Project Team attempted to identify areas of improvement with both Materiel and non-Materiel solutions in the context of the DOTMLPF concept.

1.5 CONCEPT OF OPERATIONS

The modern battlefield contains a wide variety of weapon systems, each with unique capabilities, limitations, tactics, and technology. Employing these weapons, and their associated lethal or nonlethal effects, in a synchronized manner to achieve a desired outcome is the essence of fire support. The weapon systems that will be used to affect JFS operate from different environments (land, air, sea) and may be operated by different service components. The mechanisms by which a commander can improve the synergistic effects of these weapons systems can be anything from a small organizational structure change to the development of large, complex battle management systems. The tactical complexity of this type of situation has challenged past leaders and continues to challenge current efforts to deploy a system that efficiently utilizes all available resources on the battlefield.

As a historical reaction to this complexity, major weapon systems and the fire support they provide have been deployed and controlled along service and functional guidelines. For example, the methodology and routing for requesting artillery support is completely different from the methodology and routing for Close Air Support (CAS) requests. In a similar way, although the methodologies for requesting US Army or Marine artillery support are very similar, the routings of the requests are through different channels. Similar distinctions exist for naval

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[8] Department of Defense, “Report of the Defense Science Board Task Force on Integrated Fire Support in the Battlespace,” Office of the Undersecretary of Defense for Acquisition, Technology, and Logistics, October 2004, p. 55.

fire support providers and close air support, to include a conspicuous separation between the Navy/Marine aviation and Air Force aviation request and tasking systems. Despite the differences in request formats and methodologies, the basic target information is all essentially identical throughout these processes.

These organizational or functional fire support request “stovepipes” were intended to simplify the problem and allow for relatively efficient movement of requests and tasking within the associated systems, but they inhibit the movement of requests and/or tasking across these stovepipes. This placed the burden for selection of a fire support asset on the requesting unit, and assumes the unit possesses the equipment, training, and routing knowledge to send their request. It also required duplication of capabilities *between* stovepipes in order to minimize response time *within* each stovepipe.

The current system can be described using the simplified example in the graphical depiction shown in Figure 1. A forward element, represented by the figure at the bottom of the graphic, has identified a target and determined that fire support is required. In the current system, that forward element must choose a fire support provider and the associated functional stovepipe to send their fire support request through. In this example, the forward element is capable of sending their request through four request pathways: Army artillery, Air Force CAS, Marine CAS, or naval gun fire. There is no way for the forward element to know which request pathway will provide the most effective response, in terms of both response time and response effects. If a request is vetted through a stovepipe and there are no weapons or providers available to service the request, the forward element must then re-send the request through a different stovepipe. These delays and repetitive requests add delays and reduce the effectiveness of the response.

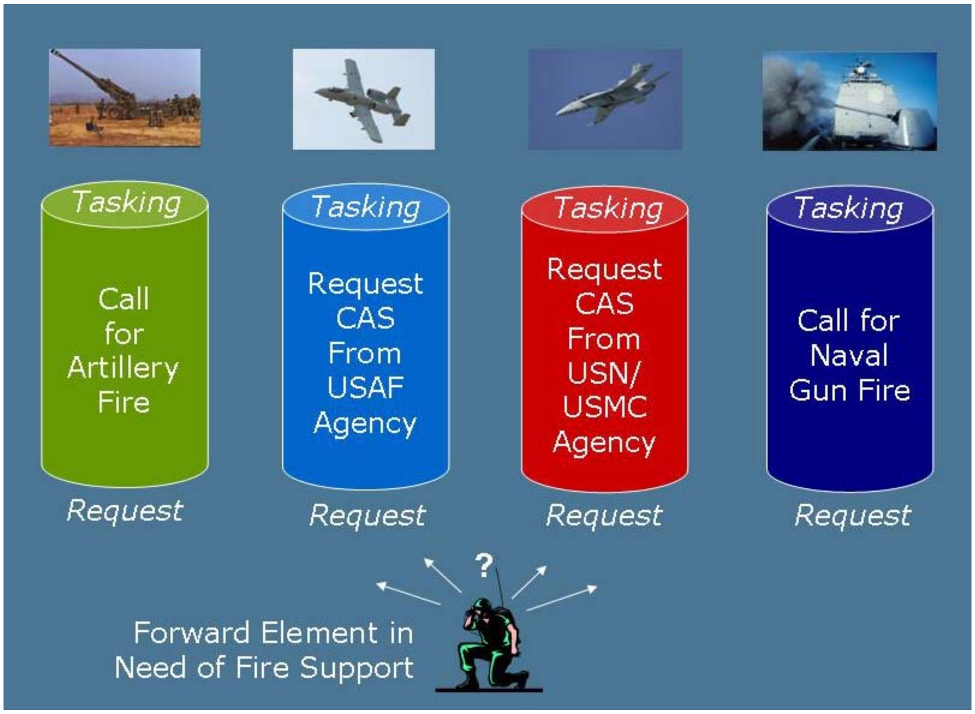

Figure 1: Current Fire Support Request System Stovepipes

An improved concept for Joint Fires should effectively eliminate these stovepipes in order to more efficiently use the wide variety of systems deployed on, above, or near the battlefield. The conceptual design could be built to efficiently pass requests and tasking orders across these functional or service-specific stovepipes, or it could eliminate the stovepipes altogether and route all requests and tasking orders through a single pathway or methodology. A conceptual system that strikes a balance between these two alternatives may be the most effective. This type of system would transition those requests into the appropriate fire support provider stovepipe for tasking and response. In much the same way that a “911” call center connects callers with the appropriate emergency response agency (police, fire, ambulance), this conceptual system could allow all units with compatible equipment to receive any of the available fire support from any available providers. Using the simplified example and available fire support providers shown in Figure 1, the same forward element no longer has to choose the functional stovepipe to contact. The conceptual system shown in Figure 2 allows the requesting element to use a common methodology and routing to send a request for fire support. This request is then tasked to the "best" available provider. The choice of which provider is "best" is defined by numerous factors including, but not limited to: intent of the request and/or the force commander, the availability of the weapon systems, the degree to which the weapons are capable of meeting the requested effect, and the characteristics of the target. *This type of request system would allow for fire support that is effects-based rather than fire support that is service-centric*. This conceptual system could improve the efficiency of JFS; and when combined with the improvements in weapon lethality and precision, it could affect a dramatic increase in JFS effectiveness.

Figure 2: Concept of Operations

1.6 INITIAL PROBLEM FORMULATION AND SCOPE

The transformation of the DoD from traditional roles and equipment into scalable, expeditionary units demands effective JFS. The overall reduction in the organic fire support capability of proposed future ground and littoral forces is driving a requirement for responsive and reliable fire support from any available weapon, regardless of service component. There is an increased risk to any military mission if it cannot get the fire support it needs at the time and place needed. This risk can be reduced through sound operational planning, but not all fire support needs can be anticipated. Military elements that are presented with unplanned opportunities that could benefit from effective JFS may not be able to take advantage of them due to a lack of timely support.

It is essential, therefore, that integrated functional, physical, and operational architectures are developed that efficiently link joint fires requests with weapon system tasking. Within these architectures, the mechanisms and entities processing and tasking the requests to the weapon systems need to be identified and assessed. The most basic needs of such a construct would include speed of response and effectiveness of target-weapon pairings.

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2.0 PROBLEM DEFINITION

2.1 NEEDS ANALYSIS

In order to understand the challenges of designing a joint fires system, the purpose and functions of the proposed system must be completely understood. According to Blanchard and Fabrycky, "The identification of a problem and associated definition of need provides a valid and appropriate starting point for design at the conceptual level."[9] The Needs Analysis that was performed for the Joint Fire Support in 2020 began with the identification of a "desire" for Joint Fire Support that was based on a real deficiency in execution. The remainder of the Needs Analysis translates the "broadly defined 'want' into a more specific system-level requirement."[10] By addressing questions such as: *What are the functions that the system needs to perform?* And *When and how often does the system need to perform these functions?*, the Needs Analysis defines the *WHATs* of the problem and avoids the *HOWs*.[11]

2.1.1 Context and Components

In order to provide a useful and accurate solution, the designer must first completely understand the problem and the context in which it exists. To do this, we must define all of the elements and components that affect the system. Fires are "the effects of lethal or nonlethal weapons" and fire support is defined as "fires that directly support land, maritime, amphibious, and special operations forces to engage enemy forces, combat formations, and facilities in pursuit of tactical and operational objectives."[12] Joint Fires are simply "fires produced during the employment of forces from two or more components in coordinated action toward a common objective."[13] Those fires may be from similar weapon

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[9] B.S. Blanchard and W.J. Fabrycky, *Systems Engineering and Analysis*, 4th ed., Pearson Prentice Hall, 2006, p. 54.

[10] Ibid, p. 56.

[11] Ibid.

[12] Department of Defense, *Doctrine for Joint Fire Support*, Joint Pub3-09, May 1998, p. I-1.

[13] Ibid.

systems like Air Force, and Navy aircraft, or from completely dissimilar weapon systems.

The challenges to joint fires execution may include the weapon tactics, the weapon release authority, or the deconfliction of weapon effects. Joint Fires are not specific to weapon systems or missions, but are defined by their effects and the component source. According to the Joint Pub,

> Joint Fire Support may include, but is not limited to, the lethal effects of close air support (CAS) by fixed- and rotary-wing aircraft, NSFS, artillery, mortars, rockets, and missiles, as well as nonlethal effects such as EW.[14]

A common tool used to describe the necessary sequence of events leading to destruction of a target is called the Find, Fix, Track, Target, Engage, Assess (F2T2EA) model.[15] This sequence of events is often referred to as the "kill chain" and covers the entire lifespan of a target, from discovery through confirmed destruction. Although several DoD components, government agencies, and contractors have defined alternative models to describe this process, the basic process is identical in all of these models. In the context of the F2T2EA model, the proposed system examines the JFS process from the end of the track phase through targeting to the beginning of engagement. The F2T2EA model and the portions of the kill chain studied in this project are shown in Figure 3.

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[14] Department of Defense, *Doctrine for Joint Fire Support*, Joint Pub 3-09, May 1998, p. I-1.

[15] US JFCOM, Joint Networked Fires Capabilities JNFC Roadmap, 30 September 2004, p.10.

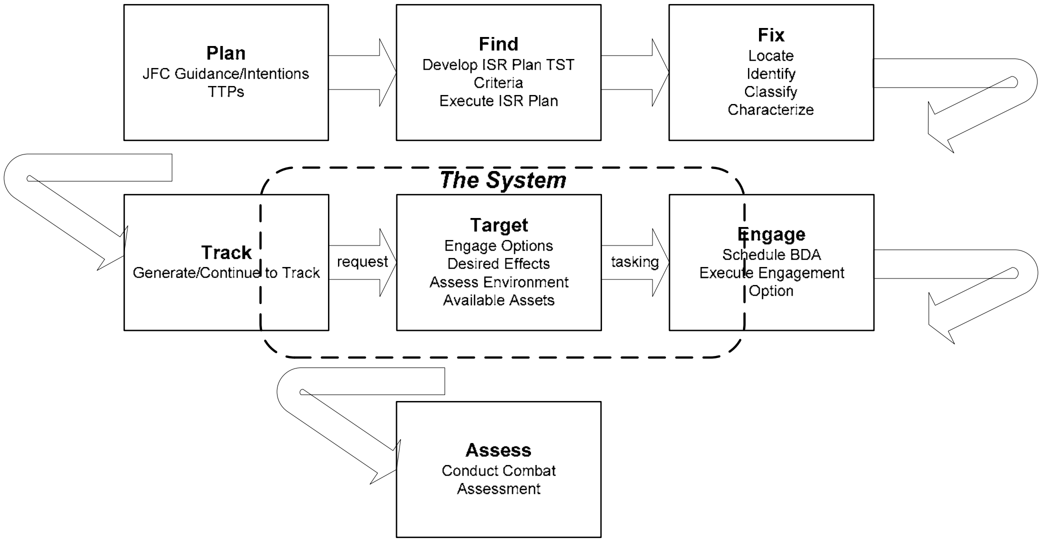

Figure 3: F2T2EA Concept and Design Area

The design challenge of this project was to create a framework for an improved system, but the multifaceted nature of JFS required boundaries on the areas addressed by this study. The scope of this project included the actual request for fire support, but not the means by which the target was found, identified, and tracked nor the methods and equipment by which the necessary request data was compiled into the request. This is the final step of the Track phase. Likewise, future engagements will undoubtedly utilize tactics and weapons that are impossible to predict accurately. For these reasons, this design only included the tasking of the weapon to service a target and not the future hardware that will be used to send and acknowledge the tasking. It also does not specify the methods or tactics by which the target should be engaged or the required outcome from that engagement. This is the first step in the Engage phase. Additionally, this system design does not include a mechanism for Battle Damage Assessment (BDA) of tasked targets or the ability of BDA results to force another engagement of the target.

Another large facet of JFS that was not specifically tackled in this report was the deconfliction of joint fires. Deconfliction of fires is a task that must be accomplished throughout fire support planning, tasking, and execution. This includes not only deconfliction between weapon systems (i.e., artillery and CAS), but also deconfliction between weapons effects and the environment (i.e., fratricide and collateral damage). Deconfliction is an area that requires considerable future study and although this project does not specifically address it, many of the insights gained from this study can be leveraged towards improved deconfliction.

Additionally, the hardware system and methodology used to prioritize requests was not studied in this report. The mechanisms by which the fire support requests will be prioritized are assumed to exist. There are numerous methods for prioritization of requests and a future system will have to be built to perform a prioritization. The choice of the best way to prioritize requests is another area that will require additional study and analysis outside of this report.

2.1.1.1 Evolution of Fire Support

As the lethality and mobility of weapons improves, the process by which those weapons are employed should also improve to take full advantage of new capabilities. JFS, as we think of it today, epitomizes the complexity of modern warfare and its evolution from battles won by virtue of mass towards battles won through synergistic effects. Fire support for forward ground units is not a new concept and it has been, for the most part, the sole dominion of the artillery since well before Napoleon. Although naval gunfire was sometimes used in preparation for a ground assault or amphibious landing, it was not used in concert with ground force maneuvers until much later. In fact, the concept of non-artillery fire support of ground forces was not practiced until the evolution of CAS around the beginning of the 20th century. Until then, the weapons available to each military branch didn't possess enough range and accuracy to effectively support the other and therefore didn't merit the coordination and training involved to do so. Each service component essentially fought by itself—Army supported Army and Navy supported Navy. As a result of this exclusivity, the organizations and procedures for fire support were tailored to the capabilities of the weapons systems being employed. In a simultaneous growth process, the procedures and methods of fire support were developed in parallel with the capabilities of the weapon and communication abilities. This has led to organizations that were built to fit the weapon and integrate it into the service branch. Even today, that legacy continues to an extent in the organizations and control systems being developed to "include" new weapons into the battlespace.

The complexity of executing effective fire support can present daunting DOTMLPF challenges to military leaders that can result in lost or passed up opportunities in training and battle. Despite the expanded capabilities of today's joint fires, military leaders are sometimes reluctant to completely rely on those capabilities or engage the enemy in a way that challenges historical truisms. For instance, despite the plethora of long-range, joint fires available to today's ground commander, they are typically reluctant to advance at a faster rate than their artillery support can sustain. With regard to CAS,

> Recent conflicts in Kosovo, Iraq and Afghanistan have shown Joint Close Air Support successes and failures. Since the evolution of Close Air Support in Vietnam, the Army and Air Force had grown apart. Successes were forgotten and correct doctrine was not documented. Differences in equipment, doctrine, attitude and outlook inhibited integration.[16]

Despite the evolution of equipment on and above the battlefield, for the most part the fire support integration measures and techniques developed during the Vietnam Conflict are still being used today.

The evolution of technology and its proliferation onto the battlefield has enabled changes in the Joint Fires integration processes, but the measures used to integrate those fires have not changed significantly. Due to historical or other reasons, the service components have "paired up" and declared themselves joint; the Army with the Air Force and the Navy with the Marines. Unfortunately, these pairings have not adopted similar organizational structures and methodologies that could also be applied to components outside of the pair. Fires that are truly "Joint" will include and synchronize weapons from across the

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[16] A.E. Lindahl, "Integrating Naval Surface Fire Support into an Improved Joint Close Air Support Architecture," Master's Thesis, Naval Postgraduate School, Monterey, California, June 2006, p. 15.

spectrum of the armed forces, including traditional air power from all service components, artillery, naval fires, guided missiles, and unmanned vehicles. Effective Joint Fire Support will be the fusion of these diverse weapons capabilities and limitations into a usable benefit for the supported commander. Despite this straightforward description, Joint Fires is difficult to execute effectively, primarily due to the number of entities and conflicting requirements involved.

JFS in the future should continue to evolve into a system that is focused on the effects of the weapon instead of the employment of the weapon. This evolved system will be flexible with respect to the weapons available and employed because effects can be applied regardless of the weapon. This approach will enable the service components to standardize and restructure their JFS organizations into units that are built around generic weapon capabilities or functions, not a specific type of weapon.

2.1.2 Existing Command and Control (C2) Relationships

Although sometimes used synonymously, Command and Control are separate functions that are applied simultaneously by the military leader. Command concepts are primarily applied to organization and authority relationships whereas the concepts of Control deal primarily in the flow of information and intent. The Joint Chiefs of Staff define Command and Control as

> The exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission.[17]

C2 systems bring all applicable information together for collation and decision making. C2 systems, personnel, equipment, and a variety of related procedures support the execution of JFS missions. Unity of effort is one of the keys to the

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[17] Department of Defense, *Department of Defense Dictionary of Military and Associated Terms*, Joint Pub 1-02, 12 April 2001, p. 101.

effective coordination of JFS. Vertical and horizontal coordination is also essential for effective JFS. For this reason, service and functional components currently provide a hierarchy of fire support coordinators, fire support coordination agencies, and liaison officers. These fire support entities have one goal in common—to efficiently direct the use of fire support to accomplish the mission. However, the number and sheer variety of C2 systems challenges these entities to comprehend different information from different systems in order to make fire support decisions. For example, the screen displays of a few of the more prevalent C2 systems are shown in Figure 4. Although the information displayed by these systems is similar, the presentation of that information is very different between these systems.

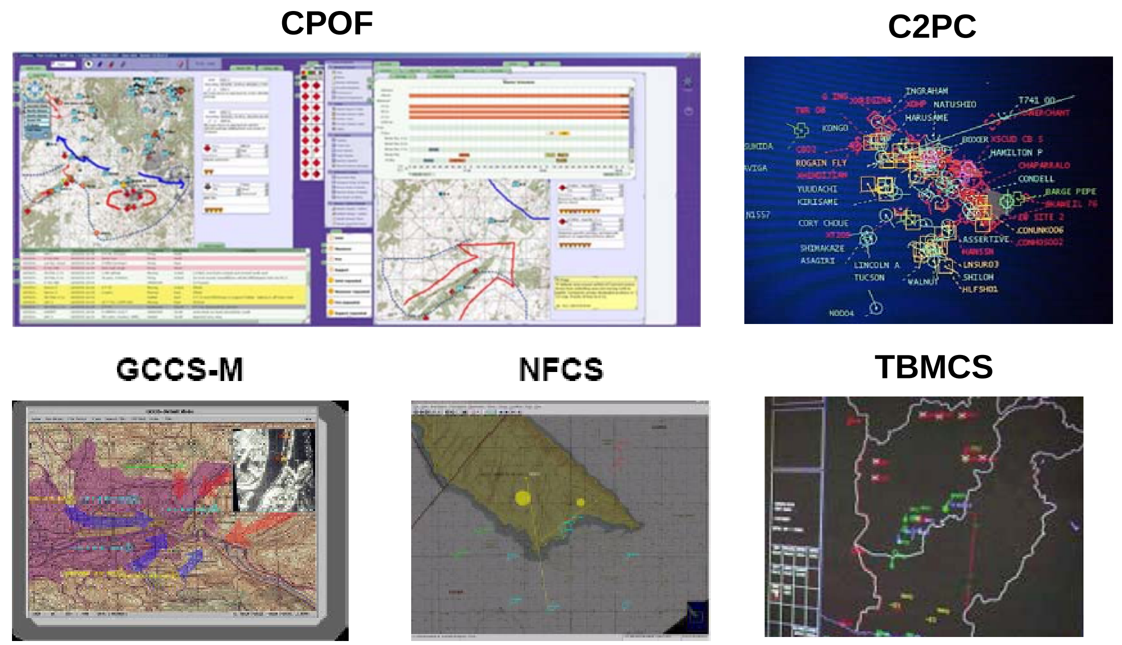

Figure 4: Sample of C2 System Duplicity

Currently, each of DoD’s service components use different C2 systems to manage its operations. For example, the Marine Corps maintains the Command and Control, Personal Computer (C2PC) as its primary C2 system. The Army maintains the Command Post of the Future (CPOF), part of the Maneuver Control System (MCS), at its division level but has separately developed systems at other levels, such as Force XXI Battle Command, Brigade and Below (FBCB2) and Blue Force Tracker (BFT). The Air Force maintains the Global Command and Control System, Air Force (GCCS-AF) and the Theater Battle Management Core System (TBMCS) as its primary C2 systems. The Navy maintains a completely different version of GCCS called Global Command and Control System-Maritime (GCCS-M) as its primary C2 system. However, the Navy also has a capability to receive inputs from TBMCS and is projecting a level of interoperability with C2PC.

The C2 required for JFS requires intensive coordination between affected agencies. Two interrelated functions account for the complexity of this coordination: planning and coordination, and execution planning. The first of these functions is the overall C2 planning process for employing fire support assets within a service or functional component during joint operations. This process includes fire support planning and coordination, tactical fire direction procedures, air operations procedures, and other general supervisory tasks.

The second interrelated function involves the tactical planning required to execute JFS missions. This execution planning provides the requisite technical parameters—including weather data, terrain, target location data, defenses, and weapon system data—needed to deliver accurate JFS. The many different platforms and training and execution requirements set by each of the services complicates the process further. This often leads to a wide variability in the execution of Joint Fires between commanders. For this reason, technical execution planning is normally accomplished within a single service or functional component, although some input of data may come from outside the service or functional component.[18]

2.1.3 Existing Organizational Components

As a result of many years of organizational and leadership refinement, today's military operations are executed under the construct of the Joint Force Commander (JFC). In this chain of command, the JFC is the single responsible

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[18] Department of Defense, *Doctrine for Joint Fire Support*, Joint Pub 3-09, May 1998, p. II-5.

agent for the Joint Force Area of Operations (JFAO). Each military branch which operates within the JFAO aligns its service-specific chain of command under the JFC and provides its most senior leadership to his support staff. Establishing supported and supporting command relationships among or between components helps the Joint Force Commander integrate operations inside the JFAO. Although sometimes challenged by service parochialisms, command relationships are defined and clarified in the Joint Publications issued by the Joint Chiefs of Staff.[19] However, because every theater of operations is unique, the overall military commander must specifically define the command relationships within their area of operations. A generic joint task force upper-echelon command hierarchy is illustrated in Figure 5.

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[19] Department of Defense, *Doctrine for Joint Fire Support*, Joint Pub 3-09, May 1998, pp. 1-95.

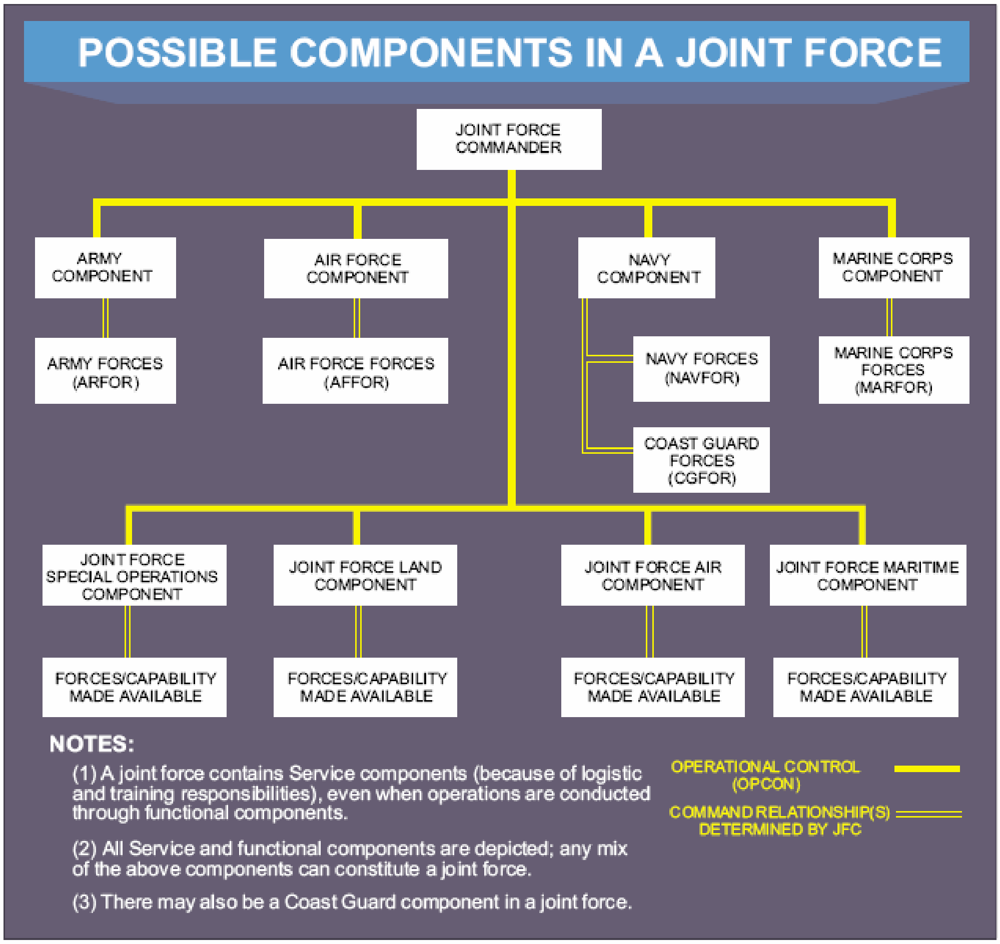

Figure 5: Possible Joint Force Organization (From[20])

Successful military campaigns depend on how effectively all the elements of joint fires are coordinated within a Joint Force Area of Operations. Within the JFAO, a high density of friendly weapons systems and air power vehicles, with overlapping operating envelopes and flight profiles, must contribute maximum combat effectiveness without interfering with each other. All weapon platforms must be coordinated effectively without hindering the blue force combat maneuvers. The JFC, through his component commanders, with the assistance of their staffs, controls the JFAO at the Joint Operations Center (JOC). These staffs are responsible for the organization, personnel, procedures, and

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[20] Department of Defense, *Unified Action Armed Forces (UNAAF)*, Joint Pub 0-2, 10 July 2001, p. V-3.

equipment necessary to plan, direct, and control joint fires operations by coordinating fires amongst the services (and allied forces, when required).

To execute a plan for Joint Fires, it is imperative that the services be flexible, versatile, and have a common understanding of joint doctrinal matters and terminology. Even when speaking the same language, communicating intent jointly across the services has been a stumbling block due to cultural and service differences in terminology and organization and translating the understanding into actionably items that have the intended results. For example, each service has an organization and/or an individual, who plans for the use of air power, controls the function of air defense, coordinates air-to-ground support operations, and coordinates ground fires. Each of these entities performs similar, if not identical, functions within their service but depending on the component, each organization or individual has a different title and command relationship.

The combatant commanders, through subordinate commands, assign responsibilities, establish or delegate appropriate command and support relationships, and establish coordinating instructions to effect Joint Fires coordination. Fire support coordination includes efforts to deconflict attacks, avoid fratricide, reduce duplication of effort, and assist in shaping the battlespace.[21] As an example of the complexity of these relationships, the coordination of air-to-ground fires is connected through the organizations or systems shown in Figure 6. Keep in mind that Figure 6 only shows the lines of authority and communication for air-to-ground fire support (i.e., CAS) and not the entire fire support organization. A complete list of the acronyms used in Figure 6 is provided in Table 1 following the figure.

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[21] Department of Defense, *Doctrine for Joint Fire Support*, Joint Pub 3-09, 12 May 1998, pp. III-11.

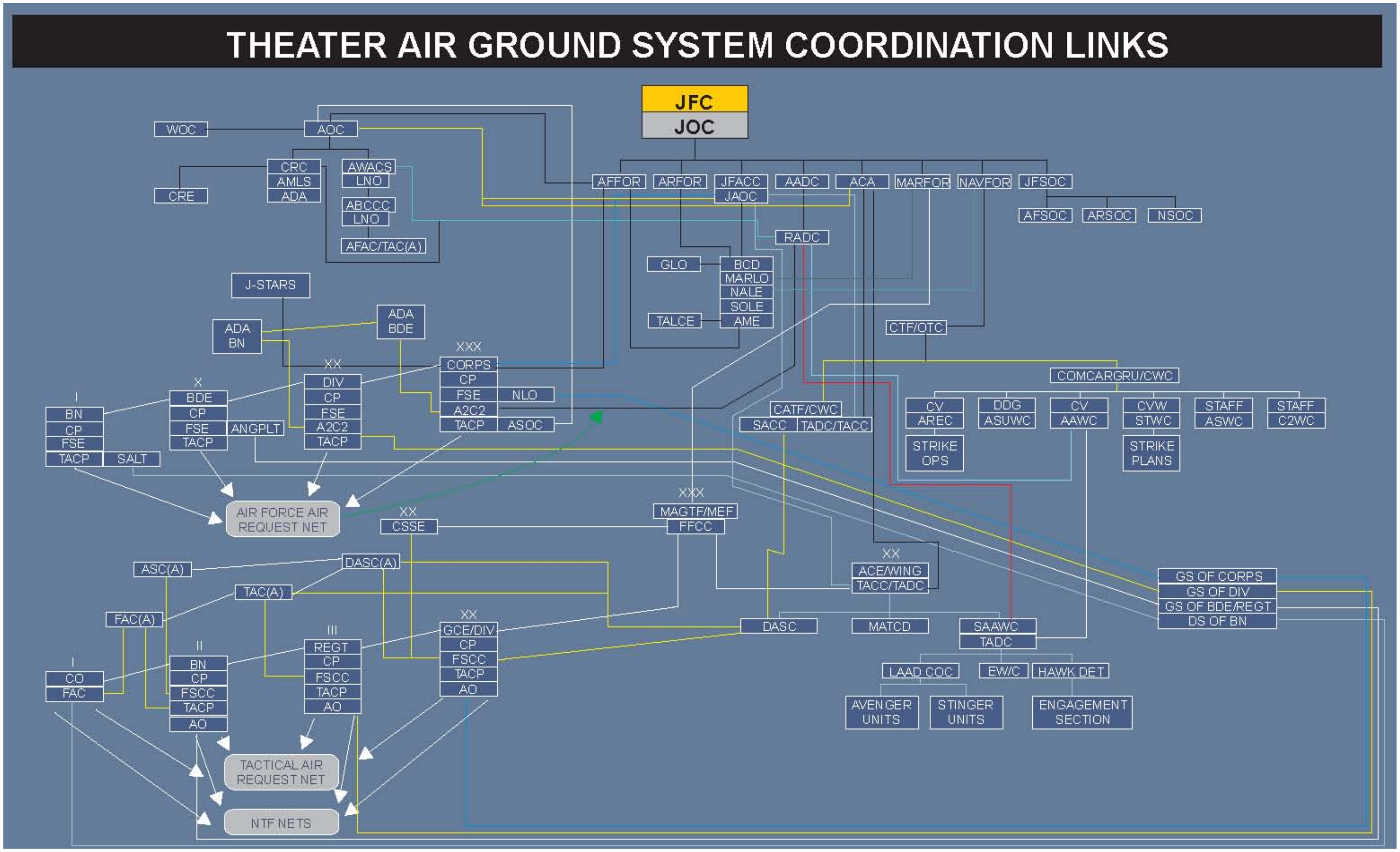

Figure 6: Theater Air Ground System Coordination Links (From[22])

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[22] Department of Defense, *Doctrine for Joint Fire Support*, Joint Pub 3-09, May 1998, p. III-8.

ABCCC	airborne battlefield command and control center
ACE	aviation combat element
ADA	air defense artillery
AFARN	Air Force Air Request Net
AFFOR	Air Force forces
AFSOC	Air Force special operations component
AME	air mobility element
AMLS	airspace management liaison section
AOC	air operations center (USAF)
ASOC	air support operations center
AWACS	airborne warning and control system
BCD	battlefield coordination detachment
BDE	brigade
BN	battalion
CCT	combat control team
CRC	control and reporting center
CRE	control and reporting element
DIRMOBFOR	Director of Mobility Forces
DIV	division
FAC(A)	forward air controller (airborne)
FSCC	Fire Support Coordination Center
GLO	Ground Liaison Officer
JAOC	joint air operations center
JFACC	joint force air component commander
JMCC	Joint Movement Control Center
JOC	Joint Operations Center
JSTARS	joint surveillance, target attack radar system
MAGTF	Marine air-ground task force
MARLO	Marine liaison officer
MEF	Marine expeditionary force
MLE	Marine liaison element
NALE	naval and amphibious liaison element
RECCE	reconnaissance
SF	special forces
SOLE	special operations liaison element
TAC(A)	tactical air coordinator (airborne)
TACC	tactical air command center (USMC); tactical air control center (USN); tanker airlift control center (USAF)
TACP	tactical air control party
TARN	Tactical Air Request Net
TALCE	tanker airlift control element
TADC	Tactical Air Direction Center
WOC	Wing Operations Center

Table 1: Theater Air-to-Ground System Coordination Agencies

In order to better understand these existing organizational components, the following sections (arranged by service component) describe the functions of these key service organizations that advise commanders on the use of Joint Fires.

2.1.3.1 Army Fire Support Organizations

The Army provides the Army Forces Commander (ARFOR) to the JFC staff. ARFOR is responsible for all Army forces within the JFAO and is subordinate to the JFC.

ARFOR establishes a staff to assist him in the execution of his duties. With respect to the coordination of battlefield functions, a Battlefield Coordination Detachment (BCD) is created. The BCD provides direction to subordinate army units and acts as the senior liaison between ARFOR and the other services. The BCD is usually collocated with the Air Operations Center (AOC) or Joint Air Operations Center (JAOC). The BCD is also the army's primary liaison with other specialized functions like the Air Force Air Mobility Element (AME), the Marine Liaison Officer (MARLO), the Naval and Amphibious Liaison Element (NALE), and the Special Operations Liaison Element (SOLE).

The BCD interface includes exchanging current intelligence and operational data. The BCD is not a Fire Support Element (FSE), but acts as the ARFOR senior liaison element and also can perform many fire support functions. Figure 7 illustrates a simplified Army organizational structure for fire support.

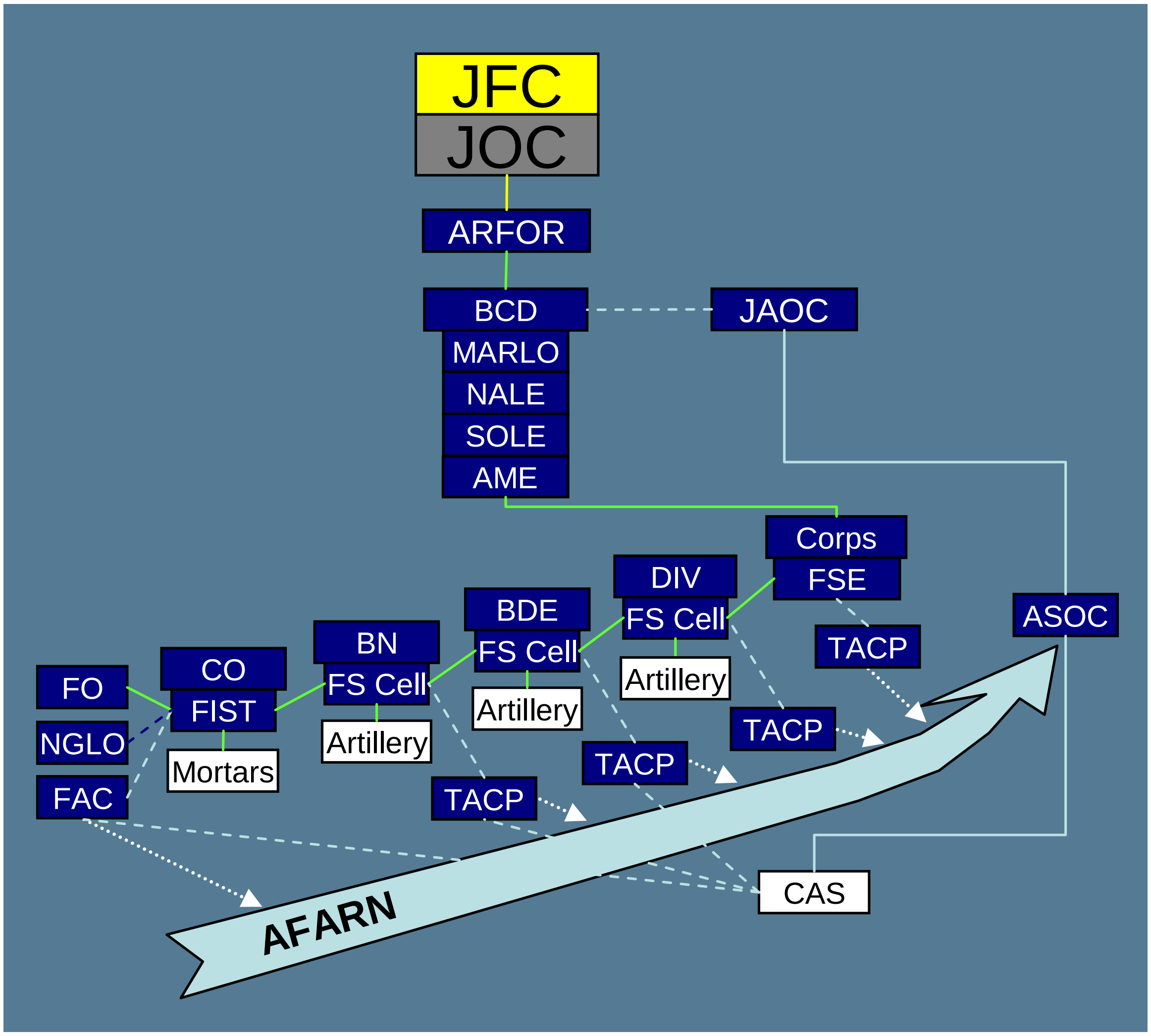

Figure 7: Simplified Army Organizational Structure for Fire Support

At the company level, the basic fire support organization is called the Fire Support Team (FIST). The FIST is led by the company Fire Support Officer (FSO). The FIST coordinates field artillery and mortar fire support for the company. When it is available, the FIST initiates the request and helps coordinate the delivery of CAS and naval fires. In addition to the FSO, the FIST may directly interface with other specially trained personnel such as the Forward Air Controller (FAC), Forward Observer (FO), Air Liaison Officer (ALO), Navy

Ground Liaison Officer (NGLO), Combat Lasing Teams, or others.

At the battalion and brigade levels, the basic fire support organization is called the Fire Support Cell (FS Cell). The FS Cell is led by the Fire Support Coordinator (FSCOORD). Typically, the senior field artillery commander is designated the FSCOORD and therefore serves as the maneuver commander's principal assistant for the integration and application of fire support. The FS Cells coordinate field artillery and mortar fire support for subordinate FISTs and between adjacent fielded units. Additionally, the FS Cell helps coordinate CAS and naval fires. The FS Cells are located in the maneuver Tactical Operations Center (TOC).

The division also maintains a FS Cell. In addition to coordinating artillery and mortar support, these units also support specialized functions like the Deep Operations Coordination Cell (DOCC), coordination with Army aviation units, Electronic Warfare (EW) support elements, Air Force Tactical Air Control Party (TACP) planning, and others.

The Army uses a wide variety of equipment to complete its fire support missions. The equipment fielded today will no doubt be improved in the future. The following discussion of particular systems, in addition to providing a general background in the topic, is designed to outline the desired functions of such systems so they may be reproduced in the overall system design.

In order to conduct coordinated artillery and mortar fire support efficiently, each FIST team is equipped with a Target Location, Designation, and Hand-off System (TLDHS) or similar equipment that is compatible with the Advanced Field Artillery Tactical Data System (AFATDS). The TLDHS allows operators to accurately determine their own location, the location of their targets, and digitally transmit (hand-off) this data to supporting arms elements through AFATDS. Once received by AFATDS, AFATDS terminals at the FS Cell provide fully automated support for planning, coordinating, controlling, and executing fires and effects. The TLDHS and AFATDS combination may be networked from the FIST to the BCD, providing a common operating picture to connected units.

Portions of this network (usually at the battalion and below) are maintained via FM radio links (SINCGARS/JTRS radios) which have low data rates (1-10 kb/s). Above the battalion, more robust connectivity via the TCP/IP backbone significantly reduces network latency. However, since virtually all of the requests for fires originate from a company FIST or a battalion FS Cell, data rates remain a concern.

The primary method to request Close Air Support (CAS) involves a VHF/UHF radio and the Air Force Air Request Network (AFARN). While targeting information may have been collected via TLDHS/AFATDS, the CAS request will be sent by voice and recorded manually onto a DD Form 1972, Joint Tactical Air Strike Request (The AFARN will be described in the Air Force section below).

2.1.3.2 Navy Fire Support Organizations

The Navy provides the Naval Forces Commander (NAVFOR) to the JFC staff. NAVFOR is responsible for all Navy forces within the JFAO and is subordinate to the JFC. Due to the close ties with the Marine Corps, NAVFOR has two primary divisions under him: the Commander, Task Force (CTF), which deals with the fleet, and the Marine Air-Ground Task Force (MAGTF), which deals with all Navy support to the Marine Corps. A Marine Expeditionary Force (MEF) can be compared directly to a MAGTF and their differences have more to do with overall campaign timing than organizational structure.

The CTF has three divisions that cover Navy operations from the shore to the open ocean: the Commander, Landing Forces (CLF), the Commander, Amphibious Task Force (CATF), and the Commander, Carrier Strike Group (CSG). A simplified Navy organizational structure for fire support is shown in Figure 8.

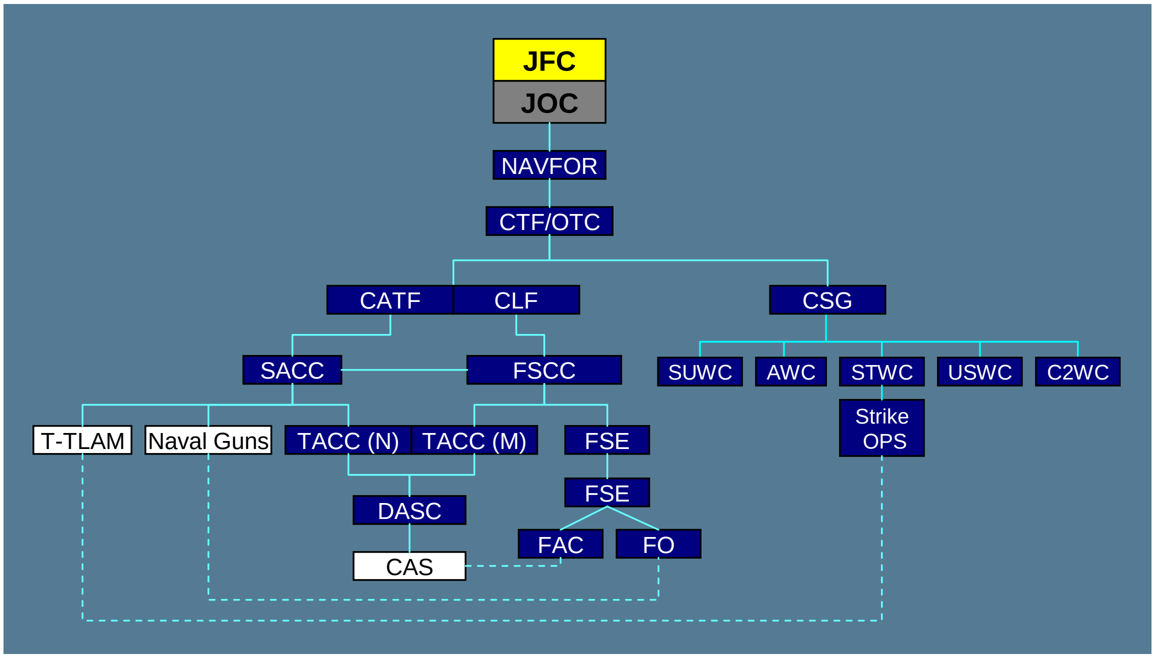

Figure 8: Simplified Navy Organizational Structure for Fire Support

In order to effectively and efficiently address the dynamics of Navy and Marine landing operations, two, cross-service, single point-of-contact organizations have been created. The first of these is the Supporting Arms Coordination Center (SACC), which coordinates all artillery and most naval surface fires. The second is the Tactical Air Coordination Center (TACC), which coordinates air support from Marine or Navy aviation units. The SACC and TACC serve the requirements of both the Navy and Marine Corps. Organizationally, the SACC and TACC usually report directly to CATF, but there are many other formal and informal command and control links which evolve during an operation.

During the initial phase of an amphibious operation, while control and coordination responsibility of supporting arms is still afloat, the Marine Air-Ground Task Force (MAGTF) typically provides the landing force representation in the Navy's Supporting Arms Coordination Center (SACC). Functioning as a Fire Support Element for the naval forces, the SACC is supervised by the supporting arms coordinator.

In an amphibious operation, the Commander, Amphibious Task Force (CATF) exercises the overall responsibility for coordination of Naval

Surface Fire Support (NSFS), air support, and landing force artillery fire support. When the Commander, Landing Force (CLF), normally the MAGTF commander, is established ashore, the CATF may pass this responsibility to the CLF. Once the passage of control ashore is executed, the CLF will coordinate fires within the AO. When control is afloat, the senior naval fire support coordination agency is the SACC. The SACC is then the primary agency that coordinates and controls all supporting fires for the CATF in order to establish the landing force ashore.

Despite the operation of the SACC, control of the naval surface fire assets (i.e., the ships which carry the naval guns, rockets, and missiles) is retained by the CVBG. The carrier battle group maintains strike planning and operations staffs to deconflict SACC direction and to perform specialized support for certain assets. These relationships are further defined in Joint Pub 3-02, “Joint Doctrine for Amphibious Operations,” and Joint Pub 3-02.1, “Joint Tactics, Techniques, and Procedures for Landing Force Operations.”

The Tactical Air Control Center (TACC) controls all air operations within the Amphibious Objective Area (AOA). Like the Air Force Air Operations Center (AOC), the TACC is responsible for planning and conducting Close Air Support (CAS). Its air support control section coordinates with the SACC to integrate CAS and other supporting arms. The organizational relationships of these Navy and Marine organizations are illustrated in Figure 9.

Within the TACC, the Direct Air Support Center (DASC) is the central coordination point for all aircraft support. The DASC assigns direct air support aircraft to terminal control agencies, provides aircraft ingress and egress route instructions, disseminates advisory information, and other key tasks. The DASC conducts its operations via a communications network referred to as the Tactical Air Request Net (TARN).

A number of specially trained personnel are required to provide comprehensive support. The Navy has established the positions of Air and Naval Gunfire Liaison Company (ANGLICO), Naval Gunfire Liaison Officer (NGLO), and Forward Air Controller (FAC).

The Navy has fielded the Naval Fire Control System (NFCS) to assist in the coordination of most naval fires. A few other, stand-alone, systems are required in certain cases. In the future, NFCS should have a degree of interoperability with AFATDS. These systems have significant capability overlap which has been noted by various government agencies including the General Accounting Office.[23]

The primary method to request CAS involves a VHF/UHF radio to send the request via voice over the TARN. While targeting information may have been collected via NFCS or AFATDS (if a Marine unit), the CAS request will be translated by a human operator into a Joint Tactical Air Strike Request.

2.1.3.3 Marine Corps Fire Support Organizations

The Marine Corps provides the Marine Forces Commander (MARFOR) to the JFC staff. MARFOR is responsible for all Marine Corps forces within the JFAO and is subordinate to the JFC.

The Marine Air Ground Task Force (MAGTF) or Marine Expeditionary Force (MEF) command element organizes a Force Fires Coordination Center (FFCC), which is responsible for fire support coordination within the Marine Corps and the primary interface with the SACC for coordinated actions. At each level below the MEF command element (division, regiment, and battalion), a Fire Support Coordination Center (FSCC) is established as an advisory and coordination agency within the Ground Combat Element (GCE). The FFCC and each FSCC is staffed with representatives of the various Marine Corps and Navy supporting arms.

The Marine Tactical Air Control Party (TACP) establishes and maintains facilities for liaison and communications between supported units and appropriate control agencies. An air officer leads the TACP, normally with two teams assigned per maneuver battalion. Their mission is to inform and advise the supported ground unit commander on the employment of supporting aircraft and to request and coordinate air support missions. In addition, the TACP provides final attack control for CAS missions. A simplified Marine organizational

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[23] Department of Defense, *Acquisition of the Naval Fires Control System*, Office of the Inspector General Report No. D-2002-036, January 8, 2002, pp. 1-49.

structure for fire support, including the ties to Navy, is shown in Figure 9.

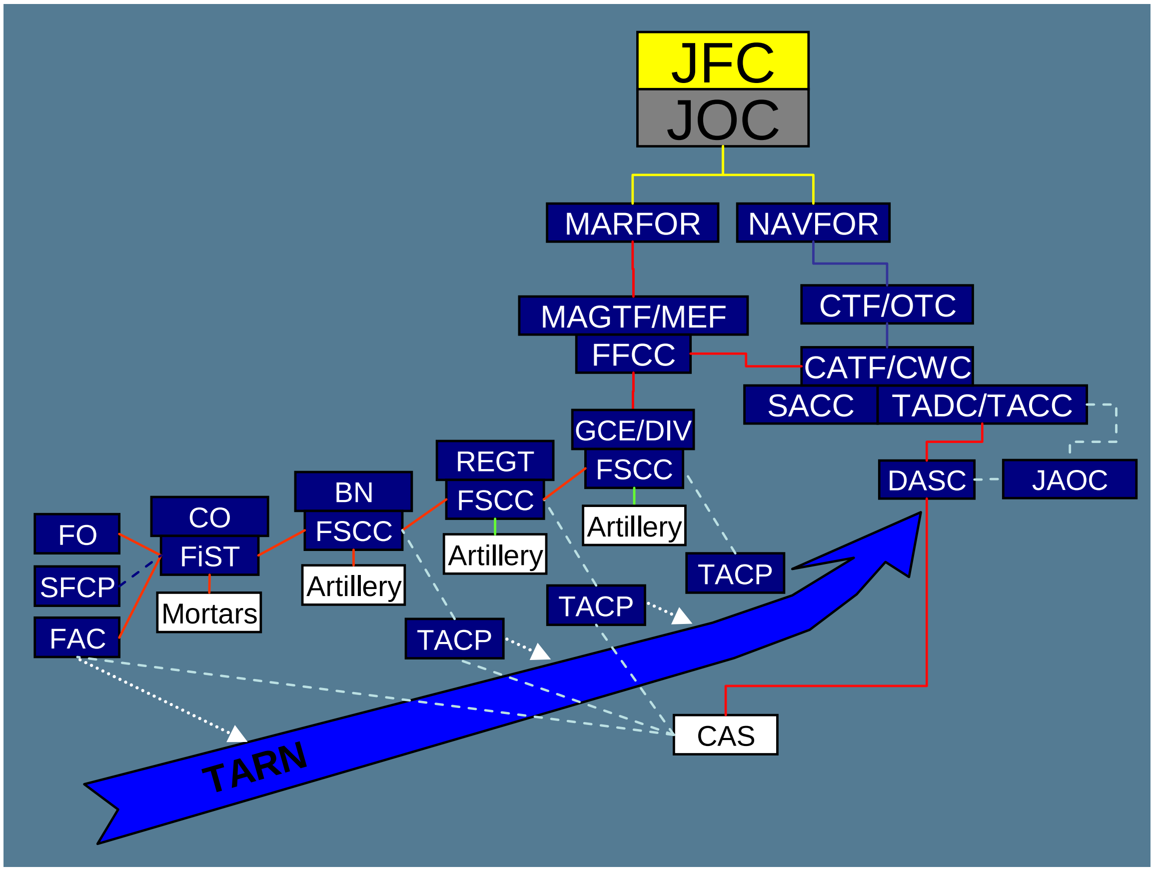

Figure 9: Simplified Marine Organizational Structure for Fire Support

The supporting Marine Corps artillery battalions provide Shore Fire Control Parties (SFCPs) to supported units. The SFCP consists of a liaison team and a spot team. The liaison team is headed by a Navy officer and is located in the supported battalion’s Fire Support Coordination Center (FSCC). The FSCC is a single location that centralizes communications facilities and personnel for the coordination of all forms of fire support. The FSCC is organized and supervised by the FSCOORD and is collocated with, and in support of, the operations officer. The SFCP spot team is led by a Marine Corps officer and is normally employed with the maneuver companies.

There are very few differences in fire support between the Marine Corps and Army below the brigade (Army) and regiment (Marine Corps) levels. Army FSEs and Marine FSCCs are virtually identical in function and the fire support execution methods and data processing equipment used are the same.

Even though they are organizationally tied to the Navy, the Marine Corps has designated the AFATDS, not NFCS, as their preferred system for fires support.

2.1.3.4 Air Force Fire Support Organizations

The Air Force provides the Air Forces Commander (AFFOR) to the JFC staff. AFFOR is responsible for all Air Forces within the JFAO and is subordinate to the JFC.

The Air Force component commander exercises operational control over assigned forces through the Air Operations Center (AOC) or Joint Air Operations Center (JAOC). The AOC implements the Theater Air Control System (TACS). Subordinate TACS elements perform the tasks of planning, coordinating, monitoring, controlling, reporting, surveillance, and executing air operations. This includes creating and distributing the daily plan for flying operations called the Air Tasking Order (ATO). The TACS elements include: the Air Support Operations Center (ASOC), the Control and Reporting Center (CRC), the Control and reporting Element (CRE), Tanker and Air Lift Control Element (TALCE), and TACPs. TACS functions may also be executed from airborne assets such as the Airborne Warning and Control System (AWACS), the Joint Surveillance, Target Attack Radar System (JSTARS), and/or an Airborne Battlefield Command and Control Center (ABCCC). The AOC coordinates CAS and other joint air operations that support land, amphibious, and maritime forces. It does so through the ASOC, TACPs, Forward Air Controllers (FACs), and Air Liaison Officers (ALOs). The following paragraphs describe key Air Force elements that relate to JFS.

The ASOC is the key Air Force TACS agency involved in coordinating CAS for ground forces. It performs coordination, direction, and control of the air effort to support land forces' maneuver objectives, usually at Army corps level and below. The ASOC is an operational component of the TACS, subordinate to the AOC. The ASOC processes requests for "immediate CAS" which have been submitted by ground maneuver forces. These requests are sent via voice over the AFARN in the Joint Tactical Air Strike Request format.

The ASOC also tasks aircraft to service those requests in accordance with command guidance. The established TACS organization between the Air Force and Army elements is depicted in Figure 10.

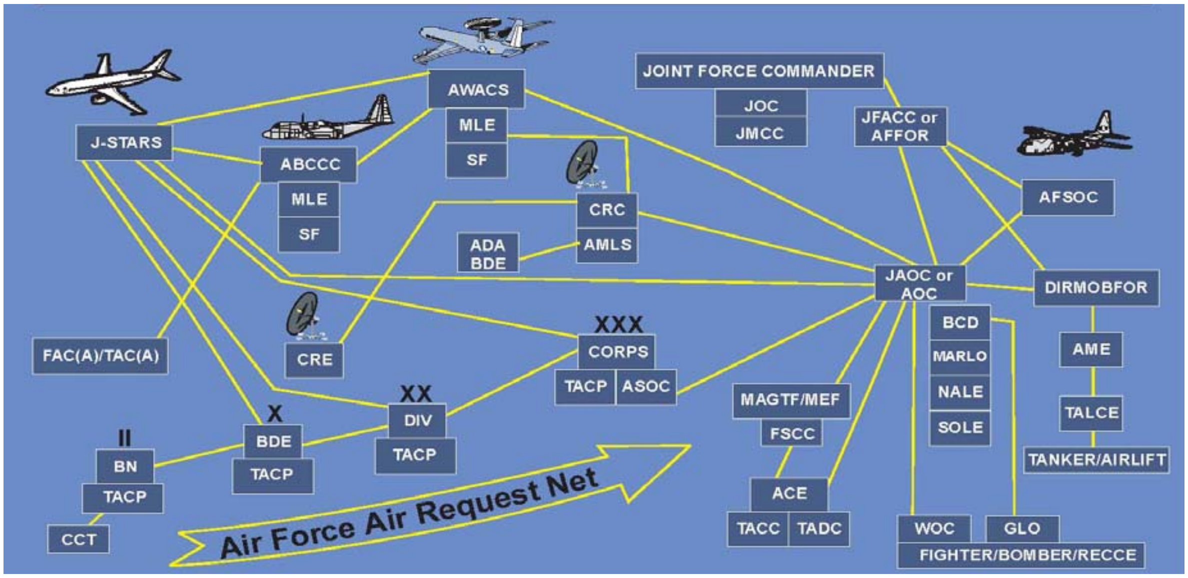

Figure 10: Air Force/Army Coordination Links (From[24])

Additional information on the functions of specific Air Force C2 elements can be found in Joint Pub 3-09.3, "Joint Tactics, Techniques, and Procedures for Close Air Support (CAS)," and Joint Pub 3-56.1, "Command and Control for Joint Air Operations."

The Air Force TACP is a control element usually stationed with and supporting an Army combat unit. Air Force TACPs are not normally aligned with Marine Corps combat units. Located at Army corps, division, brigade, and battalion levels, TACPs are tailored to the unit they support. The TACP provides the interface between the unit it supports and the TACS system. The TACP advises the ground commander on the capabilities and limitations of tactical aircraft and weapons and assists in planning for tactical air support. The TACP also provides final attack control for CAS missions. However, TACPs above brigade do not normally perform Forward Air Controller (FAC) functions.[25]

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[24] Department of Defense, *Doctrine for Joint Fire Support*, Joint Pub 3-09, May 1998, p. II-13.

[25] Department of the Army, *Army Airspace Command and Control in a Combat Zone*, Field Manual 100-103, October 1987, p 1-8.

TACPs are under the operational control of the ASOC or senior TACP element deployed.

The FAC, also known as a Joint Terminal Attack Controller (JTAC), is a member of the TACP who executes control of close air support aircraft and integrates air attacks with fire and maneuver of supported ground forces. He may operate from an aircraft airborne or from a ground position. The FAC maintains contact with the CAS aircraft, other TACS elements, and the appropriate fire support coordinator or ground commander. His airspace functions include coordination of air attacks with field artillery, Air Defense Artillery (ADA), and appropriate aviation elements of the supported force in the target area.[26]

The Control and Reporting Center (CRC) is directly subordinate to the TACC and is the primary TACS radar element concerned with decentralized execution of air defense and airspace control functions. Within its area of responsibility, the CRC directs the region or sector air defense; provides threat warnings to friendly aircraft; provides aircraft guidance or monitoring for both offensive and defensive missions; relays mission changes to airborne aircraft; coordinates control of missions with subordinate TACS elements and other agencies; and provides positive identification of aircraft. During joint operations, the CRC assigns appropriate hostile airborne targets to the Army air defense system through the air defense liaison officer (ADLO) located within the CRC.[27] The AWACS aircraft provides radar control and surveillance of air traffic. It can also function as an alternate CRC and as a limited-capability AOC. As a result of its elevated line-of-sight, the AWACS can establish communication linkages with the ground AOC allowing it to also communicate warnings and surveillance reports to other designated liaison agencies, such as an ASOC.

Joint Surveillance, Target Attack Radar System (JSTARS) is a joint surveillance, targeting, and battle management C2 system designed to provide near real time, wide-area surveillance and targeting information on moving and

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[26] Ibid.

[27] Department of the Army, *Army Airspace Command and Control in a Combat Zone*, Field Manual 100-103, October 1987, p. 1-8.

stationary ground targets. JSTARS is a component of the theater wide battle management system and/or a C2 platform that conducts ground surveillance to develop an understanding of the enemy situation and supports attack operations. These functions support the primary mission of JSTARS, which is to provide dedicated support of ground commander requirements. However, the JFC determines the most effective use of JSTARS based on the situation and the concept of operations.

The Air Force does not have an automated system to process requests for fires that could be closely compared to TLDHS, AFATDS, or NFCS. Wide variation in the installed equipment across the fighter/bomber fleet would create serious interoperability challenges for such a system. JFIIT has compiled a matrix of system compatibility, which is included in Appendix A. While there have been numerous exercises and demonstrations that have, in some fashion, connected the "sensor-to-shooter," none of these solve the problem across the organization.

2.1.3.5 Special Operations Forces Fire Support Organizations

The Joint Forces Special Operations Component Commander (JFSOCC) (or Joint Special Operations Task Force [JSOTF] commander, if established) is the commander within a unified command, subordinate unified, or JTF on the proper employment of SOF. The JFSOCC is responsible for establishing planning and coordinating Special Operations (SO) or accomplishing such operational missions as they may be assigned. The JFSOCC will normally be the commander with the preponderance of SOF and the requisite C2 capabilities. When the geographic combatant commander designates a JFC, the theater special operations command may be designated as the JFSOCC. The JFSOCC exercises overall responsibility for coordination of all fire support in support of SO and, when tasked, fire support using SOF assets in support of other elements of the joint force. A simplified SOF organizational structure for fire support is shown in Figure 11.

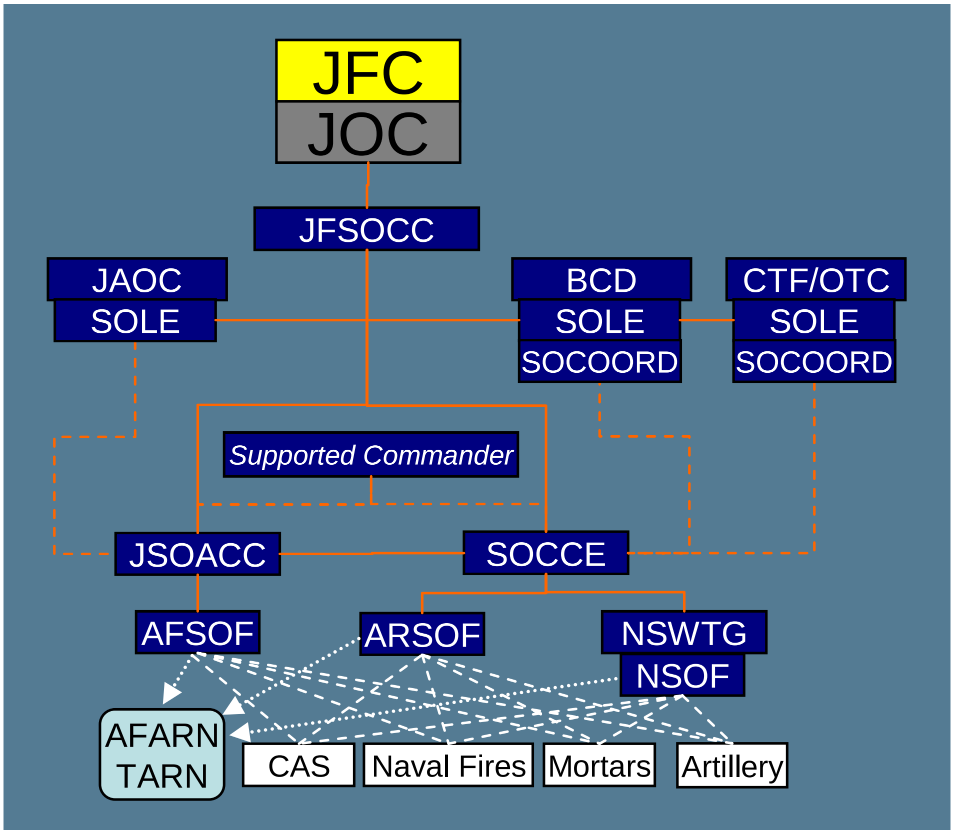

Figure 11: Simplified SOF Operational Structure for Fire Support

The Joint Special Operations Air Component Commander (JSOACC) is the commander within the joint force special operations component responsible for planning and executing joint special air operations and for coordinating and deconflicting such operations with conventional, non-SO air activities. The JSOACC normally will be the commander with the preponderance of assets and/or greatest ability to plan, coordinate, allocate, task, control, and support the assigned joint special operations aviation assets. The JSOACC may be subordinate to the JFSOCC (or JSOTF commander) or to any non-SO component or directly subordinate to the JFC. The Special Operations Command and Control Element (SOCCE) is the focal point for the synchronization of SOF activities with land and maritime operations. The SOCCE is normally employed when SOF conduct operations in conjunction with a conventional force. It is collocated with the command element of the supported commander and performs C2 or liaison functions directed by the JFSOCC (or JSOTF commander). The focus of the coordination is on the synchronization of effects and deconfliction of fires. To do this, the Special Operations Liaison Element (SOLE), who works directly for the JFSOCC, places liaison officers where required with the JFACC and/or JFC staff as appropriate within service component C2 facilities and operations centers. The SOLE coordinates during development of the ATO to reconcile duplicate targeting, resolve airspace deconfliction, and prevent fratricide of SOF contingents spread across the battlefield.

Naval SOF assigned to the JFSOCC are normally under the C2 of a Naval Special Warfare Task Group (NSWTG) or Naval Special Warfare Task Unit (NSWTU). The NSWTG is a naval special warfare organization that plans, conducts, and supports SO in support of fleet commanders and JFSOCCs (or JSOTF commanders). The NSWTU is a subordinate unit of a NSWTG.

The Special Operations Coordination Element (SOCOORD) serves as the primary advisor to an Army corps or MEF commander with regard to SOF integration, capabilities, and limitations. The SOCOORD is a functional staff element of the corps (or MEF) operations officer (G-3) and serves as the J-3 SO advisor, with augmentation, if the corps (or MEF) is established as a JTF.

2.1.3.6 Summary of Existing Fire Support Organizations

Each of the services has tailored its own organizations, personnel, and systems/equipment to aid them in prosecuting targets. This has resulted in duplicate systems and agencies. In many instances, direct comparisons between organizations can be made both in terms of capabilities and span of control. Additionally, the diversity of these systems and organizations has created personnel training requirements that are different but parallel. The understanding that an Army FS Cell is functionally comparable to a Marine Corps FSCC would come easily to all involved. However, in some areas, like in C2 systems of record and favored fires support systems, the differences are designed into the system and much harder to reconcile. For example, if each service uses different information systems to maintain their C2 common operating picture, no one can be certain that decisions made across the services have comparable quality. Even if the input data to these systems is identical, the different presentations and functions may not permit comparable analysis by the decision makers. The growth of unmanned systems, especially unmanned vehicles, continues to complicate these C2 systems further. A comparison of the C2 differences between the services is illustrated in Table 2.

	Air Force	Army	Marine Corps	Navy
Fielded Personnel	**Forward Air Controller (FAC), Forward Air Controller - Airborne (FAC-A), Tactical Air Control Party (TACP)**	**Fire Support Officer (FSO), Forward Observer (FO), Air Liaison Officer (ALO)**	**Shore Fire Coordination Party (SFCP), Tactical Air Control Party (TACP)**	**Forward Air Controller (FAC), Forward Air Controller - Airborne (FAC-A), Navy Ground Liaison Officer (NGLO)**
Ground Organizations (Mortar / Artillery type fires)		**Fires Support Team (FIST), Fire Support Cell (FS Cell), Fire Support Coordination Center (FSCC)**	**Fire Support Element (FSE), Fire Support Coordination Center (FSCC), Forced Fires Coordination Center (FFCC), Supporting Arms Coordination Center (SACC)**	**Supporting Arms Coordination Center (SACC), Air and Naval Gunfire Liaison Company (ANGLICO)**
Air Organizations	**Air Support Operations Center (ASOC), Air Operations Center (AOC)**	**Fire Support Coordination Center (FSCC), Battlefield Coordination Detachment (BCD)**	**Tactical Air Control Center (TACC)**	**Direct Air Support Center (DASC), Tactical Air Control Center (TACC)**
Others	**Special Operations Liaison Officer (SOLE)**	**Ground Liaison Officer (GLO)**	**Marine Air Liaison Officer (MARLO)**	**Navy and Amphibious Liaison Officer (NALE)**
C2 Systems of Record	**Global Command and Control System (GCCS) and Theater Battle Management Corps System (TBMCS)**	**Command Post of the Future (CPOF)**	**Command and Control, Personal Computer (C2PC)**	**Global Command and Control System - Maritime (GCCS-M)**
Fires Support System	**See JFIT capability matrix (Appendix A)**	**Target Location, Designation, and Hand-off System (TLDHS), Advanced Field Artillery Tactical Data System (AFATDS)**	**Target Location, Designation, and Hand-off System (TLDHS), Advanced Field Artillery Tactical Data System (AFATDS)**	**Naval Fires Control System (NFCS)**

Table 2: Parallel Organizational Structures

2.2 CURRENT FIRE SUPPORT REQUEST SYSTEM

Within the organizational structure of these units there are processes and methodologies for requesting fire support. There are currently three basic categories of fire support request systems in the DoD: Land-Based Indirect Fire

Support, Naval Fires Support, and Close Air Support. Each of these categories utilizes a different fire support request system or method and often has service-specific differences within each functional category.

Land-based Indirect Fire Support is lethal or nonlethal fires that are provided to a forward element from an artillery or rocket battery within weapons range. For the purposes of this study, this fire support comes from another unit and does not include indirect fire systems that are organic to the requesting unit, such as mortars. Land-Based Indirect Fire Support is discussed in further detail in Section 2.2.1.

Naval Fires Support is lethal or nonlethal fire support provided to a forward element by a naval vessel. This category of fires typically encompasses naval gunfire from surface ships, but can also include missiles launched from subsurface assets. It does not include naval aviation strike assets. Naval Fire Support is described in further detail in Section 2.2.2.

Close Air Support is fire support from the air by fixed and rotary-wing aircraft against targets in such close proximity to friendly forces that detailed integration with the fire and movement of those forces is required. CAS is currently being employed by all service components, although Army doctrine refers to it as “Close Combat Attack” instead of CAS.[28] CAS request systems also vary between services. CAS is described in detail in Section 2.2.3.

Each of these individual fire support request systems has been doctrinally established to work independently of the others and they do not possess a robust capability to interface with the other systems. With few exceptions, there are no established capabilities to redirect a request to another fire support category if for some reason it cannot be fulfilled by the requested method. These request systems are isolated in both communications and organizational pathways. Complicating the situation, the service components are not doctrinally obligated to provide support equally to the other services. Section 2.2.4 describes the

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[28] T. Crutchfield, W.T. Golden, IV, and T. Throne, Jr., "Close Combat Support," [http://www.globalsecurity.org/military/library/report/call/call_00-9_part1.htm], Sep 06.

challenges to the current JFS request routing system. A simplified summary of doctrinal fire support roles and missions obligations is shown in Table 3.

DOCTRINAL ROLES FOR FIRE SUPPORT		**Army** Provides Fire Support to:	**Navy** Provides Fire Support to:	**Air Force** Provides Fire Support to:	**Marine Corps** Provides Fire Support to:
SUPPORTED UNIT	**Army**	**Army**	Collateral Support	Primary Mission	Collateral Support
	Navy	No Doctrine	**Navy**	Collateral Support	Primary Mission
	Air Force	Collateral Support	No Doctrine	**Air Force**	No Doctrine
	Marine Corps	Collateral Support	Primary Mission	Collateral Support	**Marine Corps**
	SOF	Primary Mission	Primary Mission	Primary Mission	Primary Mission

Table 3: Summary of Service Doctrinal Obligations for Fire Support

2.2.1 Land-Based Indirect Fire Support

In land warfare, the generation of maximum combat power results from the most efficient use of firepower. Firepower is defined as the battlefield effects produced by all weapons and attack systems available to the force commander. Many of these weapons and attack systems are in the category of land-based indirect fire support. Army Field Manual 6-20 describes fire support as follows:

> Indirect fire support is the collective and coordinated use of land-based indirect-fire weapons, and other lethal and nonlethal means in support of a battle plan. Fire support includes mortars, field artillery, air defense artillery in secondary mission, and air-delivered weapons. Nonlethal means are EW capabilities of military intelligence organizations, illumination, and smoke. The force commander employs these means to support his scheme of maneuver, to mass firepower, and to delay, disrupt, or destroy enemy forces in depth. Fire support planning and coordination exist at all echelons of maneuver. Fire support destroys, neutralizes, and suppresses enemy weapons, enemy formations or facilities, and fires from the enemy rear area. In most land-based large-scale conflict, fire support systems such as field artillery or mortars could be the principal means of destroying enemy forces.[29]

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[29] Department of the Army, *Fire Support in The Airland Battle*, Field Manual 6-20, May 1988, p. 1-2.

A typical unplanned request for Army artillery support from an Army unit should follow the chains of command and communication as detailed below and shown in Figure 12.

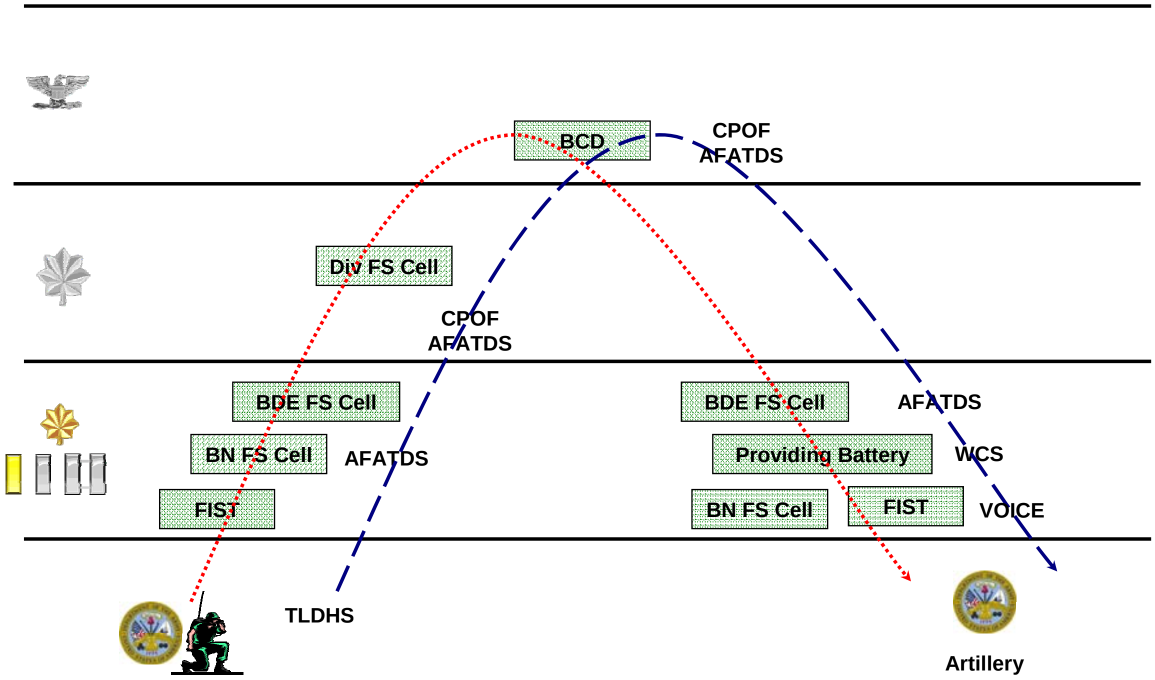

Figure 12: Typical Request Routing for Army Unplanned Artillery Support

A soldier alerts the company FIST team of a target. A TLDHS is used to accurately fix the target position. The TLDHS data is transferred into AFATDS and additional target information is added as required. The AFATDS file is transmitted up the organizational chain of command via a radio network (EPLRS, JTRS, or other). The AFATDS file is reviewed within the battalion, brigade, and division as required. At the brigade level and higher, C2 information from the CPOF system is also reviewed. The FSCOORD within the division FS Cell determines which artillery battery should provide support and assigns the tasking.

At this point, the artillery battery receives the AFATDS file for action and other organizations, like the BCD or involved FS Cells, also can review the updated file for their information. Up to this point, the target data has remained in the AFATDS system and has been transmitted via radio networks. However, within the artillery battery's Fire Direction Center, key data from the AFATDS file (i.e. target coordinates, etc) are now re-entered into the artillery control system. Additionally, the artillery battery must now make voice contact with the originating FIST team to coordinate the fire mission. Voice communications confirm the firing solutions and ordnance type, etc. This process is described in Figure 13.

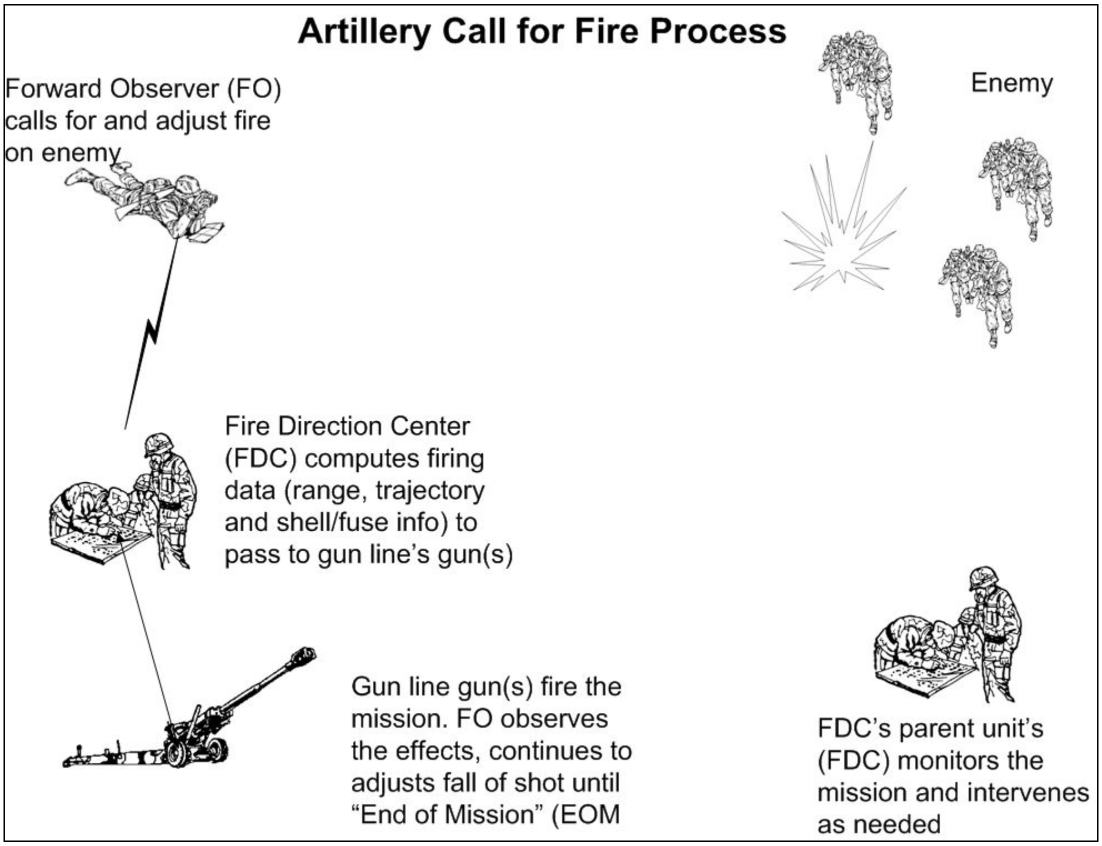

Figure 13: Artillery Call for Fire Process (After[30])

For planned fires, this organizational construct may be tailored to a more direct connection from the FIST or FS Cell to the artillery battery. However, for unplanned fire support, coordination through the division FS Cell and FSCOORD are required. In any event, even in the more complicated case, decision making is completed at a maximum of the O-5 level and the majority of the steps are completed within the AFATDS system.

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[30] Department of the Army, *Tactics, Techniques, and Procedures for Observed Fire*, Field Manual 6-30, July 1991.

2.2.2 Naval Fire Support

Naval Fire Support includes all weapons, other than naval aircraft, that are launched from the maritime environment. This includes naval gunfire from surface ships and missile fires from surface and subsurface ships. Naval guns are employed from cruisers (CG-47 class with two 5-inch guns) and destroyers (DDG-51 with one 5-inch gun; and DD-1000 with two 155 mm or 5-inch guns planned). Tomahawk Land-Attack cruise Missiles (TLAM) can be launched from cruisers, destroyers, and submarines, depending on loaded inventories.

Employment of naval fires support currently requires a qualified forward observer team (FO) ashore to propose a target to the applicable Fire Support Element (FSE). This request is forwarded up the chain of command (Marine Corps) to the senior FSE known as the shore based Fire Support Coordination Center (FSCC). A Forced Fire Coordination Center (FFCC) may also exist at the MAGTF/MEF level.

The FFCC directs both the TACC (for air support) and regiment or battalion FSE (for artillery and naval guns). To provide naval gun fire support, the FFCC contacts the navy Supporting Arms Coordination Center (SACC) to have a ship tasked for support of the request. The ship is assigned to support the requesting FO either for a single mission, a designated period of time, or until further notice. The ship then establishes radio communication with the FO and provides fire support as requested. When an FSCC is not established ashore, the forward observers report directly to the SACC. Ships will then typically be pre-assigned as gun fire support units and will be available for tasking by designated FO.

TLAM employment is directed by the Commander, Joint Task Force (CJTF) strike cell. A formalized record message exchange, along with mission plans are sent to the ship and the weapons are employed as directed. Employment of tactical Tomahawk missiles is expected to be ordered by the CJTF to the JFMCC then the ship or submarine. The initial request for fires would come from the forward observer, be validated at the CJTF level then tasked. If release authority and mission planning software was available to the SACC (or firing unit), the communication flow would follow that used for naval gunfire.

Current employment of naval guns in a fire support role closely resembles the employment of artillery. A qualified forward observer establishes and authenticates radio contact on a specified frequency with the pre-designated fire support ship. Calls for fire are passed via voice to the ship and repeated back to the observer to ensure that they were correctly understood. The coordinates are entered into the gun weapon system aboard the ship, which calculates aiming parameters, and spotting round(s) are shot. Corrections from the impact of the spotting round(s) are passed by voice from the forward observer and additional spotting shots, if required, are made until the aim point is correct. The target is then engaged with the requested volume and type of fire.

Errors in initial round impact stem from a variety of sources. Position error of both the ship and forward observer even with GPS can be several meters. Accuracy of the map in regards to the datum used will also introduce errors in positioning. Aerodynamic effects on the round, especially at longer ranges achieved by the new Extended Range Guided Munitions (ERGM) may not be consistent throughout the fires mission and cannot be perfectly evaluated prior to shooting. Precision in the quality of the target position is inherently difficult due to equipment limitations. Laser range finder accuracy in range determination is very good, but the lack of portable laser ring gyroscopes limits bearing accuracy to that obtainable by a digital magnetic compass. These errors combine to produce a “danger close” range of 750 meters which require direct communication between the firing ship and forward observer to “walk” the spotting rounds onto the target.[31]

The installation of the Mk 160 5-inch/62 caliber upgraded gun weapon system on cruisers and destroyers, along with the automated Naval Fires Control System (NFCS) provides a digital interface from the forward observer to the

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[31] Department of the Army, *Tactics, Techniques, and Procedures for Observed Fire*, Field Manual 6-30, July 1991, p. 4-4.

SACC and fire support ships. NFCS receives and processes digital data requests from various USMC fire support systems via radio frequency data links from a Military Ruggedized Tablet (MRT) or Personal Digital Assistant (PDA)-based system via AFATDS or directly depending upon specific system configuration. Fire missions are planned within NFCS and tasked to the support ships. NFCS also displays a common operational picture of the littoral area of operations and highlights conflicts of air, sea, and land assets with respect to fires response.[32]

NFCS is used along with AFATDS and Command and Control Personal Computer (C2PC) to maintain a coherent operational picture of the battlespace. Transfer of data between these systems is transitioning to a fully automated digital information exchange. Data link information is also received from USAF Theater Battle Management Core System (TBMCS) Air Tasking Orders and Air Control Orders. NFCS displays conflicts with air assets along the 5-inch projectile flight path, but these displays are dependant upon the quality of the inputs for aircraft positions from these other systems and operator interaction. One advantage of naval surface fires is the ability to reposition the firing ship. This action may allow for a suitable gun-target line to resolve airspace conflicts.

Another Naval Fire Support weapon is the Tomahawk. Improved TLAMs and the Tactical Tomahawk variants are both expected to be in the inventory in 2020. Currently, TLAM missions are designed by planning system detachments, either land-based or afloat on the carrier. The mission data is then sent to the shooter (surface ship or submarine) via tactical data link along with the tasking and authority to fire. Ship's company plots the missile flight path to the first pre-planned waypoint, ensuring the missile is deconflicted with nearby air and naval traffic, and fires the TLAM. Planned improvements in the Tomahawk Afloat Planning System (TAPS) will allow the battle group commander to plan or modify TLAM missions while at sea.[33]

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[32] G. T. Kollar, "Naval Fire Control System," *Field Artillery*, March/April 2005.

[33] Federation of American Scientists, "MK 37 TOMAHAWK Weapon System (TWS), Afloat Planning System (APS), Theater Mission Planning Center (TMPC)," [http://www.fas.org/man/dod-101/sys/ship/weaps/tmpc-aps.htm], Oct 06.

"Tactical Tomahawk has the capability to be reprogrammed in-flight to strike any of 15 preprogrammed alternate targets or redirect the missile to any Global Positioning System (GPS) target coordinates".[34] This capability for GPS targeting allows for rapid mission planning to be conducted by the firing unit (CG/DDG/SS(G)N) as a potential time sensitive fire support response. While this planning and re-tasking option will reduce the time required for response, the TLAM as a weapon is not well-suited for un-planned targets. One reason for this is the subsonic fly-out of the TLAM that limits response time, especially for long range targets. Although the range of a TLAM is nearly 1000 miles, at 600 mph only targets within 100 miles could be reached within 10 minutes. "Tactical Tomahawk will have a limited capability against time-sensitive targets. Unlike an armed unmanned aerial vehicle or the unmanned combat aerial vehicle, Tactical Tomahawk cannot be recalled, and its ability to loiter over the battlefield is limited by its relatively short endurance."[35]

In a typical request for Naval Surface Fires from an ashore Marine Corps combat element should follow the chains of command and communication as shown in Figure 14.

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[34] Federation of American Scientists, "BGM-109 Tomahawk," [http://www.fas.org/man/dod-101/sys/smart/bgm-109.htm], Oct 06.

[35] S. Morrow, "What Comes after Tomahawk?," *Proceedings*, retrieved on October 2, 2006, from www.usni.org/Proceedings/Articles03/PROmorrow07-2.htm, July 2003.

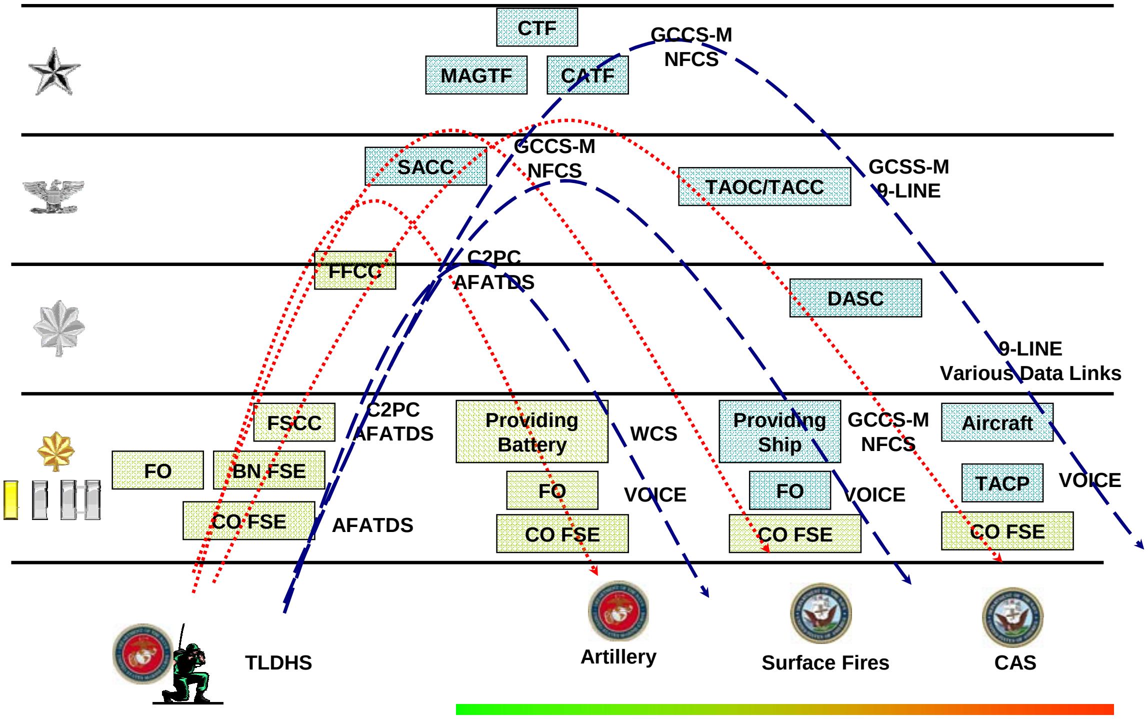

Figure 14: Marine Requests for Artillery or CAS

The Marine Corps GCE uses a TLDHS to accurately fix the target position. As before, the TLDHS data is transferred into AFATDS where additional target information is added as required. The AFATDS file is transmitted up the chain of command to the battalion, regiment, and division FSEs, the FSCC, and/or the FFCC via a radio network (EPLRS, JTRS, or other). At the FFCC, for a Marine Corps-only scenario, C2 information from the C2PC system is also reviewed. If this fires request will involve naval surface fires, C2 information from GCSS-M is also considered.

For the case where Marine Corps mortars/artillery will support, the FFCC director tasks the appropriate providing battery. Again, while the AFATDS file is forwarded to the providing battery, key targeting data is re-entered into the artillery weapon control systems. Also, a voice link from the providing battery to a forward observer (usually in the originating FSE) is established to coordinate the fire mission.

For the case where Naval Surface fires will support, the FFCC must interface with the SACC. At this point, the original AFATDS request is re-entered into NFCS. GCSS-M is also reviewed. Once the SACC decides on a course of action for potential NSF support, leadership for the MAGTF, CATF, and or CTF must be notified (also known as the Supported and Supporting commanders in some theaters). A tasking message for the Commander of the providing ship is generated and the NFCS targeting information is passed to that ship via standard ship-to-ship communication networks. The providing ship makes voice contact with a FO within the requesting organization to direct fires. The CAS case will be described in the following section.

In the Marine-supporting-Marine example, decision making is completed at a maximum of the O-5 level and the majority of the steps are completed within the AFATDS system. However, in order to get support from the Navy, the level of leadership complexity increases to the O-7 level with a corresponding number of extra steps. From a communications/networking perspective, re-entering the data into NFCS and the integration of a separate C2 system, GCCS-M, is problematic. It is unlikely that a Marine FO, using his AFATDS system, will be completely in synch with the providing ship, using its NFCS system. So the coordination step requires comprehensive voice communications support, which is often difficult for ship-to-shore message traffic. The same dilemma is posed by using different C2 "systems of record" which, by definition, display information differently.

2.2.3 Close Air Support

According to Joint Pub 3-09.3, "CAS is air action by fixed- and rotary-wing aircraft against hostile targets that are in close proximity to friendly forces and that require detailed integration of each air mission with the fire and movement of those forces."[36] CAS includes a variety of weapons delivered from Air Force, Navy, and Marine Corps aircraft. These weapons include guided and unguided bombs, rockets, and missiles as well as nonkinetic effects delivered by aircraft. CAS effects on the target vary dramatically according to the weapons employed and the platform that employs them.

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[36] Department of Defense, *Joint Tactics, Techniques, and Procedures for Close Air Support (CAS)*, Joint Publication 3-09.3, Change 1, 2 September 2005, p. GL-7.

Close Air Support engagements are inherently difficult to perform well due to coordination and integration challenges. This employment difficulty stems from several sources, including the physical differences between the land and air environments, the contrasts in equipment speeds, and the communications challenges between these two settings. These are some of the many reasons why CAS employment typically requires a qualified FAC or JTAC who is intimately familiar with the supported friendly force status and intent. The JTAC and the TACP, which the JTAC is a part of, is the ground commander's sole conduit to CAS fires and the primary mechanism he uses to maximize the employment of CAS. Joint Pub 3-09.3 describes the commander's responsibilities for CAS employment:

> CAS is an element of joint fire support. Synchronizing CAS in time, space, and purpose with supported maneuver forces increases the effectiveness of the joint force…The supported commander establishes the priority, timing, and effects of CAS fires within the boundaries of the land, maritime, SOF, or amphibious force's area of operations.[37]

The "synchronization" of CAS in time and space with other fires is an art that requires training, practice, and understanding of the ground situation and intent.

CAS requests can be divided into two categories: planned CAS and immediate CAS. Planned CAS is typically requested to support offensive operations or as a preventative measure based on anticipated target opportunities. Immediate CAS requests are reactive by nature and are unplanned but too urgent to wait for tasking via the day-long ATO cycle. Whether tasked via a preplanned or immediate request, there are typically CAS assets available or "on-call" to strike evolving targets. The concept of "Push CAS," where CAS aircraft are launched to an on-call mission in anticipation of an immediate CAS request, was used extensively in Operation Iraqi Freedom but its successful application is reliant on an abundance of CAS assets.

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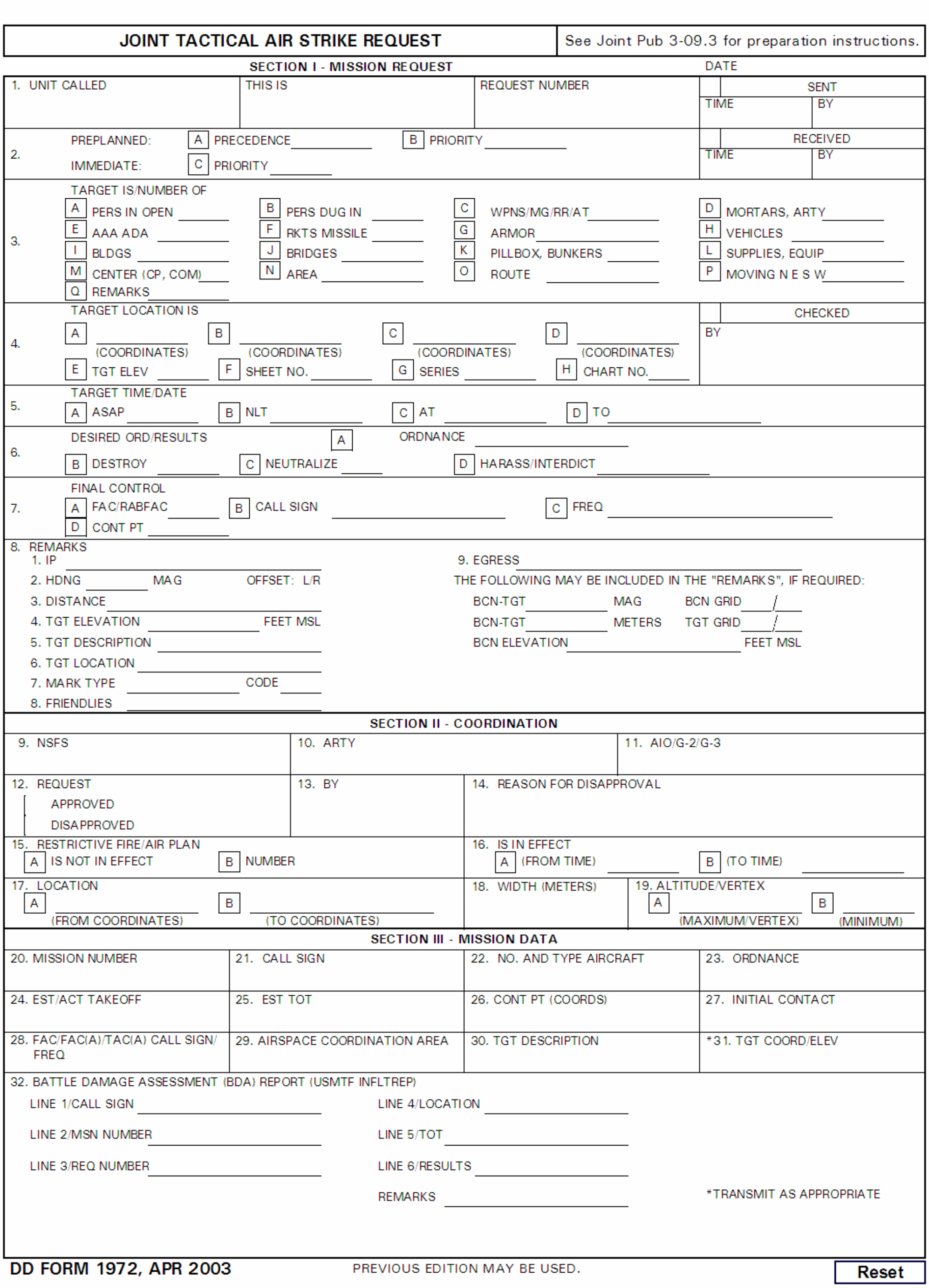
[37] Department of Defense, *Joint Tactics*, *Techniques*, *and Procedures for Close Air Support (CAS)*, Joint Publication 3-09.3, Change 1, 2 September 2005, p. I-1.

In a typical immediate request for CAS, the ground commander will have to first decide to request CAS in lieu of or in addition to other fire support. Upon making the decision to request CAS against a target, the commander instructs his TACP to send a request via the AFARN (Army request) or the TARN (Marine request). The critical request information is compiled by the TACP onto Section I of the DD Form 1972, Joint Tactical Air Strike Request, and sent via voice over the AFARN to the ASOC, or over the TARN to the DASC. The portion of the target and engagement data in block 8 of the DD Form 1972 is commonly referred to as the “9-line.” Figure 15 shows a sample of the DD Form 1972. (Note: There are actually 21 different versions of the 9-line. Please see Appendix B for an explanation of data formats.)



JOINT TACTICAL AIR STRIKE REQUEST See Joint Pub 3-09.3 for preparation instructions.

SECTION I - MISSION REQUEST

1. UNIT CALLED | THIS IS | REQUEST NUMBER

DATE

SENT: TIME | BY

2. PREPLANNED: A PRECEDENCE ___ B PRIORITY ___
IMMEDIATE: C PRIORITY ___

RECEIVED: TIME | BY

3. TARGET IS/NUMBER OF
A PERS IN OPEN ___
E AAA ADA ___
I BLDGS ___
M CENTER (CP, COM) ___
Q REMARKS ___
B PERS DUG IN ___
F RKTS MISSILE ___
J BRIDGES ___
N AREA ___
C WPNS/MG/RR/AT ___
G ARMOR ___
K PILLBOX, BUNKERS ___
O ROUTE ___
D MORTARS, ARTY ___
H VEHICLES ___
L SUPPLIES, EQUIP ___
P MOVING N E S W ___

4. TARGET LOCATION IS
A ___ (COORDINATES) B ___ (COORDINATES) C ___ (COORDINATES) D ___ (COORDINATES)
E TGT ELEV ___ F SHEET NO. ___ G SERIES ___ H CHART NO. ___

CHECKED
BY

5. TARGET TIME/DATE
A ASAP ___ B NLT ___ C AT ___ D TO ___

6. DESIRED ORD/RESULTS A ORDNANCE ___
B DESTROY ___ C NEUTRALIZE ___ D HARASS/INTERDICT ___

7. FINAL CONTROL
A FAC/RABFAC ___ B CALL SIGN ___ C FREQ ___
D CONT PT ___

8. REMARKS
1. IP ___
2. HDNG ___ MAG OFFSET: L/R
3. DISTANCE ___
4. TGT ELEVATION ___ FEET MSL
5. TGT DESCRIPTION ___
6. TGT LOCATION ___
7. MARK TYPE ___ CODE ___
8. FRIENDLIES ___

9. EGRESS ___
THE FOLLOWING MAY BE INCLUDED IN THE "REMARKS", IF REQUIRED:
BCN-TGT ___ MAG BCN GRID ___/___
BCN-TGT ___ METERS TGT GRID ___/___
BCN ELEVATION ___ FEET MSL

SECTION II - COORDINATION

9. NSFS | 10. ARTY | 11. AIO/G-2/G-3

12. REQUEST
APPROVED
DISAPPROVED

13. BY | 14. REASON FOR DISAPPROVAL

15. RESTRICTIVE FIRE/AIR PLAN
A IS NOT IN EFFECT B NUMBER

16. IS IN EFFECT
A (FROM TIME) ___ B (TO TIME) ___

17. LOCATION
A ___ (FROM COORDINATES) B ___ (TO COORDINATES)

18. WIDTH (METERS)

19. ALTITUDE/VERTEX
A ___ (MAXIMUM/VERTEX) B ___ (MINIMUM)

SECTION III - MISSION DATA

20. MISSION NUMBER | 21. CALL SIGN | 22. NO. AND TYPE AIRCRAFT | 23. ORDNANCE

24. EST/ACT TAKEOFF | 25. EST TOT | 26. CONT PT (COORDS) | 27. INITIAL CONTACT

28. FAC/FAC(A)/TAC(A) CALL SIGN/ FREQ | 29. AIRSPACE COORDINATION AREA | 30. TGT DESCRIPTION | *31. TGT COORD/ELEV

32. BATTLE DAMAGE ASSESSMENT (BDA) REPORT (USMTF INFLTREP)
LINE 1/CALL SIGN ___
LINE 2/MSN NUMBER ___
LINE 3/REQ NUMBER ___
LINE 4/LOCATION ___
LINE 5/TOT ___
LINE 6/RESULTS ___
REMARKS ___

*TRANSMIT AS APPROPRIATE

DD FORM 1972, APR 2003 PREVIOUS EDITION MAY BE USED. **Reset**

Figure 15: DD Form 1972, Joint Tactical Air Strike Request (From [38])

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[38] Department of Defense, *Joint Tactics, Techniques, and Procedures for Close Air Support (CAS)*, Joint Publication 3-09.3, 2 September 2005, pp. B-5.

When the request is received at the ASOC or DASC, it is aligned with one of the available CAS providers available. The ASOC typically only has Air Force aircraft available for tasking and the DASC typically only has Navy and Marine aircraft available for tasking. In practice, if either the ASOC or the DASC do not have enough CAS providers to fulfill their requests they contact the other to attempt to pass target requests.

As the CAS request system exists today, there is very little, if any, consideration given to the synchronization of CAS providers and desired effects. The immediate CAS requests are sent to the ASOC or DASC and an available asset is assigned to fulfill each request. These pairings are completed in a more or less “first come, first serve” manner with only some consideration given to urgency of the request (“troops in contact” requests are given priority).

The target tasking orders that fulfill the requests are then passed to the CAS aircraft via a UHF/VHF voice transmission. Once the aircraft arrive near the target area, they contact the JTAC directly via UHF/VHF radio. The JTAC provides the CAS aircraft with a brief description of the ground situation, the known or suspected anti-aircraft threats, and describes any deconfliction measures in place to protect the fire support providers (separating the aircraft from other aircraft or ballistic fires like artillery). The JTAC then verbally or digitally passes the target data to the CAS aircraft using the “9-line” format or derivative. Once the CAS provider has the required information and a situational awareness of the engagement area, the JTAC will then typically send a verbal description of the target to the aircraft to aid in acquisition of the target during the attack. Once the attack begins, the JTAC or FAC will give final weapons release approval to the CAS aircraft only when he is satisfied that the aircraft is attacking the intended target. Because of the amount of coordination involved to execute a CAS engagement, it typically takes at least 10 minutes from first radio contact with the aircraft to weapons impact on the first target in the area. Subsequent target attacks in the vicinity take less time. A typical Army request for Air Force CAS support should follow the chains of command and communication as detailed below and shown in Figure 16.

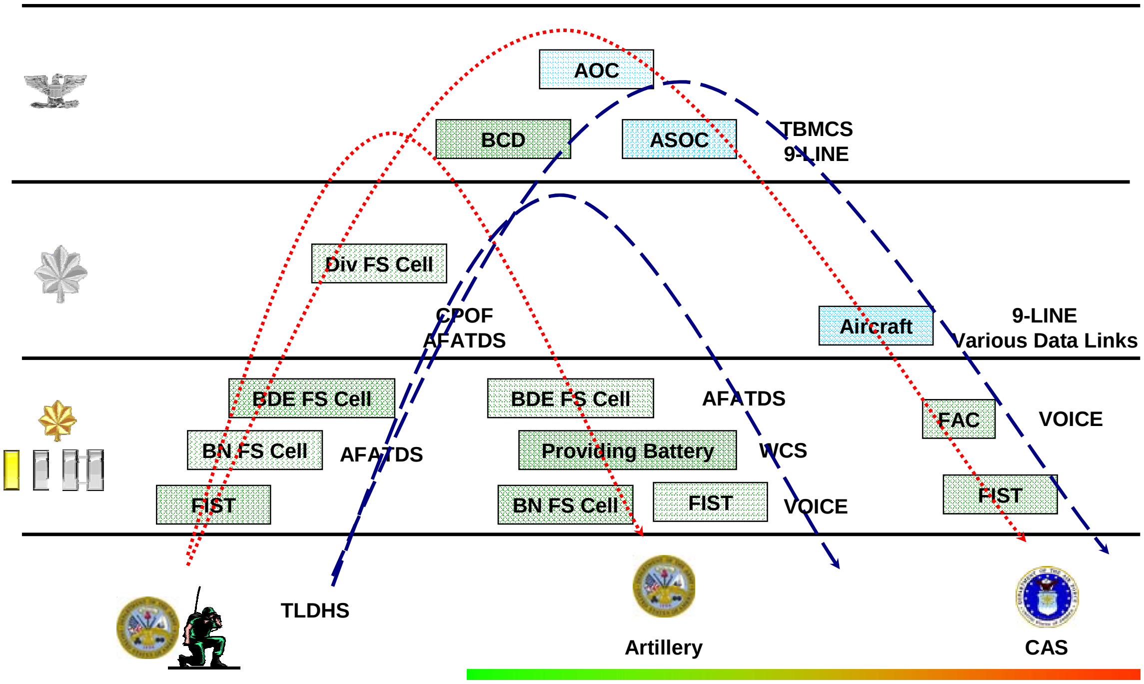

Figure 16: Army Request Routing for Artillery or AF CAS

A soldier alerts the company FIST of a target. Again, a TLDHS is used to fix the target position and the data is routed up the chain of command via the AFATDS system and the radio networks. At one of the command levels up through the BCD, based on the target characteristics, permission is given to a FO, FAC, TACP, or JTAC to contact the ASOC to request Air Force CAS support. At this point, the AFATDS file is manually transcribed into the “9-line” request format and read to the ASOC. The ASOC (within the AOC) considers the resources it has under its control and the C2 operational picture as presented by TBMCS (or GCCS). It makes a decision to task one of its assets and makes a voice connection to that platform via one of many possible communications routes. (The complexity of aircraft communications and data links is shown in Appendix A, JFIIT Interoperability assessment matrix.)

The ASOC may pass part or all of the “9-line” data to the tasked platform with instructions to contact the originating FAC, TACP, or JTAC. The aircraft commander will confirm “9-line” data, coordinate with the FAC or JTAC, and complete the engagement.

While it has been technically demonstrated that AFATDS data can be passed to specifically configured aircraft and presented in the cockpit via particular data links and special on-board systems, this capability is not high priority for the services as it could not be generally applied across an aircraft fleet with divergent communication link and on-board system baselines. Continued translation to a verbal 9-line format is far more likely.

2.2.4 Challenges of a Joint Fire Support Request

The examples above outline the basic chains of command and communication for fires support requests. The environment becomes significantly more complicated when non-standard service pairings are considered. The example in Figure 17 illustrates the coordination and decision making complexity within a Marine request for JFS from providers outside of standard request channels.

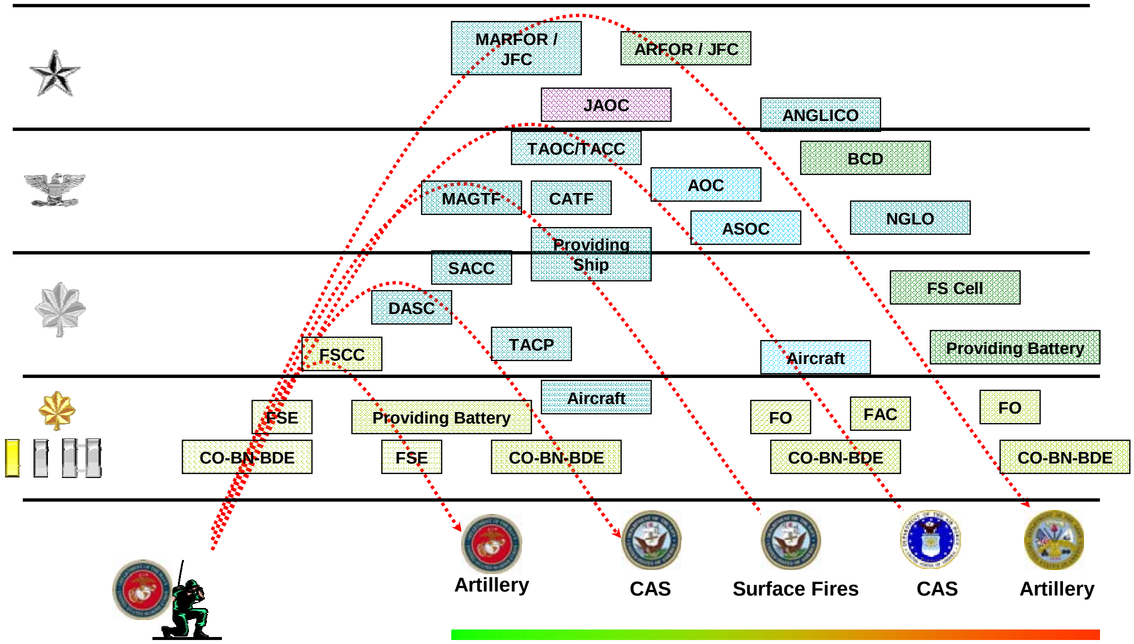

Figure 17: Coordination and Decision Making Complexity of JFS

The Project Team approached this analysis from the perspective of standard, published organizational constructs that preserve standard operational, tactical, and administrative lines of control. This was done for two primary reasons. First, it allowed decision-making to be completed within the boundaries of fielded systems and current training methods. It also allowed system failures to be traced back to the appropriate level of command within the owning service.

The team concedes that there are probably an infinite number of ways to assemble an organizational structure if different assumptions are applied. For example, a capabilities-based construct could be used to greatly simplify the overhead associated with chains of command. However, that construct would assume perfect interoperability of all underlying systems. The team deemed an approach like this one as more risky than the one chosen.

Coordination and decision making complexity examples are shown in Appendix C. Networking and automated information system complexity is evaluated in Section 4.3.1. Conclusions from these diagrams may be found in the metrics summary table in Section 2.6.

2.3 FUNCTIONAL ARCHITECTURE

The SEDP (as described in Section 1.3) transforms the stakeholders' requirements and needs into a set of system functions and process descriptions that generate information for decision makers and provide input for the next level of functional development. These system functions and process descriptions also form a "blueprint" of what the system needs to do and what performance criteria are used for assessment of alternative solutions. This set of artifacts forms the functional architecture.

Many Systems Engineering experts refer to this process as a functional analysis. According to Blanchard and Fabrycky, a function is "a specific or discrete action (or series of actions) that is necessary to achieve a given objective."[39] The objective of this analysis is to determine *what* the system must do but not constrain the solution space into *how* it must be done.

2.3.1 Input-Output Modeling

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[39] B. S. Blanchard W. J. Fabrycky, *Systems Engineering and Analysis*, 4th ed., Pearson Prentice Hall, 2006, p. 62.

The JFS system and environment can be described on the basis of the inputs and the outputs of the system, and this Input-Output model serves as a key artifact of the overall functional architecture. These system flows include Controllable and Uncontrollable Inputs and Intended and By-Product Outputs. The Input-Output (I-O) Model for a fire support request is critical to ensuring the end-product is flexible and responsive to any operating environment in which the end-product may be used. The I-O Model was a tool used by the Project Team to help scope and bound the problem.

The system being proposed consists of a process that accepts a valid target, generates and transmits a tasking order to the "best provider" based on the current rules of engagement, commander's intent and COP. The intended output of the system is secure tasking orders with an expectation of improved timeliness and reduced risk of fratricide. Unintended results of the system were evaluated to include risk of transmission intercept; undetected errors in the fires request; and uncontrollable environmental interference preventing transmission of request or tasking. The process used for determining the inputs and outputs is described in more detail in Appendix C. Neither the input nor the output items were prioritized in this modeling step. The resulting input and output model is described in Figure 18.

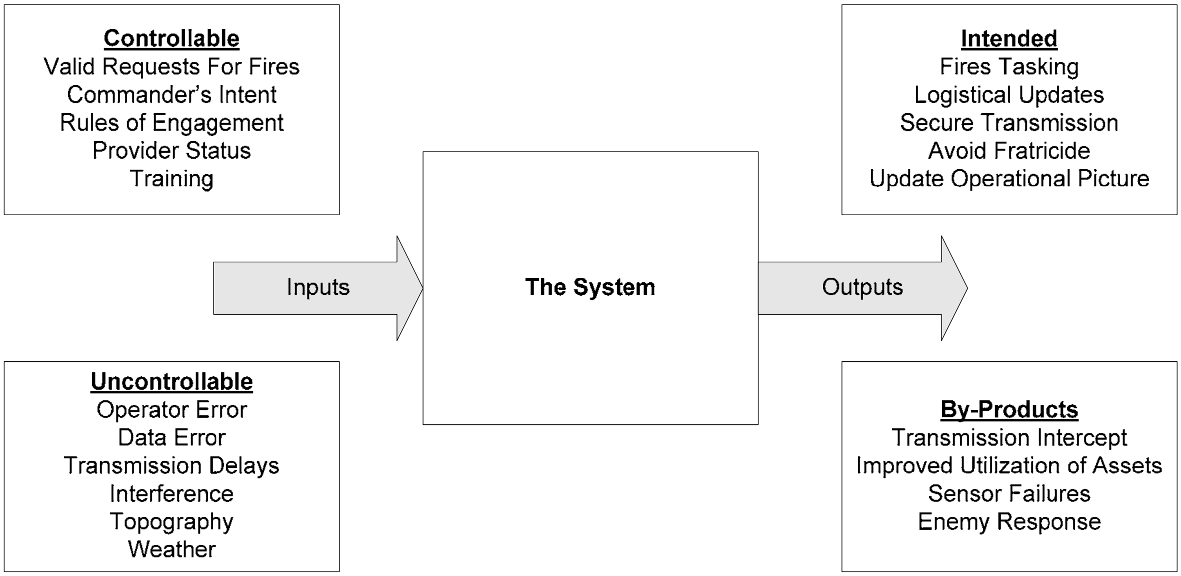

Figure 18: Input-Output Model

2.3.2 Functional Decomposition of Joint Fires

Due to the complexity of the existing Joint Fire Support system and the constructs chosen thus far, a time-flow approach was taken to perform the initial functional breakdown. In a general request for fire support, the following steps are completed:

- First, details on a potential target are collected by a fielded unit.
- Second, when a unit decides it cannot prosecute the target with its resources, the target details are forwarded to higher organizational levels in some form of Joint Fire Support (JFS) request.
- Third, at the higher organizational levels, a data collection and synthesis occurs. There are organizational constraints on the range of data that can be collected so the data synthesis that results is a function of the data input. Steps two and three can happen repeatedly until one of the organizational levels has the ability to act.
- Fourth, a decision and a corresponding action plan are made.
- Fifth, the decision and action plan are disseminated to affected organizational levels.
- Sixth, the involved organizational levels execute the action plan.

This functional flow is outlined in Figure 19. The functional flow within the project design space aligns with the Track, Target, and Engage functions described by the F2T2EA model.

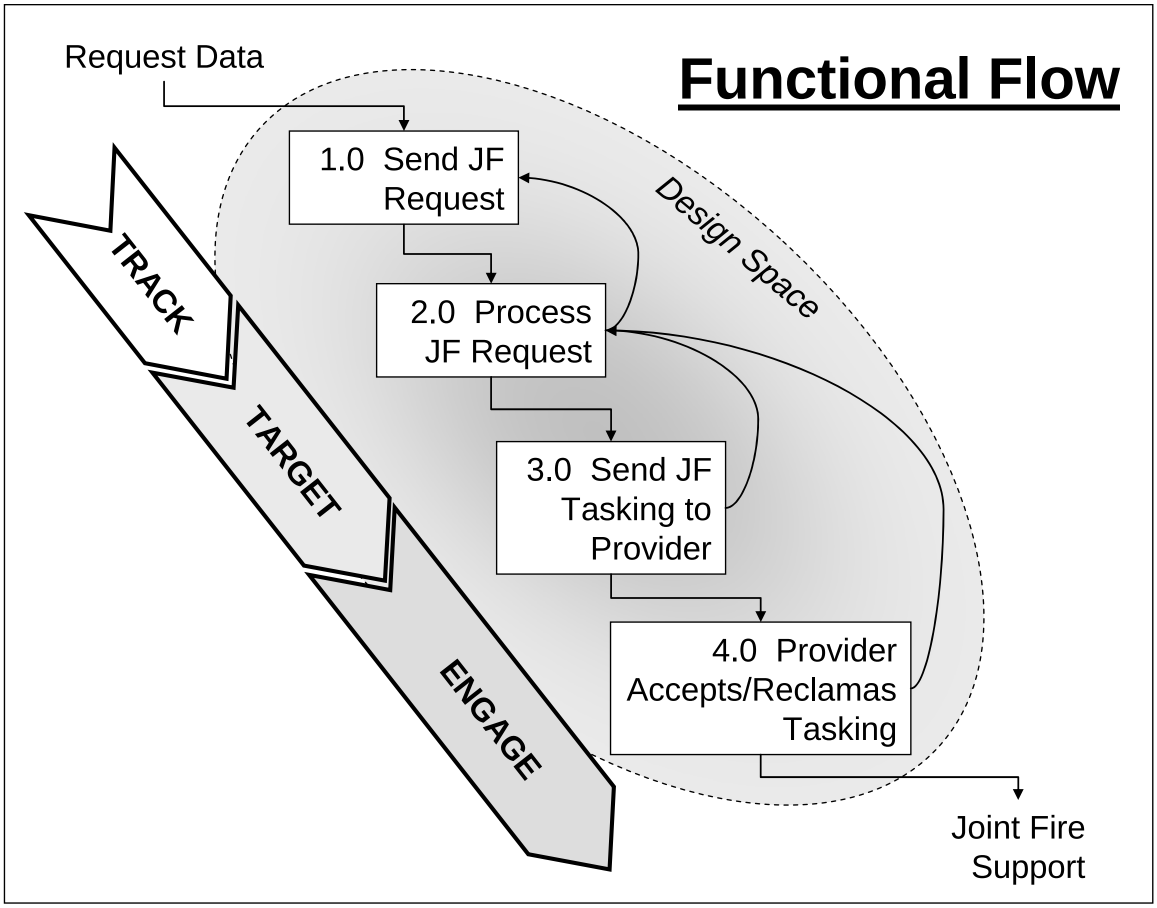

Figure 19: Functional Flow Diagram of the System

These system functions are multi-faceted and inter-related. This system's primary functions include: sending the JF request, processing the JF request (which includes making a decision based on collected information), sending the JF tasking to the provider, and receiving feedback from the provider that the tasking was either accepted or rejected (reclama). Additionally, this system must have a sufficiently capable communications infrastructure to transmit and receive the necessary information. The following are descriptions of what is involved in each one of these overarching, top-level functions (see Appendix D: Functional Flow Analysis, for a more detailed analysis):

Send JF Request: This system function involves the process of gathering information about the target, the requester, and the desired effects on the target. The output of this function is a majority of the actionable information for the rest of the system. (See Appendix B for more information about fire support request formats)

Process JF Request: This function involves gathering information from other sources to help decision makers develop a preferred course of action. The ability to pull data from C2 systems regarding position of Blue/Red forces, as well as other on-going operations, and link this information with provider availability is a key component of this function. This function will also prioritize each request within the context of the larger area of operations. It will also provide a listing of necessary actions to deconflict a particular fires provider with the target area (i.e. avoid flying aircraft through artillery landing zones). The output of this function is all available information to make a preferred requester/provider pairing. This quality of the output is highly dependent on the source data. Based on the information available to the appropriate decision-maker, a preferred course of action will be selected.

Send JF Tasking to Provider: At this point, the request along with relevant additional information will be transmitted to the fires provider. This may be the first time the fires provider has been contacted regarding a particular mission, so complete and accurate information transfer is important.

Provider Accepts/Reclamas Tasking: Based on the mission tasking and current provider status, there is an opportunity for a provider to opt out of a tasking. Until the designated fires provider accepts a tasking and coordinates (as required) with the requesting unit, the management structure will continue to track the fires request.

Communication: Underlying these other system functions, this system requires communication. Lack of adequate communications is a primary failure mode of this system so it will be tracked as a stand-alone function.

2.3.3 F2T2EA Functional Analysis

The "Find, Fix, Track, Target, Engage, Assess" kill chain forms the basis of the Joint Fires chronological process. The target type is an "unanticipated, immediate target" that was not planned to be struck and needs to be serviced outside of the normal air tasking order planning cycle.[40] An analysis of the functional sequence and the chronological order of the functions provide additional insight into the design problem. Additionally, the data that must be utilized by each of these functions must be identified. The movement of essential data between functions is summarized in Figure 20.

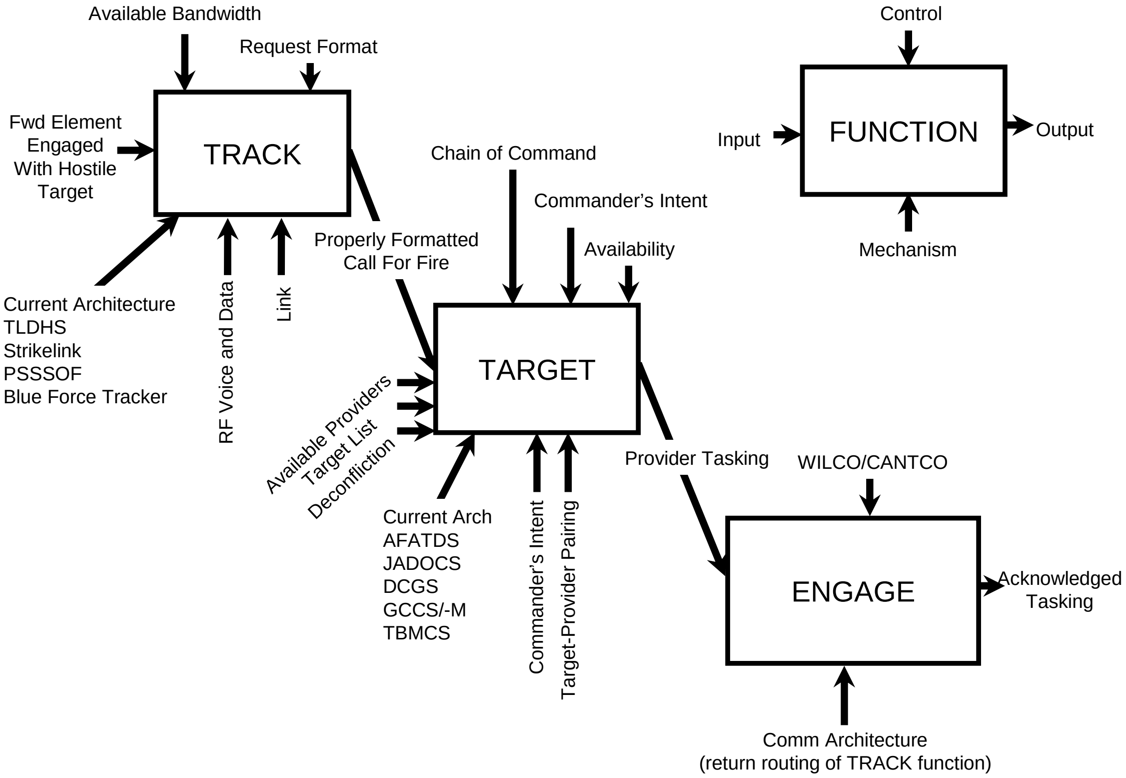

Figure 20: Context Diagram of Functional and Data Flow

2.3.4.1 Track Functional Analysis

During the track phase, the requester has a valid target position and maintains contact throughout engagement. The request message is sent to

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[40] Secretary of Defense, *Commanders Handbook for Joint Time-Sensitive Targeting,* Department of Defense, 22 March 2002, p. I-2.

the appropriate authority for processing and approval. Target updates may be made through the same process until ordnance is delivered.

The request for fires process is subdivided into a series of sequential events. First, a formatted request message is created (either voice or data message). Regardless of the method used, the request message is sent and receipt is acknowledged by the receiving entity. The request may be filtered through several levels of command based on organizational structure, rules of engagement, and commander's intent. Next, the target is approved as valid for prosecution and assigned a priority. The following items would normally be considered prior to validating the request: proximity to friendly forces; presence of special operations or coalition forces without real-time blue force tracking; battle damage assessment from previous attempts against target; collateral damage estimates; military law or Intel pre-set no-fire zones; and request duplication. The validated target is then forwarded to a target-provider pairing authority and/or an automated algorithm within the target system function.

2.3.3.2 Target Functional Analysis

The targeting phase begins with a validated target. To generate a provider tasking the system will assess desired effects, engagement options, assets available, location of available assets, and target environment. The algorithms required to generate the pairings can be automated or manually processed within a system, organization, or staff.

The request processing function and the assignment of a fire support provider are intertwined, but the methodology options to determine the pairings of the requests with the providers is a unique function with numerous options. Regardless of the specific methodology involved, a method or process is needed to perform the function of matching or pairing a request with a weapon system.

The system should allow providers responding to a validated target to be re-tasked, if required. If a higher priority target "pops up", assets on the ATO with lower priority targets should be considered as available providers.

Depending on operational tempo, it may not be advantageous to change the ATO. However lessons learned from Desert Storm indicate that “flexibility of the ATO must be improved to account for changes, shifting priorities and real time target requirements as the campaign progresses.”[41]

When the provider-target pairing (and deconfliction functional process, if required) is completed, the authority to task the asset is obtained and tasking message is generated.

2.3.3.3 Engage Functional Analysis

The engagement phase begins when the tasking order is transmitted to the designated fires provider and receipt is acknowledged. This tasking can be voice or a data message specific to the provider platform receiving the order (i.e., NFCS, AFATDS, ATWCS, Link 16, etc.). The provider should have the capability to return the task to the tasking authority (reclama or cantco [can not comply] for authorized reasons such as low fuel state or lack of weapons). Additionally, the requesting unit should be informed of the tasking and, at a minimum, be provided with a reply delineating who is providing the support and when it should be expected.

Concurrent with the provider tasking, an asset to provide battle damage assessment (BDA) should be identified. For the targets considered, time sensitive in direct contact, the requester is assumed to be capable of providing this BDA.

For some targets, it may be required to establish direct communications from the provider to the requester. This may include “Danger Close” situations with artillery or naval guns, and most close air support missions rely on voice communications to prevent fratricide.

The proposed system does not consider the actual engagement. Once the provider is tasked and the requester is informed. The engagement becomes a matter of the tactical operation of the weapon platform. BDA is presumed to feed into the common operating picture so that destroyed targets

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[41] Department of the Navy, “U.S. Navy in Desert Storm and Desert Shield,” [http://www.history.navy.mil/wars/dstorm/ds6.htm], Sept 06.

are not re-attacked. Similarly, requests for re-engagement are treated as a new request with an updated priority based on current operational situation.

2.3.4 Functional Hierarchy

The functions identified in the F2T2EA functional analysis were distilled and arranged into a hierarchy of functions. The advantage of this construct is that it allows analysis of functions based on functional groupings instead of a chronological sequence.

The Track phase of the F2T2EA process is simply the transmission of the fire support request data. The next phase of the system can be sub-divided into four distinct functions: process request, match user to provider, task the provider, and send tasking feedback to the requester. Once tasked, the provider acknowledges the receipt of the tasking by accepting or declining the tasking. This reply from the provider defines the end state boundary of this system design. All of these functions are enabled by the communication of data, intent, and authority between the functions. The hierarchy of functions for the proposed system is shown in Figure 21.

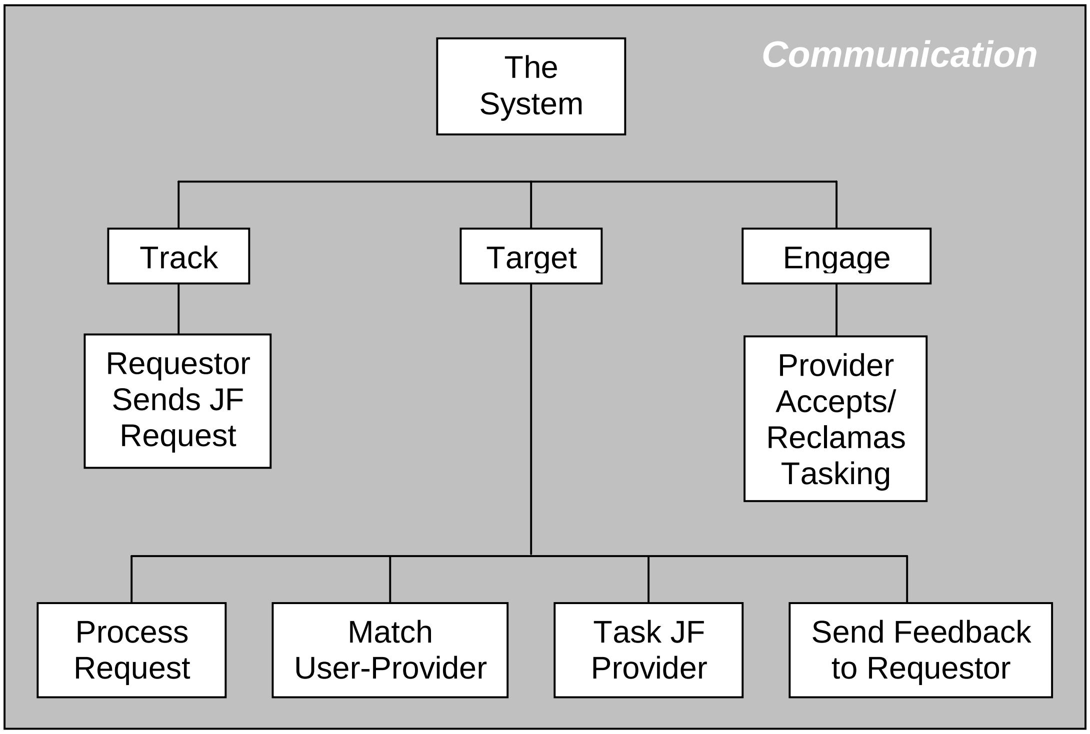

Figure 21: Functional Hierarchy

2.4 NEEDS ANALYSIS

In accordance with the SEDP, the stakeholder's needs and desires were decomposed, assessed, and compiled in an Analysis of Needs.

2.4.1 Stakeholder Analysis

The primary purpose of stakeholder analysis is to identify the people or agencies that are relevant to the design problem and to determine their needs, wants and desires with respect to it.[42] Due to the size and complexity of the design problem, and the broad scope of the JFS study area, determining the stakeholders was a difficult task. Thanks to the joint nature of the Naval Postgraduate School's student body, the Project Team was able to speak with numerous groups of students intimately familiar with JFS procedures and challenges. The service-diverse makeup of the team also improved the team's ability to identify and contact stakeholders both on and off-campus. Throughout the stakeholder analysis process, the stakeholders were asked to specifically identify and discuss their "needs, wants, concerns and desires" for a Joint Fire Support system of systems in the year 2020.

During the interview process the team conducted several trips to visit stakeholders, arranged video teleconferences, and made numerous telephone interviews with stakeholders outside of the local area. Group meetings were held periodically with the student and faculty stakeholders identified at NPS. All of these interviews were vital to the process of extracting the specific and overall expectations of a proposed JFS system.

Stakeholders for a JFS system are a diverse group with different perspectives and priorities. Identifying the perspective of the stakeholder not only assisted with locating other stakeholders with a similar perspective, but it also helped the team to understand the motivations for the system needs and wants identified by the stakeholder. The perspectives of the identified stakeholders run the gamut between decision makers and end users in the field.

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[42] B. S. Blanchard, and W. J. Fabrycky, *Systems Engineering and Analysis*, 4th ed., Pearson Prentice Hall, 2006, p. 323.

The stakeholders' perspectives were considered when the team began fusing the numerous stakeholder needs and wants into a manageable and conclusive list.

The decision making stakeholders have the authority to make impacting and final project decisions when multiple design choices are available. For a Joint Fire Support system that may include tasking of joint military assets, one of the primary decision makers is Joint Forces Command (JFCOM). Additionally, the Combatant Commander (COCOM) and the acquisition leadership of each service component were also identified. JFCOM has established the Joint Fires Integration and Interoperability Team (JFIIT) at Eglin AFB, Florida to "act as the lead agent for USJFCOM to investigate, assess, and improve the operational effectiveness of joint fires."[43] The team contacted JFIIT and conducted several telephone interviews. Additionally, the team traveled to JFIIT in June 2006 and met with them again at the National Training Center, Fort Irwin, California in October 2006. JFIIT's insights were vital to the identification of JFS needs.

The organizational leadership entities of any proposed JFS system would certainly have a significant input into the decision maker category. This includes leadership utilizing the system to lead, direct, and protect their forces. At higher command levels further from the battlefield, the military leader's needs and wants are not the same as the needs and wants of the battlefield commander. For this reason, the team consulted with mid-level military leaders from all of the combat services. Through trips to Fort Sill, Oklahoma, Fort Irwin, and Nellis AFB, Nevada the team was able to gather the wants and needs of a wide range of military leaders involved in JFS. At Fort Sill, the team interviewed the USMC detachment responsible for training Marines to operate AFATDS and its associated systems and later the AFATDS program manager for software development. At Fort Irwin, the team interviewed National Training Center exercise participants in the field during maneuvers and assisted JFIIT personnel with data collection efforts during the exercise. At Nellis Air Force Base, the

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[43] Department of Defense, "Joint Fires Integration and Interoperability Team (JFIIT)," [http://www.jfcom.mil/about/com_jfiit.htm], May 06.

team consulted with the cadre of Air Warrior, the organization responsible for the CAS component of the National Training Center exercises. Additionally, the team met with the Joint Test & Evaluation agency for Joint Fires Coordination Measures and the Joint Air to Ground Operations Group.

The team had the unique opportunity to attend the National Fire Control Symposium in Tucson, Arizona to discuss JFS with both defense contractors and academia. The involved agencies that presented concepts for future JFS included Raytheon, NAVSEA, MIT Lincoln Labs, and Lockheed, among others.

The most obvious group of stakeholders for a JFS system is the engaged troop requesting the JFS. Discussions with numerous combat veterans on NPS, at Fort Sill, and at Fort Irwin provided the team with a very solid understanding of the desires for this group of stakeholders. Additional information on the methods used to identify and specific comments made by the stakeholder can be found in Appendix D.

After fusing the input from all of the stakeholders, the following list of “needs, wants, concerns and desires” that defines the characteristics of any proposed JFS system. The list below is arranged in relative order of importance:

- Efficient Turn-Around Time On Fire Support Requests
- Reliable System
- Very High Level Of Availability
- Flexible Communication Methods
- Ability To Manually Override Any Automation
- Easy To Maintain And Setup
- Simple Training
- Scalable System
- Interoperability With Current Platforms
- Share A Common Awareness
- Efficient And Accurate Decision Support
- Reliable Archiving Of Historical Message & Tasking Data
- Uncomplicated, Straightforward System Operation

2.4.2 Effective Need

The Needs Analysis process allows for a summation of the stakeholder defined needs into a refined and summarized need statement. Based on the current state of JFS, the anticipated future capabilities for JFS, and the needs and desires of the stakeholders involved, the effective need that will drive the proposed system design and define the functional, physical, and operational architectures of the solution is to: "Define an operationally feasible Joint Fires request, coordination, and tasking architecture that enables rapid battlefield effects for the Commander." Any system design alternatives will be measured by their ability to satisfy this effective need statement.

2.4.3 Hierarchy of Objectives

The individual needs identified through stakeholder analysis and review of source documents were consolidated and organized into the Objectives Hierarchy shown in Figure 22. System objectives are composed of functions and attributes. This Objectives Hierarchy allowed the Project Team to develop relevant metrics and measures of effectiveness used to evaluate the performance of design alternatives. A detailed discussion of the system attributes and metrics follows in Sections 2.5 and 2.6.

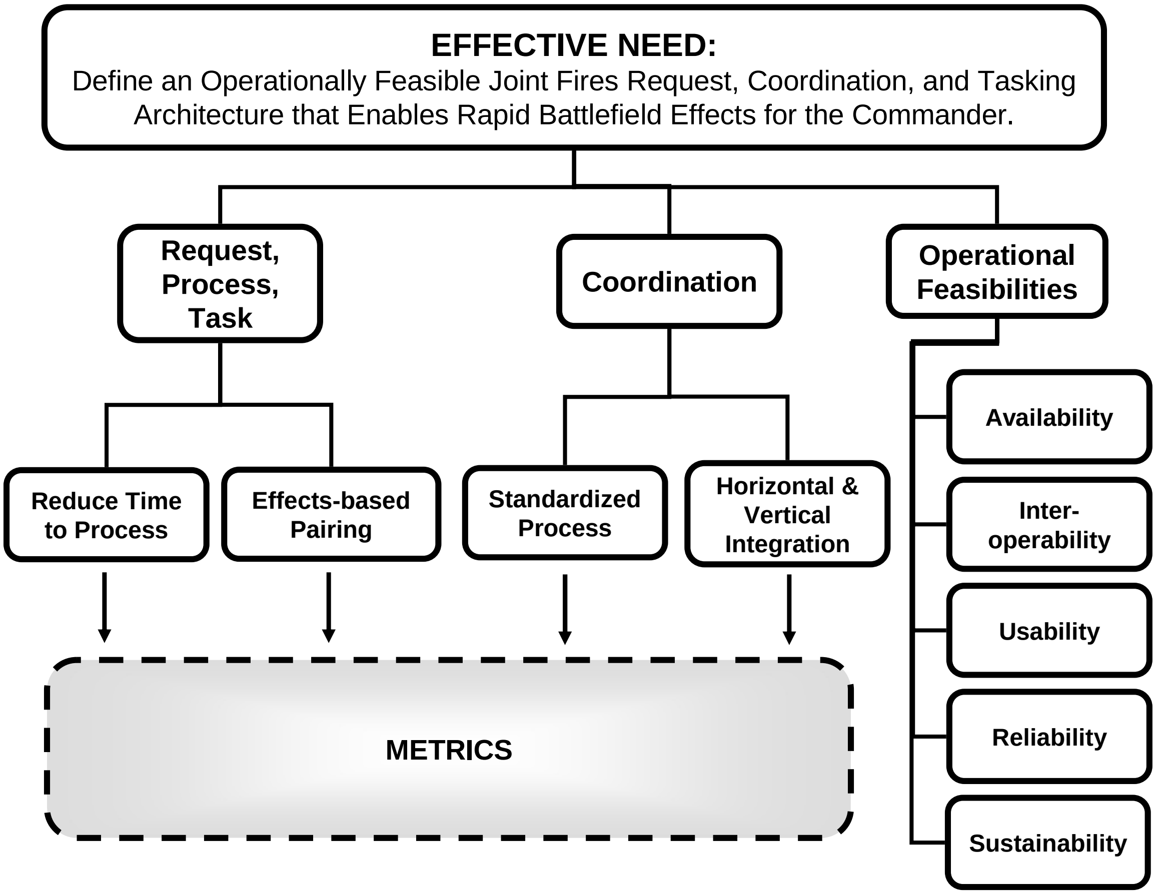

Figure 22: Objectives Hierarchy

2.5 NECESSARY SYSTEM OBJECTIVES

The functions and attributes that the proposed system must possess can be traced to three sources: the intended environment of the system, essential stakeholder needs, and analysis of the source documents requesting the system. The Project Team sorted and evaluated these objectives according to the primary needs the proposed JFS system will support. These objectives have been segmented according to the objectives hierarchy and are described below.

The primary system objectives are: Request, Process, and Task, Coordination, and Operational Feasibilities. The sub-objectives that make up these top-level system objectives are described Figures 23 and 24. Any proposed system must efficiently process a joint fires request and then select an appropriate provider. The processing of the request must be accomplished in less time than the current JFS system (Figure 23).

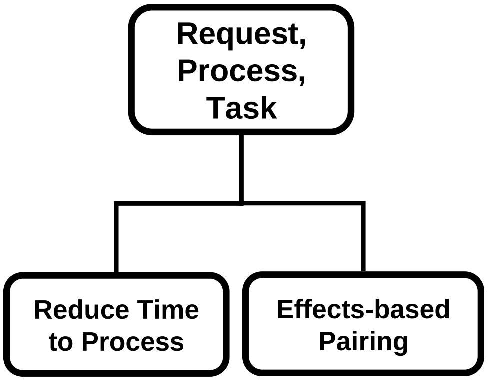

Figure 23: Request, Process, and Task Objectives of the System

The proposed system must provide efficient procedures for tasking of effects-based requests and must be able to pass those tasking orders to a variety of weapon systems in a format that is useable. A variety of methods and procedures exist to request fire support depending on the service, type of delivery platform, and area of operations. Any proposed JFS system must simplify the request process and standardize the information required to engage the target.

The prioritization, pairing, and deconfliction algorithms used in this process must be flexible in order to support a variety of operational environments and changing ROE in support of the commander's intent. A single, fixed algorithm for pairing, prioritization or deconfliction is insufficient to support the broad spectrum of commander's intent. Dynamic algorithms, or a selection of algorithms that provide varying degrees of control, collateral damage considerations, and asset risk are appropriate and required to support a variety of operations and enable the process to be scaled and tailored to the current environment. The system must also possess key attributes related to the coordination of requests and tasking orders (Figure 24).

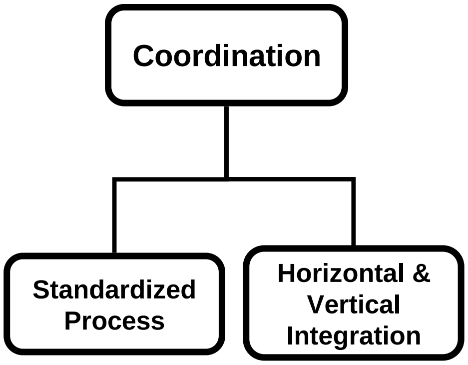

Figure 24: Coordination Objectives of the System

The proposed system must integrate the individual service capabilities into a joint fires effort, standardize training, tactics and procedures, and consolidate and fuse a variety of C2 information. It should provide greater horizontal and vertical integration. The final top-level system objective is operational feasibility (Figure 25).

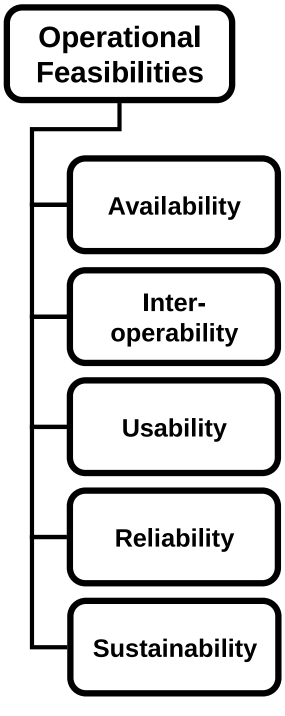

Figure 25: Operational Feasibility Objectives of the System

Feasibility encompasses the foundations required to actually produce and field the family of systems that enable joint fire support. In short, the system must work in the way that it was intended to work. Operational feasibility must be assessed in the fielded environment and it must meet or exceed accepted levels

of performance. A JFS system, as the basis of its design, should be interoperable, usable, reliable, available, and sustainable over the duration of an operation
or mission.

In order to meet the need for interoperability, the system under consideration must be able to accept requests from all four service components, SOCOM, and potential allied or coalition forces and pass data and tasking orders along to a similar variety of providers. Individual fielded systems, including request input devices, radios, data fusion tools, and C2 systems should meet specified usability, reliability, maintainability, and availability requirements developed in the detailed design.

The usability of the system is an attribute that assesses or determines the ease-of-use of interfaces. It should include system efficiency, errors, and satisfaction of the user. Reliability of the system refers to the ability of the system to perform and maintain its designed function in routine, hostile, or unexpected situations or circumstances. The standard for maintainability should be that the system will be maintained in or restored to the specified working condition within a set standard of time, provided the appropriate maintenance is performed in accordance with the designed maintenance procedures and available resources. Availability standards refers to the degree to which a system or sub-system is available and operable. In simple terms, it is the time a system is available to perform the function it was designed to perform. A true assessment of Operational feasibility can only be done on a more detailed, physical SoS design. Reliability of the conceptual systems is qualitatively assessed in chapter 6, Risk and Reliability

2.6 SYSTEM METRICS

The necessary system attributes and essential functions defined in the previous sections were assessed and divided into those objectives that could be directly measured (quantifiable metrics) and those that could only be subjectively assessed or validated (qualitative metrics). The Objectives Hierarchy developed in Section 2.4.3 was studied to determine how to assess satisfaction of those needs. The results of that analysis were the metrics that should be evaluated. Several quantifiable metrics were identified for evaluation using modeling and/or simulation. Those metrics are:

1. Processing Time (for a Request to be Serviced)
2. Pairing Effects Ratio
3. Number of Systems Involved (in the Request-to-Tasking Process)
4. Number of Decision Points (involved in the Request-to-Tasking Process)
5. Number of Steps Involved in the Process
6. Number of Process Gaps (in the Request-to-Tasking Process)
7. Blue Force casualties.

These metrics can each be traced to an identified need in the Objectives Hierarchy, as seen in Figure 26.

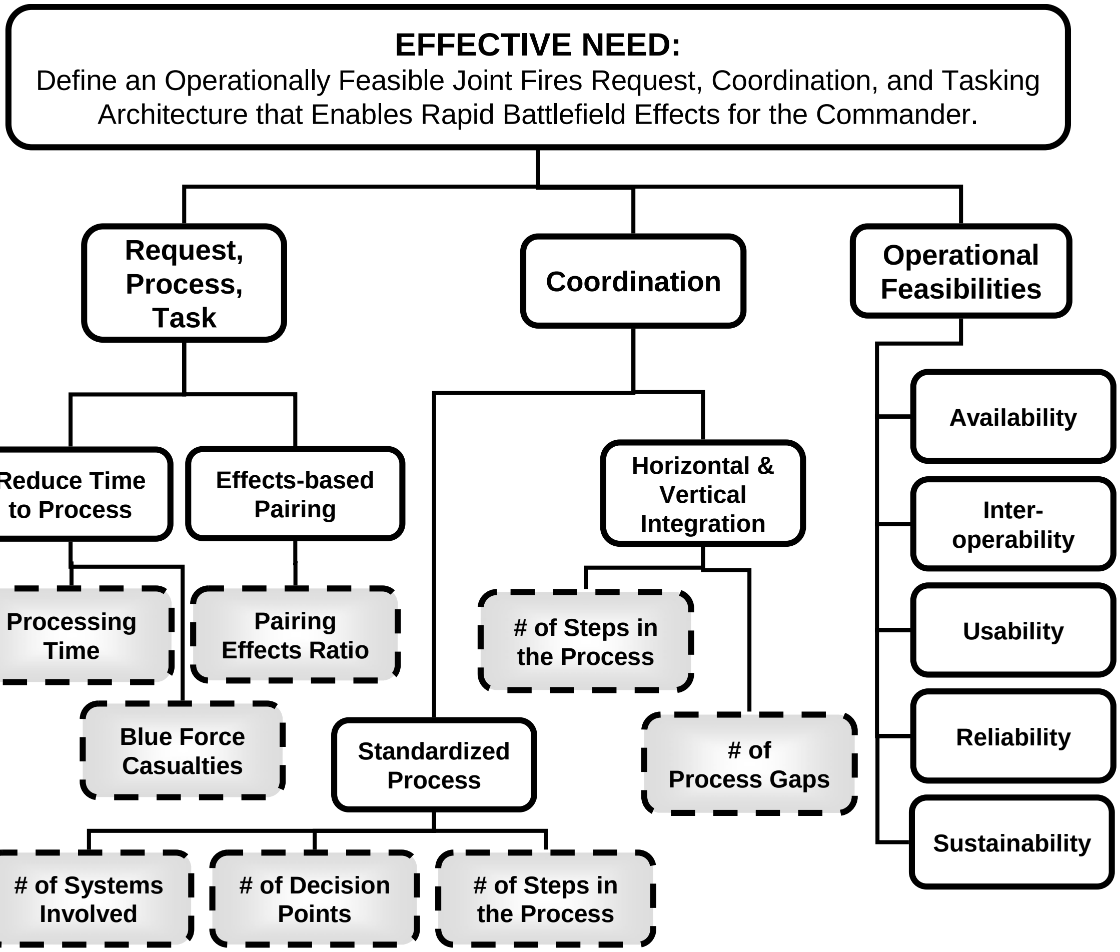

Figure 26: Traceability of Quantifiable Metrics to Identified Needs

Qualitative metrics were identified and assessed based on discussions with stakeholders and among team members. Additionally, qualitative metrics were influenced or defined by the environment in which any JFS system will operate in and the capabilities of the current JFS system. A summary listing of potential metrics and functional breakdown is shown in Table 4.

Functions	**System Objectives**	**Metrics**
Coordination	Standardized Process	# of Systems Involved
		# of Decision Points
	Horizontal & Vertical Integration	# of Steps in the Process
		# of Process Gaps
Request, Process, Task	Reduce Time to Process	Processing Time
		Blue Force Casualties
	Effects-based Pairing	Pairing Effects Ratio
Operational Feasibility	Availability	*Future Studies*
	Interoperability	Subjective Assessment
	Usability	*Future Studies*
	Reliability	Subjective Assessment
	Sustainability	*Future Studies*

Table 4: Performance Metrics of System Objectives

These metrics will be used to compare proposed JFS system alternatives through modeling, simulation, risk assessments, and subjective evaluation by subject matter experts.

3.0 PHYSICAL ARCHITECTURES

Continuing with the deliberate SEDP and building on the functional architecture developed in Chapter 2, alternative physical architectures were developed. By design, a physical architecture "should provide resources for every function identified in the functional architecture."[44] To do this, the physical alternative must be built in a way that meets the identified needs and fulfills the identified functions. The physical architectures generated by the Project Team accomplished this because they were conceived in the context of the DOTMLPF construct and address the uncertainties of several scenario concepts. This section will first describe the proposed system alternatives. Then, scenarios will be used as the backdrop for evaluation of those alternatives presented. The anticipated environment and the associated threats to a JFS system are also elaborated as part of the development of the physical architectures.

3.1 GENERATION OF ALTERNATIVES

The team began developing alternatives for the system with an understanding of the operational environment and the stakeholder needs. Using concepts developed from the stakeholder discussions or linked to the user-defined needs and wants, the team developed numerous distinct alternative concepts for the proposed system. The methodology and concepts developed during the team's generation of alternative architectures is discussed in more detail in Appendix E.

The alternative generation efforts produced five alternatives that were assessed for feasibility. Three distinct alternatives were determined to be feasible architectures in the year 2020 and are described in the following sections. It is important to note that the alternatives all assume a similar level of peripheral materiel acquisition. For instance, current plans for improvement in communication abilities for FOs include some type of digital entry device that can send data (equivalent or follow-on to TLDHS). Additionally, a continued

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[44] D.M. Buede, *The Engineering Design of Systems*, John Wiley & Sons, Inc., 2000, p. 246.

improvement in networking infrastructure and the maturation of the Global Information Grid (GIG) is assumed for all three alternatives. The environment the alternatives will exist in is a factor in defining the feasibility of alternatives and therefore need to be included and addressed.

3.1.1 Alternative 1: Status Quo Plus

The JFS process will certainly evolve between now and 2020. There are already programs under development that will attempt to meet the needs of JFS in 2020 and beyond. The Status Quo Plus alternative is an expansion of the current "as is" system based on the growth path of existing programs of record. This system alternative is based on realistic improvements in both capabilities and materiel during this timeframe, but it also retains many of the current aspects of fires support organizations and processes.

With respect to doctrine, the relationships between the services are not projected to fundamentally change. The Marine Corps remains closely linked to the Navy, and the Army to the Air Force. Each service continues development of its own command and control systems, although information sharing between them is still considered a benefit to interoperability.

With respect to organization and leadership, technological advances permit faster transmission of battlefield data through the same hierarchical structures used today. Where duplication of functionality exists between services (e.g. the FFCC (Marines), BCD (Army), and SACC (Navy)) a separate but equal relationship remains. There is no effort to consolidate these organizations to a more comprehensive joint capability.

With respect to materiel, each service continues its essentially independent development efforts. Systems which provide service to fielded troops and to delivery platforms continue to be thought of as mutually exclusive projects, stratified by service, development community, and prime contractor. Interoperability is thought of as a "connector" that links otherwise distinct development efforts. Service experimentation is characterized by configuring very specialized data channels to complete a specific mission rather than viewing data transmission as a utility that can be broadly applied for any and all missions. Artillery requests can be sent digitally to the requester's parent service for processing and pairing. For example, although the Army and Marines both use AFATDS, or an AFATDS derivative/follow-on, their databases and assets remain functionally separated and requests do not freely flow between these two services. Continued development of the Marine version of AFATDS will allow communication directly to NFCS through a data converter resulting in some degree of shared targeting database.

The pairing of requests and providers for all other JFS requests is primarily completed using a blended methodology based on service component of the requesting party and a weapon system priority. The Air Force and Navy are continuing the practice of "push CAS" to expedite servicing of tasking orders.

The command and control structure that forms the organizational framework for the sharing, processing, and tasking of JFS in the Status Quo Plus alternative is depicted in Figure 27.

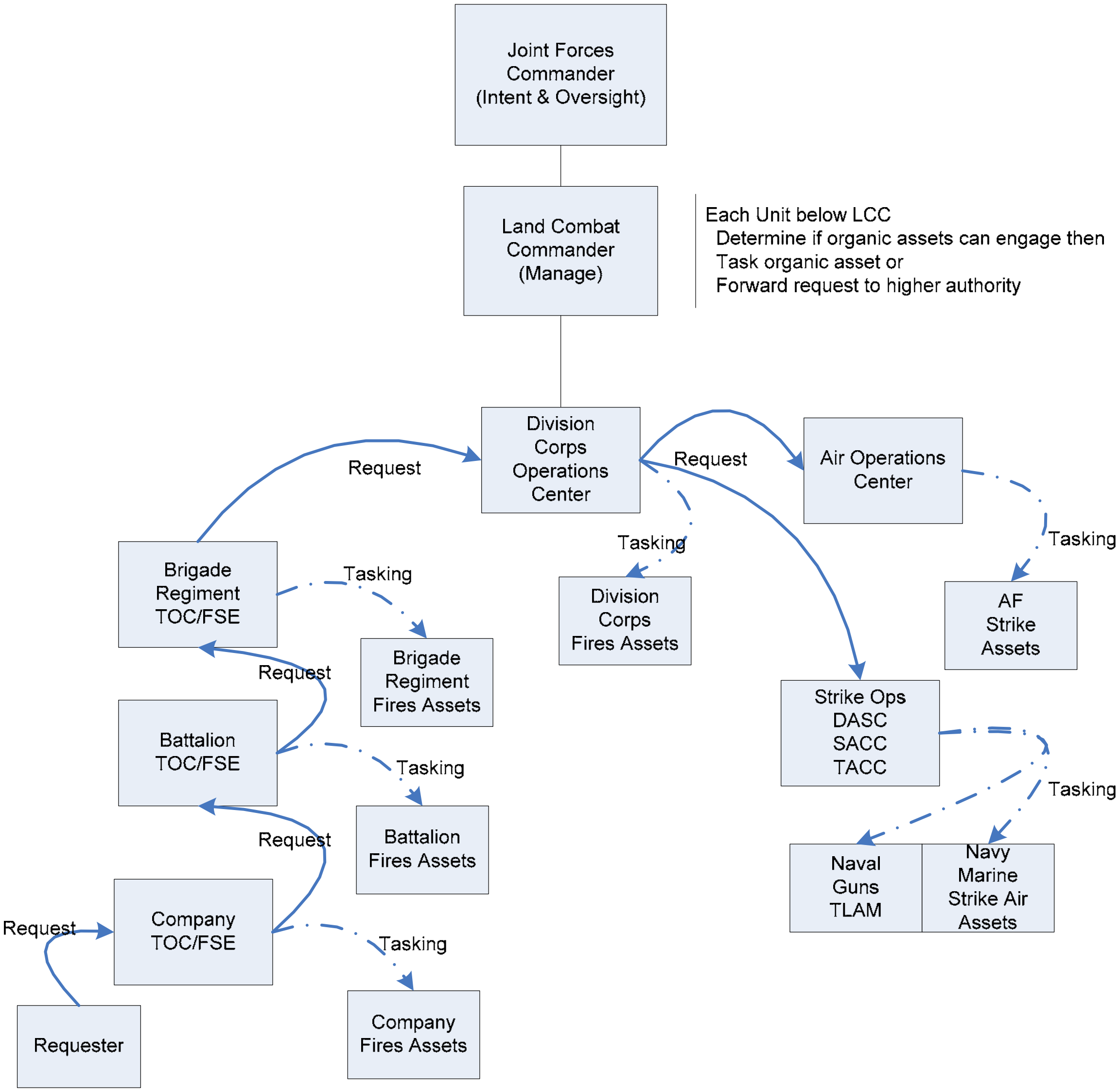

Figure 27: Status Quo Plus Alternative Architecture

The requester is a forward element, such as a FO or JTAC, routing a request for fire support up the chain of command. In this architecture, the call for fire request is sequentially sent to the next organizational level and the target is either engaged with assets available to that organization or the request is forwarded to the next echelon for tasking. If the request is passed up to the Division or Corps Operations Center, that agency has the communications and coordination ability to send the request to a joint functional organization for support, such as the ASOC, DASC, or SACC. The request is then vetted within those organizations and a provider is selected and tasked for support of the request.

3.1.2 Alternative 2: Centralized Joint Fire Support Network

This alternative will enable a fire support request to be sent into a single decision making organization and then allocated and tasked to a provider. Of these three alternatives, this alternative most closely resembles the “911 Call Center” concept discussed in Section 1.5. The requesting unit would send a JFS request to one processing entity that is either a single organization at one physical location (like a JAOC), or geographically dispersed virtual organization. The function of this organization will be to receive, acknowledge, process, pair, and task the requests to a provider. This organization maintains interfaces with and integrates portions of similar organizations such as the SACC, BCD, FFCC, and ASOC.

With respect to doctrine, the roles and missions of the services do not fundamentally change, but both the Joint doctrine and the service doctrine change to reflect functional interoperability with respect to JFS. The Marine Corps remains closely linked to the Navy, and the Army to the Air Force, but broader implementation of JFS procedures improves performance between the pairs. Changes in doctrine have very little impact on the DoD acquisition process or acquisition planning.

With respect to organization and leadership, significant changes to the request routing procedures increase the availability of fire support providers. Headquarters level organizations that previously shared similar functions are consolidated and combined. The organization of JFS-related entities is not as vertical as the current system, especially prior to selection of a provider. The reduction in organizational complexity, the shift from voice to data messages, and technological advances in communication systems result in faster transmission of battlefield data through this JFS network. Overall processing, pairing, and decision making is faster because the JFS resource owners are organizationally intertwined and combined.

With respect to materiel, the services teamed up to develop and field a common data entry device that allows transmission of requests back to the centralized processing agency. This common data entry device is interoperable with artillery systems but not other providers. Interoperability with the other providers is partially achieved through commonality of other installed equipment. Service specific organizations continue to use separate, weapon system-specific equipment to task providers.

Training requirements are simplified for most personnel in the JFS network due to system commonality. The reduction in specialized talents and training reduces manning problems for requesting unit types. As a result of common training requirements, there is a greater diversity of service and functional experience mixed throughout the JFS network. This amalgamation of fire support expertise improves the common knowledge base of personnel within the JFS entities.

This process and the framework for the organization and coordination within the Centralized Joint Fire Support Network alternative is depicted in Figure 28.

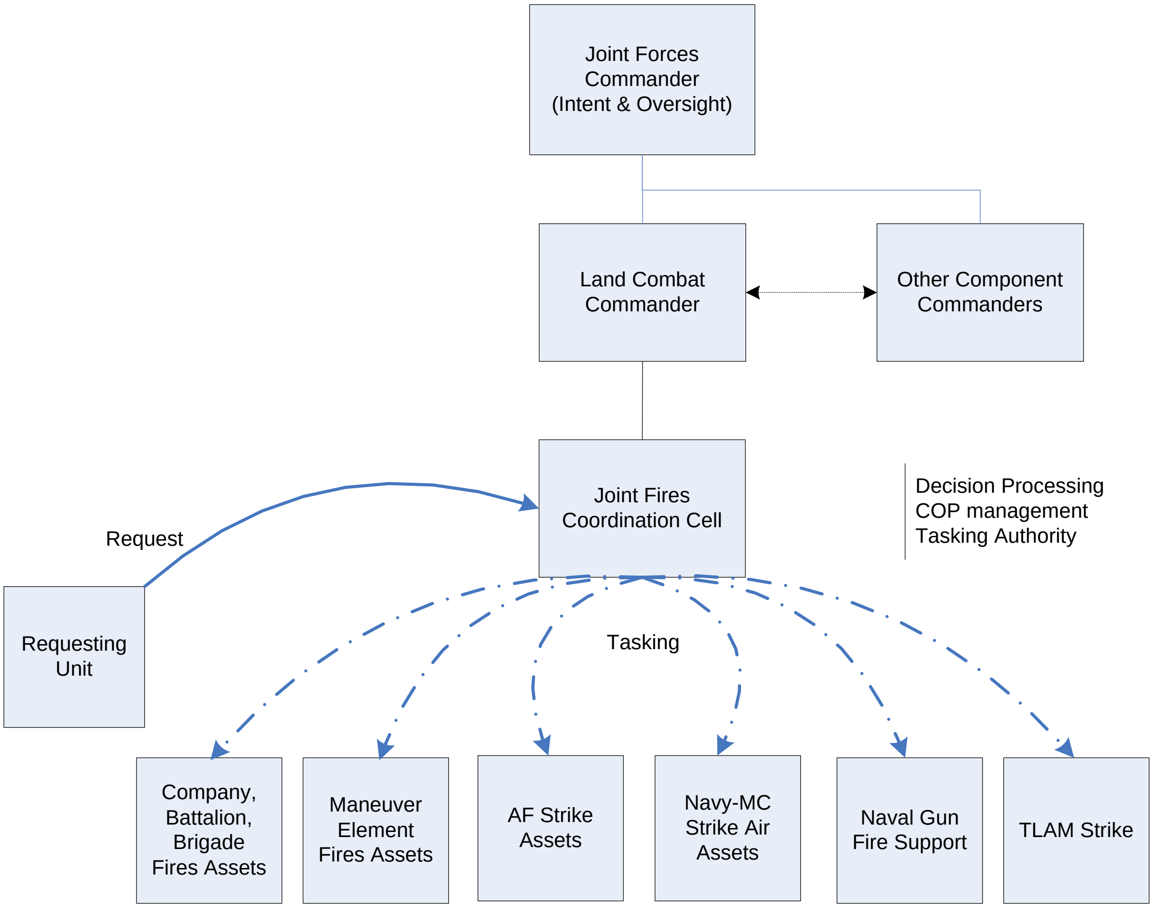

Figure 28: Centralized Joint Fire Support Network Architecture

The Centralized JFS Network functions as follows: the requests for fire would be sent primarily as a digital data packet through RF or IP-based communications, but units would also have a backup ability to send requests using RF voice. A reply acknowledging receipt of the request, and the notification of provider tasking and impending fire support, would be sent back to the requesting unit (via the same method). The effects-based pairing of requests with providers would be accomplished by the Joint Fires Coordination Cell. Weapon system tasking orders would then be formatted to the provider's needs and sent to the tasked weapon system using established or legacy tasking mechanisms. Of course, as with the existing system, if the provider is unable to perform the requested tasking then there will be an option for them to "reclama" the tasking or reply with a "CANTCO" (can not comply) message. The need for this denial of tasking option will be reduced by improving the accuracy of the central processing facility's "available for tasking" list.

3.1.3 Alternative 3: Distributed Joint Fire Support Network

A fully networked force that is able to search and share information globally would have great potential for a JFS request and tasking system. This alternative requires fully internetworked capabilities for all JFS participants, from the ground combatant to the providers. This alternative is conceptually similar to the Distributed Weapons Capability work performed by the John Hopkins Applied Physics Laboratory dealing with Theater Ballistic Missile Defense.[45] To exploit that capability, requesting units send their requests to a fire support database via the Global Information Grid (GIG). A decision algorithm assesses the available providers that are in the database at the time the request was received, processed, and posted. A common algorithm is used to determine the best tasking with regard to weapon effects, deconfliction, and availability and a preferred shooter is selected. Based on the request origin and the proposed provider, a dynamic chain of command is constructed. The pairing is immediately approved by the responsible commander and the fire support provider answers the tasking. In cases where a legacy weapon system is technologically incapable of connecting to the JFS database via the GIG, the functional agency responsible will perform surrogate duties related to the evaluation and algorithm calculation and will task the weapon as appropriate.

With respect to doctrine, in this alternative both the Joint doctrine and each service's doctrine will change significantly to reflect extensive interoperability, especially with respect to JFS. Improvements in Joint doctrine and tactics will effectively eliminate the service pairings of the past—each component is confident and comfortable working with the other. Acquisition planning and procedures evolve to reflect the shift in doctrine.

With respect to organization and leadership, the fluid process of distributed JFS spawns organizations similarly flexible in this alternative

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[45] Shafer, Phillippi, Moskowitz, and Allen, "Distributed Weapons Coordination Conceptual Framework," *Johns Hopkins APL Technical Digest*, Vol. 23, Nos. 2 and 3, 2002, pp. 223-236.

architecture. Dynamic chains of command link requesters with fire support providers and permit oversight based on weapon functionality, not service. All JFS organizations are networked and collaborative. The reduction in tasking complexity, the shift from voice to data messages, and technological advances in communication systems result in faster transmission of battlefield data through this JFS network. Legacy organizations like the SACC, BCD, and FFCC remain only as a back-up capability and are completely integrated.

With respect to the materiel envisioned for this alternative, the services widely field a common data entry device that effectively extends advanced communications capabilities to the "edge" of the battlefield. Not only does it send requests for JFS, but it can also relay information directly to and from the responding fire support providers. Legacy weapon systems continue to rely on voice coordination for engagement. Service-specific legacy C2 systems are either consolidated or eliminated and are maintained and operated jointly based on function.

Training for JFS is "Joint" in nearly all respects in this framework. Because of system interoperability and materiel commonality, there are limited specialization requirements. Common joint training is standard and adequate for any position within the JFS network. Tactics are improved through synergy in JFS execution and planning.

The framework for the organization and data processing of the Distributed JFS Network architecture as well as the flow of the request and tasking is depicted in Figure 29.

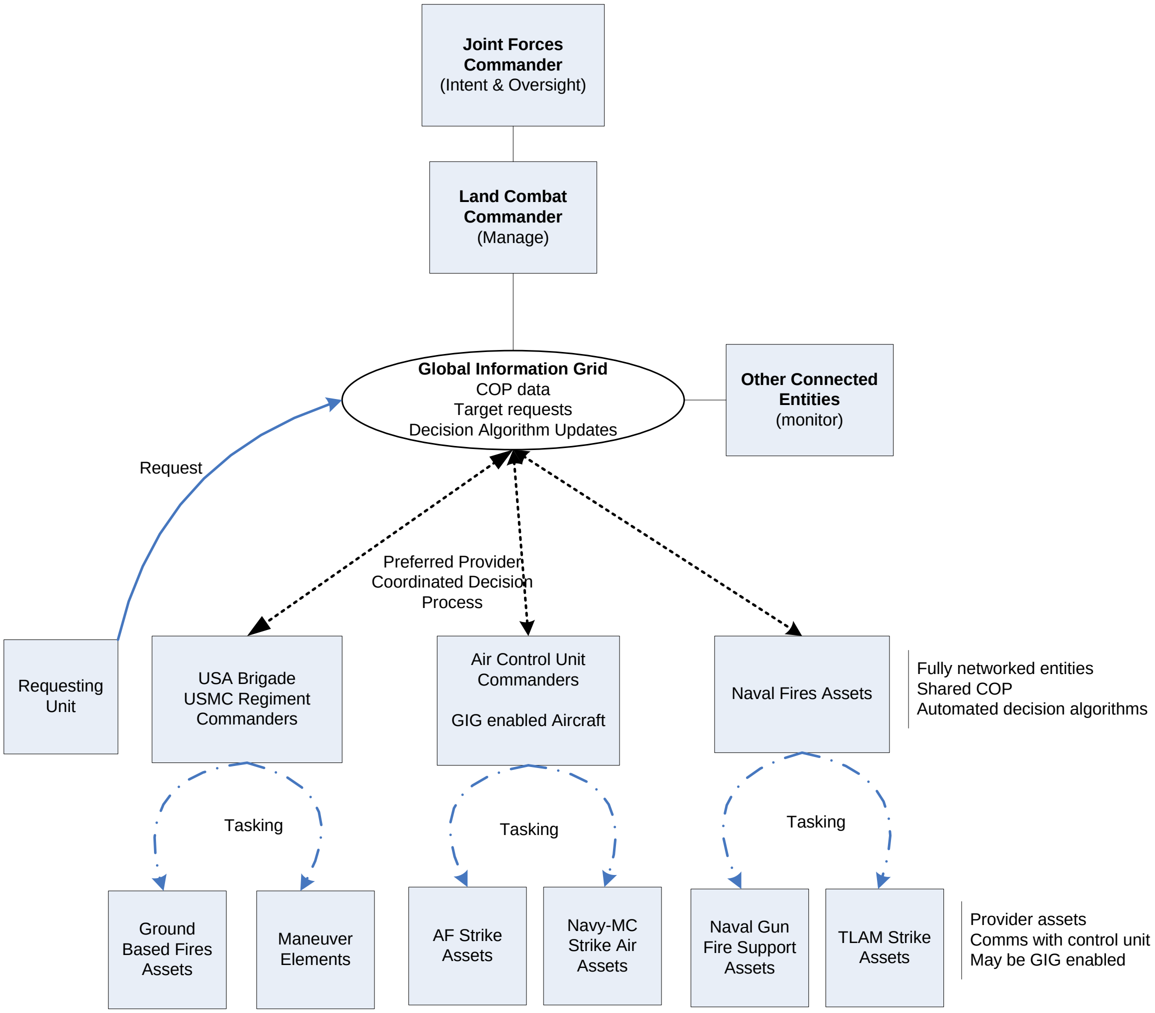

Figure 29: Distributed Joint Fire Support Network Architecture

Within this alternative, there is a potential to "over-communicate" and jam or bog down the network. This alternative assumes a fully networked decision process at the O-5 level command and above. Ships, Brigade Operation Centers, GIG-enabled aircraft (controlling units or CAS) participate in the decision process for themselves and their assigned assets. As the technology becomes realized in the field, the distributed decision process can be pushed further down to the individual units eventually resulting in a fully networked force.

3.1.4 Summary of Alternative Architectures

The three alternative architectures are distinctly different in both structure and approach. A comparative summary elaborates the differences for the reader. Table 5 provides that summary of materiel and non-materiel characteristics for all three alternatives.

Alternative ***Characteristics***	**DOCTRINE**	**ORGANIZATION & LEADERSHIP**	**TACTICS & TRAINING**	**MATERIEL**	**PERSONNEL & FACILITIES**
Status Quo Plus	*-No Change to Existing Service or Joint Doctrine.*	*-No Consolidation of Existing JFS-related Organizations.* *-Functional duplication of capability and effort remains between service-specific JFS Agencies.*	*-No Significant Changes to JFS Training Procedures.* *-Training Changes are Limited to Service-specific Training Needed to Meet Legacy System Improvements.*	*-Faster Comms due to More Efficient Networks (Only between Upper Echelons).* *-Incremental Improvements in Legacy C2 Systems.* *-Data Input Devices are Fielded (Functional or Service-Specific).*	*-No Significant Changes to Facility Requirements.*
Centralized JFSN	*-Joint and Service Doctrine Improvements, but Only with Respect to JFS.* *-Doctrinal improvements have not Transferred to Acquisition Planning.*	*-Consolidation of HQ-level Organizations with Same Roles.*	*-De-facto Improvements to Training.* *-Improvements are due to Bringing Different People & Experiences to Work Together (Air, Arty, Naval Fires Experience).*	*-Faster Comms due to More Efficient Networks (Only between Upper Echelons).* *-Incremental Improvements in Legacy C2 Systems.* *-Common Data Input Device is Widely Fielded.*	*-Cross-functional Organizations Reduce Facility Needs.* *-May be Virtual Based on Comm Capabilities*
Distributed JFSN	*-Fully Joint Doctrine with Corresponding Shift in Acquisition Planning.*	*-All significant JFS organizations are networked at all levels.* *-Dynamic Chains of Command based on Pairings.* *-SACC/FFCC/BCD, etc. are fully interoperable.*	*-Common Joint Training is Standard and Adequate.* *-Commonality Resulting from Elimination of Service/ Functional Specific Equipment* *- Specialization NOT a Premium Skill.*	*-Faster Comms due to More Efficient Networks (All Organizational Levels).* *-Comms at the "Edge" of JFS* *-Consolidation or Elimination of some Legacy Systems.* *-Common Data Input Device is Widely Fielded.*	*-Virtual, Distributed Organizations Change Facility & Manning Needs.*

Table 5: Summary of Materiel and Non-Materiel Architectures

3.2 THREATS AND FUTURE ENVIRONMENT ASSUMPTIONS

The Project Team initially developed numerous scenarios to highlight difficulties in requesting fire support with the as-is system. These scenarios challenged the depth and breadth of the system to illustrate potential calls for fire that required support from another service. The threats examined in these scenarios were similar to current threats. These types were expected to remain the most likely opposing force faced by deployed units through the 2020 timeframe. The proposed system should be capable of supporting a combatant commander during a major theater war, but the more likely future was expected to be comprised of significantly lower intensity conflicts.

The 2006 Quadrennial Defense Review states that a “greater emphasis on the need to address the war on terror and irregular warfare activities including the long duration unconventional warfare, counterterrorism, counter insurgency, and military support for stabilization and reconstructions efforts” is required.[46]

The expected threat included irregular forces operating in a relatively permissive environment. U.S. forces will likely be operating in concert with the host nation supporting counter-insurgency or counter-terrorism operations. Popular support for the insurgent forces could be high in locations. Proliferation of modern military hardware to these forces has continued, resulting in irregular forces equipped comparably to today’s light infantry. Conventional engagements are rare and short lived, but engagements of squad-sized and smaller elements are frequent.

3.3 SCENARIOS

The baseline conceptual scenario consists of a small US ground force element engaged by an equivalent or larger insurgent force. The engaged unit places an effects-based call-for-fire with sufficient precision and timeliness to allow for a variety of fire providers to be considered. The basic scenario is service independent because the challenges facing a JFS request and tasking are not different whether it is a soldier, sailor, Airman, or Marine requesting fire support. Commander’s intent and Rules of Engagement allow clearance of fires and tasking orders to be accomplished by the echelon with control over the providing asset. For example, a company has authority to clear and task mortars under its control, and a brigade authorizes and tasks artillery or helicopters under

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[46] Secretary of Defense, *Quadrennial Defense Review*, Department of Defense, February 2006, p. 4.

its control. A more detailed description of the forces within each simulation or model is described in Chapter 4.

From this generic scenario and expected threat environment, four specific and detailed scenarios were chosen to highlight the depth and breadth of the challenges to the current operations and illustrate the need for improved fire support processing and coordination. These scenario snapshots describe a wide spectrum of potential future operations in order to provide analysis results that are not specific to a particular circumstance. The DoD's recent move to a "capabilities-based" acquisition strategy includes an emphasis on evaluation of alternatives in the context of scenario uncertainty. This is done in order to develop a system that performs well across a wide range of possible situations.

The Rear-Area Ambush scenario describes a situation where an Army unit can not be supported by their own service assets. The Riverine scenario describes a Navy unit that is unable to get support from naval assets. The Urban scenario describes a Marine unit whose own fire support is unavailable. The High-Value Target scenario describes a Special Operations team operating outside the theater of operation and the weapon's range of associated tactical level fire support assets. Each of these instantiations of the common scenario is briefly discussed below.

3.3.1 Rear-Area Ambush

The Rear-Area Ambush scenario was designed to examine the challenges of an Army unit operating outside of the Army's established ground based fire support assets. An Army convoy transiting a coastal road behind the fire support zone is ambushed by irregular forces. The convoy is lightly armed, consisting of several High Mobility, Multi-purpose Wheeled Vehicle (HMMWV) escorting several re-supply trucks. An Expeditionary Strike Group, including a Navy destroyer, equipped with extended range guided munitions and tactical missiles, and Marine aviation strike aircraft are operating off the coast. These fixed and rotary wing attack aircraft, along with naval surface fires are available to the combatant commander as potential providers. The geography of this scenario is shown in Figure 30.

Figure 30: Army Call for Fire

3.3.2 Riverine

This scenario was designed to explore the challenges of the newly formed Navy Riverine Force operating without direct support from Navy-Marine Corps aircraft based on a Carrier or Expeditionary Strike Group. A four-boat naval riverine unit conducting patrols along an isolated section of the river comes under fire from hostile forces along the river. Assumed forces include the 4 small boats with .50 caliber and smaller weapons, while joint fires providers available are Air Force CAS assets, Army artillery, and Army attack helicopters.

The current concept of operations would place these naval riverine forces under the operational control of the maritime component commander, and a request for fires support within the context presented would necessitate coordination within the joint forces commander’s staff. Horizontal communication directly to the Army Battalion operating adjacent to the river would only be available if pre-arranged as an ad-hoc set up. The geography of this scenario is illustrated in Figure 31.

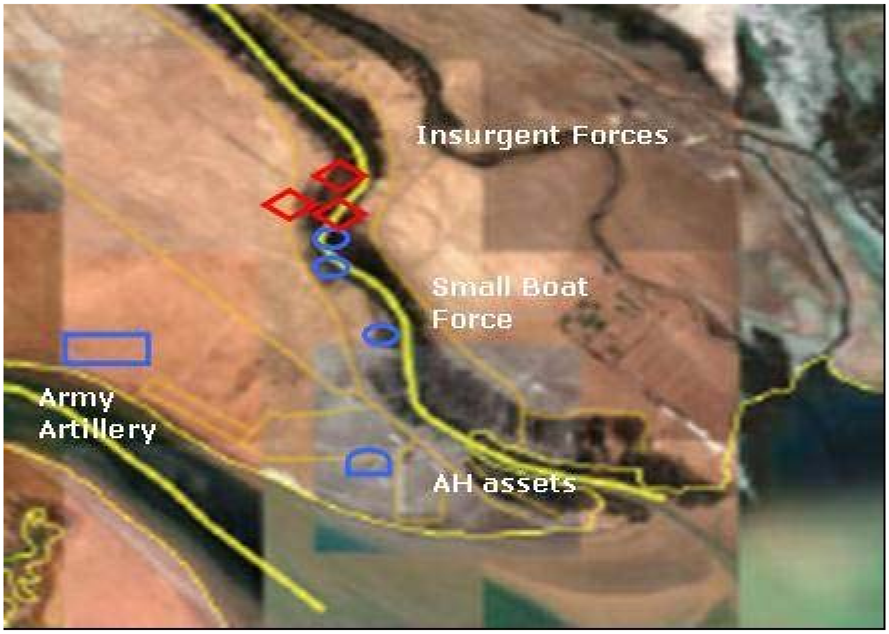

Figure 31: Navy Request

3.3.3 Urban

This Urban scenario is designed to explore the fire support options of a Marine patrol in joint fires environment. The geography and rules of engagement in this scenario limit indirect fires to a counter-battery nature only. This limits the options of fire support responders to precision guided munitions, preferably aircraft delivered.

There is no direct link from the engaged element directly to the proposed Air Force CAS assets. The connection to Air Force assets would require coordination between the DASC and ASOC through the JOC. Understandably, an ROE restrictive environment may demand higher authority for an engagement order, but the current system for routing the request through the various parallel command structures places increased risk on the operating forces. The geography of this scenario is shown in Figure 32.

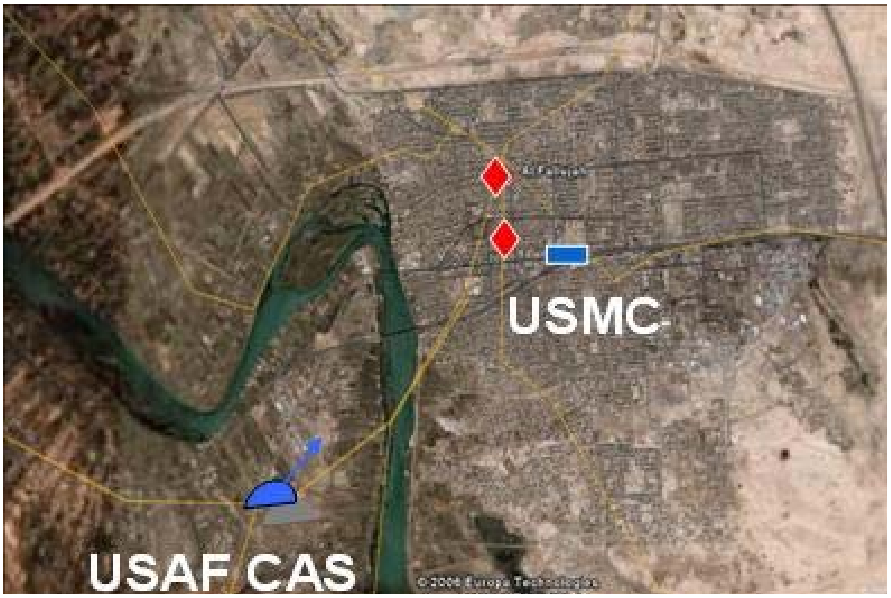

Figure 32: USMC Request

3.3.4 High-Value Target

The High-Value Target scenario was designed to explore the depth of command to approve engagement of a High-Value Target discovered outside the established area of operations of regular forces. Special Operations Forces, remote from the combat zone, locate a target of national interest. Due to target location, the request for fire will require approval from National Command Authority and strategic assets will be considered as possible firepower providers.

Irrespective of the requester and provider, the proposed system must allow communication to the appropriate level of command for authorization and tasking shown above. This highlights the depth of the command structure compared to the others which examine joint information and control across the chain of command. The notional geography of this scenario is shown in Figure 33.

Figure 33: SOF Request for High Value Target

These scenarios represent instantiations of a common scenario: a call for fire from an engaged element that requires tasking of an asset outside of his service and normal communications paths.

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4.0 OPERATIONAL ARCHITECTURE

The functional and physical alternatives were used to develop the system operational architecture. According to Buede, "the process of developing the operational architecture….is the only activity in the design process that contains the material needed to model the system's performance and enable trade-off decisions."[47]

Because the physical design of a JFS system in the year 2020 is a necessarily abstract system, the operational architecture is analyzed from a similar abstract perspective. Very little, if any, of the physical systems or software identified in the physical architectures exist today. The operational architecture therefore focuses on the comparisons of doctrinal, organizational, and tactical structures at a high level of abstraction.

4.1 MODELING ALTERNATIVES

The modeling techniques selected are grouped into two broad categories: qualitative modeling and quantitative modeling. Qualitative modeling is used to compare aspects of the alternatives that could not be physically measured, such as degrees of interoperability and usability of a system. Qualitative assessments of the material system utility and system design risks are addressed separately. Quantitative modeling enabled more traditional analysis of performance between architectures based on the Project Team's identified metrics.

The tools used in the team's modeling efforts included discrete event simulations, agent-based simulations, and simple numerical and statistical simulations. The software programs used to create these simulations and analyze the results included the Microsoft EXCEL™, Imagine That Inc. EXTEND™, New Zealand Defense Technology Agency MANA, US Army DAFS, and Minitab Inc. MINITAB™. The metrics identified during earlier phases of the study are assessed and appropriate methods of analyzing and measuring them

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[47] D.M. Buede, *The Engineering Design of Systems*, John Wiley & Sons, Inc., 2000, p. 246.

are investigated. The models used to measure these metrics are identified in Table 6.

Functions	System Objectives	Metrics	Model
Coordination	Standardized Process	# of Systems Involved	*Spreadsheet Model*
		# of Decision Points	*Spreadsheet Model*
	Horizontal & Vertical Integration	# of Steps in the Process	*Spreadsheet Model*
		# of Process Gaps	*Spreadsheet Model*
Request, Process, Task	Reduce Time to Process	Processing Time	*EXTEND Simulation*
		Blue Force Casualties	*MANA Simulation*
	Effects-based Pairing	Pairing Effects Ratio	*EXTEND-EXCEL Sim*
Operational Feasibility	Availability	Subjective Assessment	*Future Studies*
	Interoperability	Subjective Assessment	Risk Assessment
	Usability	Subjective Assessment	*Future Studies*
	Reliability	Subjective Assessment	Reliability Assessment
	Sustainability	Subjective Assessment	*Future Studies*

Table 6: Models and Simulations Used (by Metric)

4.2 QUALITATIVE SPREADSHEET MODELING OF JFS PROCESS ALTERNATIVES

Each of the proposed alternatives requires different message processing and coordination steps. A descriptive model of each proposed JFS alternative was constructed and the processes, organizations and systems involved with a variety of joint fire support requests (based on the scenarios in Section 3.3) were studied. This analysis produced three conclusions:

1) CJSFN had the fewest number of decision steps and process delays

2) DJSFN & CJFSN had the fewest systems and process gaps

3) The Status Quo Plus had the most steps for all categories

The models used to arrive at these conclusions are described below.

4.2.1 Spreadsheet Model Description

This static model traces the process delays and value added steps in the fire support request process. This includes steps when the data is reformatted and transferred from system to system (i.e., an AFATDS data file is manually reformatted into a voice radio transmission to an airborne platform) and the updates or changes to the common operating picture command and control data that are necessary for decision making.

The metrics specifically assessed in this model include: the number of different systems/equipment items needed, the number of decision points (actions taken), the number of steps needed to complete a joint fire support request, and the "process gaps" between those systems. A process gap is defined as a process step where data has to be transformed from one type to another (i.e. a data file is manually converted to voice or different data format) or where a new system input must be compared to the previously developed target information. For example, an Army call for fire to Marine Corps artillery is coordinated using the CPOF C2 system. When this request is sent to the Marine Corps, the target information may be re-validated through C2PC, GCCS-M, and/or TBMCS before organization approval may be obtained.

In order to explore the depth and breadth of the expected JFS environment, this analysis was performed for each of the four scenarios concepts and the results were averaged for comparison.

4.2.2 Spreadsheet Model Assumptions

A number of assumptions were made in this system analysis. First, the communication backbone was assumed to exist. This backbone is currently being referred to as the Global Information Grid (GIG). Counting the system permutations possible within the GIG is well beyond the scope of the project. Second, for both the CJFSN and DJFSN alternatives several fully interoperable (or common) systems are available. The system functions for AFATDS, NFCS, and any other future battlefield aid are assumed to be fully interoperable (or common). Facilitating this and enhancing interoperability with other radio systems, all fielded tactical radio systems conform to the roadmap of the JTRS program. Airborne radios are all assumed to be interoperable with a JTIDS or a JTIDS-like standard. This infers complete interoperability with JTRS. Finally, in accordance with the JBMC2 Roadmap recommendations, all C2 systems will be interoperable (or common) in this model.

4.2.3 Spreadsheet Model Results

Tables which fully outline the modeling results for each scenario may be found in Appendix I. A summary table of the model metrics is shown in Table 7.

		Status Quo +	Centralized JFSN	Distributed JFSN
URBAN	Average # of Steps	10.2	6.8	7.8
	Average # of Process Gaps	5.0	1.4	1.2
	Average # of Process Delays	6.8	4.8	5.7
	Average # of Systems Needed	9.0	3.0	3.0
CONVOY	Average # of Steps	10.0	8.2	8.8
	Average # of Process Gaps	4.2	1.7	1.7
	Average # of Process Delays	8.0	6.6	7.2
	Average # of Systems Needed	9.8	3.0	3.0
RIVERINE	Average # of Steps	8.6	7.2	8.2
	Average # of Process Gaps	4.8	2.2	2.0
	Average # of Process Delays	7.2	4.5	6.8
	Average # of Systems Needed	9.6	3.8	4.0
HI VALUE	Average # of Steps	19.0	14.5	15.0
	Average # of Process Gaps	8.5	3.0	3.0
	Average # of Process Delays	16.0	11.5	12.0
	Average # of Systems Needed	13.5	5.0	5.0

Table 7: Summary Table of Model Metrics for All Alternatives.

Lower values generally equate to a more preferred process (i.e., the fewer the processing delays the better the system will perform) and these lower values are individually highlighted in the table rows.

The average number of steps and the number of potential process delays in the alternatives are highly correlated and may be used interchangeably to describe the general behavior of the other. The organizational designs of the CJFSN and DJFSN alternatives have fewer steps than Status Quo Plus. Interestingly, DJFSN, which is the most automated alternative, has about one more step on average than CJFSN. This is due to the addition of the decision algorithm while maintaining a coordination step with the organization formerly responsible for the decision.

The average number of systems used is most highly sensitive to the number of C2 systems of record in use. The Status Quo Plus alternative retains the portfolio of C2 systems in use today whereas the other alternatives assume only one fully interoperable C2 system for all the services. For CJFSN and DJFSN, the average number of systems used approached the bottom limit of the model; one system for the data transfer, one system for the weapon control system, and one C2 system of record.

Finally, the average number of process gaps declined in step with the decrease in number of systems used. Based on our counting methods (see Appendix I), the ratio of process gaps to number of systems needed stayed relatively constant (2 process gaps: 3 involved systems). The averages of all of these metrics across all four scenarios are summarized in Table 8.

For All Scenarios:	**Status Quo Plus**	**Centralized JFS Network**	**Distributed JFS Network**
Average # of Steps	***12.0***	***9.2***	***10.0***
Average # of Process Gaps	***5.6***	***2.1***	***2.0***
Average # of Process Delays	***9.5***	***6.9***	***7.9***
Average # of Systems Needed	***10.5***	***3.7***	***3.8***

Table 8: Relative System Preferences.

This model reveals a preference of either CJFSN or DJFSN over Status Quo Plus. CJFSN may have slightly better performance than DJFSN.

4.3 QUANTITATIVE MODELING

The nature of the proposed system and the timeframe that it will exist within posed challenges to the overall modeling approach. The physical components that are proposed to make up the physical alternatives do not fit the standard agent-based modeling tools directly and networking analysis can rapidly become too complex to complete with team resources. To cope with this challenge, the Project Team developed several smaller models from a functional perspective (e.g., basic system transactions).

The modeling and analysis efforts were separated into three areas: analysis of organizational alternatives (including overall communication system disconnects and process delays), simulation of the pairing and decision making processes, and estimation of communication impacts on JFS performance in an agent-based simulation.

4.3.1 Modeling and Simulation of Organizational Alternatives

A discrete event simulation was used to analyze the proposed JFS network communication and coordination pathways in the organizational alternatives. This model represented the flow of valid requests from engaged ground elements through appropriate command elements to the provider and was built in EXTEND6^{TM}. This simulation was designed to evaluate the average time to process a call for fire from request to tasking for each of the three alternatives.

The simulation generates requests for tasking, and routes them through a series of modeling blocks representing message processing entities, transmission delays, and decision makers. To gain insight into expected performance, consistent assumptions and components were used to model the processes in each alternative. These models and subsequent analysis produced two conclusions:

1) DJFSN results in the overall fastest time to task fire support providers
2) The CJFSN process was quicker than the Status Quo Plus alternative

The following section focuses on a discussion of the modeling constructs that represent the decision flow through each alternative command and control organization. Assumed values for system parameters that represent capabilities for each alternative are presented, as well as the other parameters that remained constant for each alternative. A more detailed description of how these models were built is contained in Appendix J.

4.3.1.1 Organizational Model Descriptions

The Status Quo Plus model, simplified in Figure 34, represents a baseline case for a notional forward observer generating a call for fire and sending that request to its commanding unit, in this case the responsible company. This company-level unit evaluates its capability to engage the target with organic assets. The company then engages the target or forwards the request to the battalion. The battalion then either engages with assets under its control, or forwards the request to the brigade. Similarly, the brigade then engages or forwards the request for the joint force commander to provide air or naval strike assets.

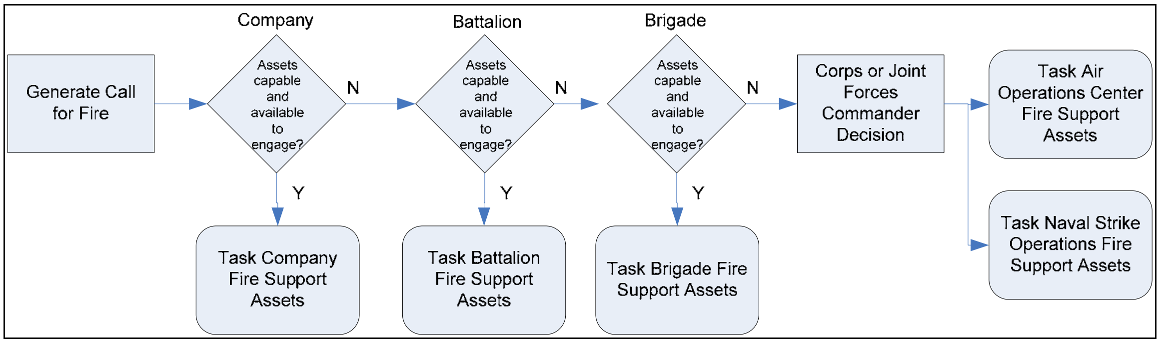

Figure 34: Status Quo Plus Organization Model.

The Centralized Joint Fire Support Network model is depicted in Figure 35. A call for fire is generated by a notional forward element as in the Status Quo Plus model, but now it is sent directly to the Joint Fires Cell (JFC). The JFC then processes the request, provides a target-provider pairing, deconflicts the air space, and authorizes the tasking. The tasking order is then sent to the applicable fire support provider asset.

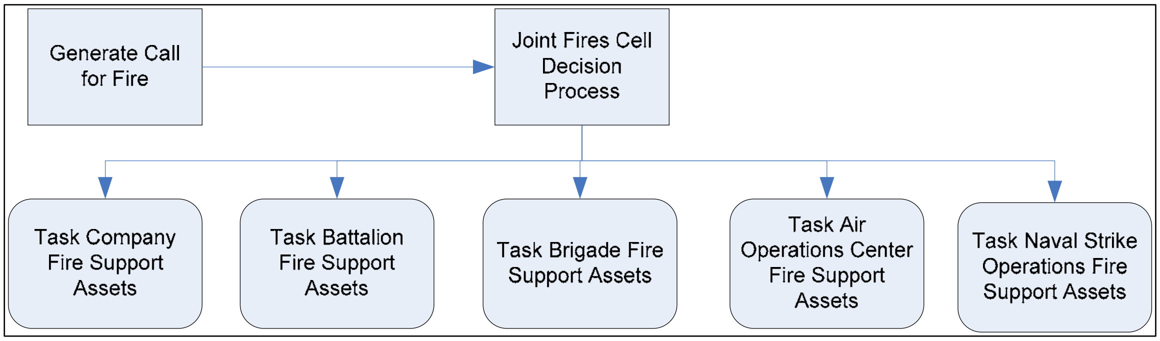

Figure 35: Centralized Joint Fire Support Network Organization Model.

The Distributed Joint Fire Support Network model is depicted in Figure 36. The same call for fire is generated by the notional forward element but it is now submitted to a target database via the Global Information Grid. This automated provider-based decision process results in a tasking order to the "best" provider based on a common decision algorithm and operational picture held at each command. This process includes all O-5 and higher commands (brigade and above ground units, ships, and aircraft) that control fire support assets collectively evaluate their capability to engage the target. The EXTEND6^{TM} block diagram flow and parameters for each of these alternatives are detailed in Appendix J.

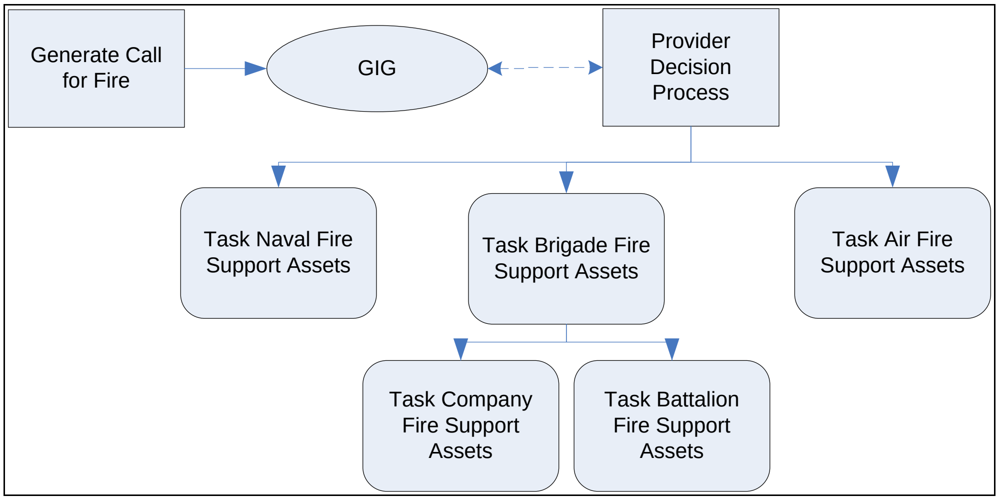

Figure 36: Distributed Joint Fire Support Network Organization Model.

4.3.1.2 Organizational Model Assumptions

There are several key assumptions in this abstract model. The first of these is distribution of target types and the weapons that are used against those target types. The notional opposing force presented 50% targets that were Type 0 and are able to be directly engaged by company level assets. Target Types 1 to 4 required sequentially higher echelon assets to be tasked against them. The probabilities listed in Table 9 were used to generate requests with these generic target types.

Generic Target Type	Probability	Provider	Assets
0	50%	Company	60
1	20%	Battalion	120
2	15%	Brigade	96
3	7%	Naval Fires	30
4	8%	Close Air Support	2 / 40 minutes

Table 9: Organization Model Target Probability Distribution Function Inputs.

Weapon-target pairing was not specifically modeled in this simulation. The target type abstractly represents the target characteristics, weapon pairing, and deconfliction of the “best” provider. The number of provider assets available was made sufficiently large enough that all of the targets presented could be appropriately prosecuted. A summary of the model input data is presented in Table 9.

Communications connectivity was assumed to be perfect and all of the targets presented were valid. All CFFs resulted in tasking orders, and were tasked to the notional “best” provider. Delays for processing, pairing, deconfliction, and authorization in each alternative were applied from statistical distributions. These average processing delay times were based on the judgment of the Project Team and other Subject Matter Experts. The average engagement times were based on a summary of response time data from Raytheon[48] and RAND[49] reports, stakeholder input, and team observations of the CFF request process at the National Training Center and AIR WARRIOR. Table 10 summarizes these delays by alternative.

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[48] U. S. Marine Corps Marine Corps Combat Development Command, “Marine Corps Fire Mission Profiling Through Experimentation with Real and Simulated Systems,” Raytheon, 2006, pp. 1-16.

[49] Pirnie, Vick, Grissom, Mueller, Orletsky, “Beyond Close Air Support,” RAND, 2005, pp. 78-161.

	Status Quo +	CJFSN	DJFSN
Initial Call for fire request	0.5	0.5	0.5
Engagement Times			
Company Asset	3	3	3
Battalion Asset	3	3	3
Brigade Asset	3	3	3
Close Air Support	10	10	10
Naval Fires	10	10	10
Process and Tasking Times			
Company Asset	3	5	3
Battalion Asset	5	5	3
Brigade Asset	5	5	3
Close Air Support	3	5	3
Naval Fires	3	5	3
ASOC/DASC/JOC	5		
Joint Fires Cell decision		5	
GIG collaborative decision			3

Table 10: Summary of Simulation Delays (Minutes).

4.3.1.3 Organizational Model Results

The model results were output to a spreadsheet for analysis in MINITAB^{TM} to evaluate the average processing time for each alternative. A more detailed description of the analytical results is discussed in Appendix J. The null hypothesis for all considerations is that there is no processing time difference caused by target type or alternative system. Analysis of variance (ANOVA) was conducted to reject or accept this hypothesis based on the simulation data. Because the assumed statistical distributions for processing time were not symmetrical, the assumption of normally distributed data required for ANOVA was suspect and a non-parametric (Kruskal-Wallis) analysis was conducted to confirm the results.

The ANOVA results rejected the null hypothesis for the full target set. The choice of Alternative System (F statistic=391, p=0.0000) had a statistically significant difference in response time, indicating at least one system is different from the others. Non-parametric results showed statistically significant differences and ranked system performance as DJFSN, CJFSN, then

Status Quo Plus (slowest). Figure 37 is a boxplot of the median delay times for each alternative.

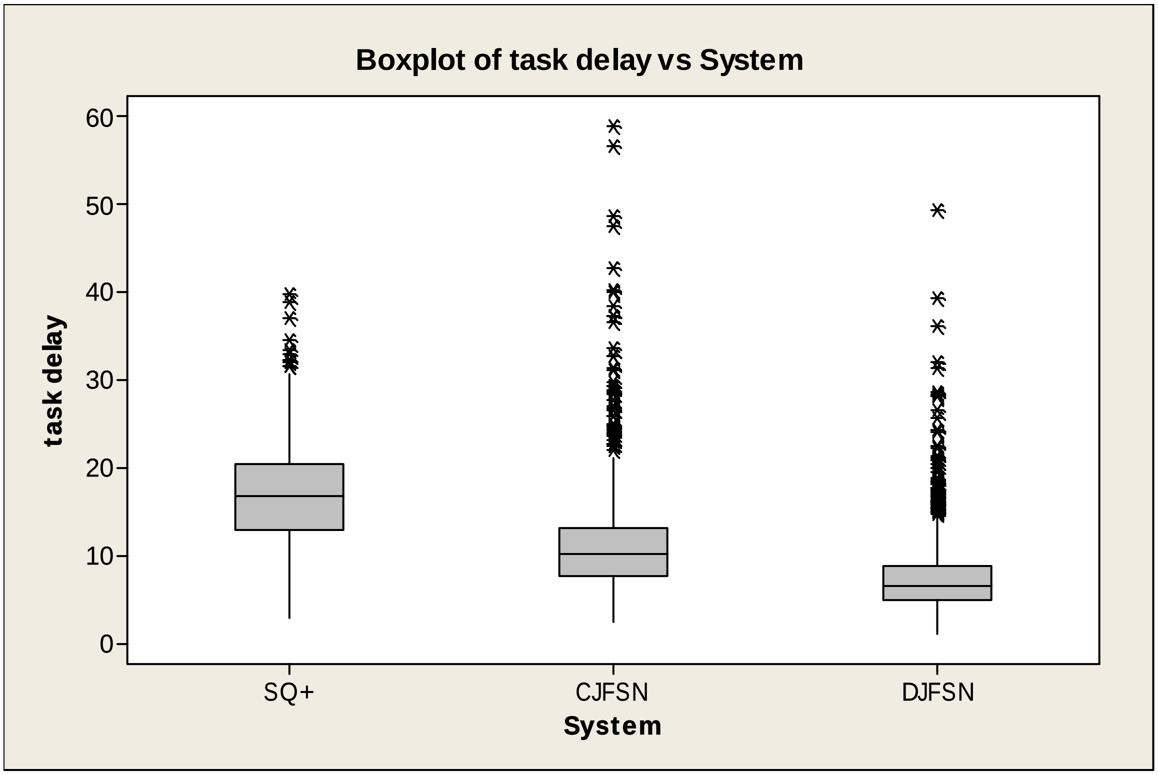

Figure 37: Boxplot of Organizational Delay Times.

In order to examine the effects of the various distribution means (the input simulation delays described in Table 10) on the performance of each system, a sensitivity analysis was conducted. Each parameter was individually varied and the overall mean tasking times were calculated for 30 runs. Of all parameters altered, only the target type distribution demonstrated an interaction with system response time. As more targets requiring a tasking above the company level (target types 1 to 4) were generated, Status Quo Plus system performance degraded while DJFSN and CJFSN alternatives remained about the same. Further detail of the statistical analysis and results is contained in Appendix J.

Overall, the DJFSN system required the least amount of time to processing a call for fire, followed by the CJFSN then Status Quo Plus.

4.3.2 Modeling and Simulation of Pairing Effectiveness

The effectiveness of request-provider taskings is a key factor in the analysis of alternative architectures. The applicable portion of the Effective Need described a requirement to “maximize rapid battlefield effects through efficient target-provider pairings.” The pairings of targets and providers was simulated by interlaced models that ran simultaneously within EXTEND6^{TM} and EXCEL^{TM}. The models that represented the three alternative architectures were distinct variations of a common model. These models were designed to evaluate the differences in overall pairing effectiveness achieved when considering either all available providers (in the CJFSN and DJFSN alternatives) or engagement with first available asset (Status Quo Plus).

These models and subsequent analysis produced two conclusions and an interesting observation:

1) An effects-based pairing algorithm improves engagement effectiveness over a service-based pairing methodology.

2) Pairing effectiveness was not sensitive to the differences in processing delay times between the CJFSN and DJFSN..

Observation: A pairing algorithm capable of rapidly producing thousands of engagement recommendations can be built to support future JFS systems.

The following section describes the steps taken to arrive at these conclusions. The model describes the processing and decision actions as the data flows through each alternative weapon-target pairing simulation. Although all of the simulation scenario structures describe an Army requester, the joint relationships are what determine the results and the requester can just as easily be modeled as a different entity if the names in the rest of the model are changed appropriately. A summary of the analytical results of the simulation data is presented as a basis for comparison of each alternative.

4.3.2.1 Pairing Model Descriptions

The simulation models each process and task an identical sequence of calls for fire that include target type, target location and desired effects. Within each model, these requests are routed through the alternative pairing processes and a notional effectiveness is then applied to the target (an estimated “probability” of achieving the “requested effect”) based on the resulting weapon-target pairing. The notional effectiveness applied to the requested target was then compared to the best possible effectiveness for that target type, location, and requested effects. A more detailed description of the models, assumptions, and results are contained in Appendix K.

The Status Quo Plus model, represented by the flow shown in Figure 38, represents a baseline case for a notional forward observer generating a call for fire that is sent to the responsible company. Each level in the hierarchical command structure (company, battalion, and brigade assets) evaluates its capability to engage the target. If they cannot service the target due to a lack of available providers/weapons, then they forward the request up the chain. Eventually, the target is engaged by the Army or forwarded to Air Force CAS. If AF CAS assets are available, then the target is engaged by AF CAS, otherwise the request is forwarded to the JOC for tasking of naval surface fires, Marine artillery, or Navy-Marine Corps CAS assets.

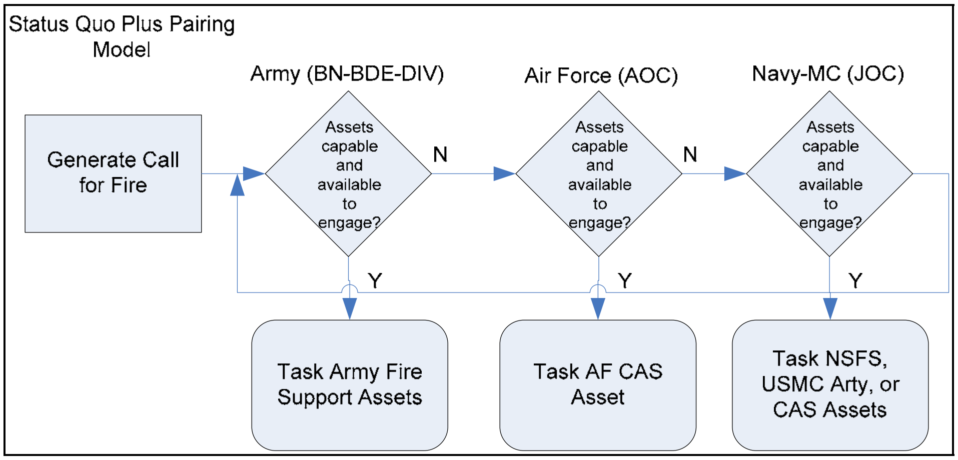

Figure 38: Status Quo Plus Pairing Model.

An effects-based pairing model representing the CJFSN alternative is depicted in Figure 39. A call for fire was generated and sent to the Joint Fires Cell. A list of prioritized providers was generated by the JFC based on target type and desired effects using a weapon effectiveness table described in the assumptions below. A target location filter then removes providers that are infeasible (out of range) from the prioritized provider listing. The process then sequentially evaluates the availability of the remaining prioritized provider assets and tasks the best one available, regardless of service.

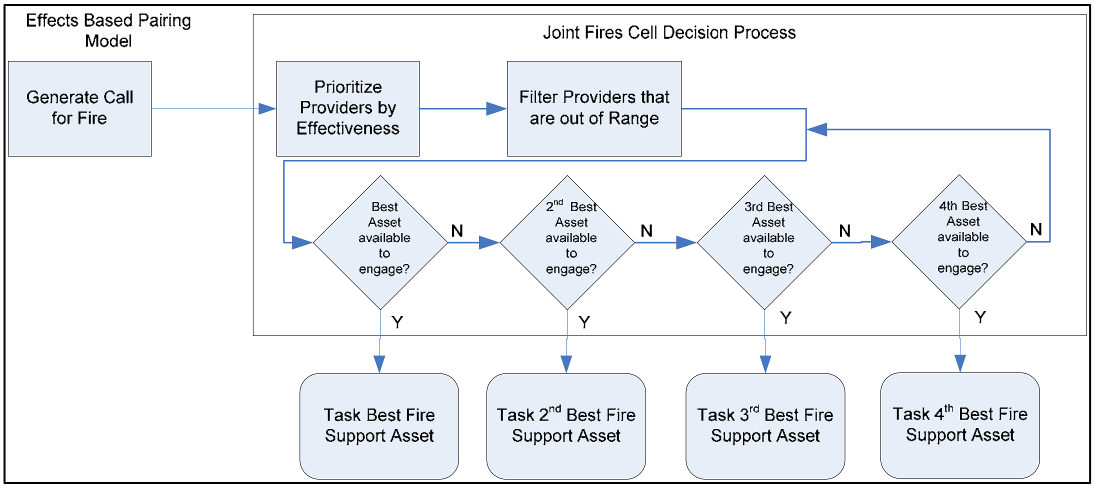

Figure 39: Effects Based Pairing Model.

The same effects-based pairing process was used by the DJFSN model, but the processing and coordination delays were different, representing that model's communications and coordination capabilities.

4.3.2.2 Pairing Model Assumptions

The engagement and decision delays developed in the Organizational Alternatives Models (Section 4.3.1) were used as the input for the average time delays within the pairing models. An additional engagement delay time of 3 minutes was added to these process delay times to estimate the total time from arrival of the requests and engagement of the target. The quantity and effectiveness of providers were kept constant between all three alternative models. The input delay assumptions are listed in Table 11.

Alternatives	**TASKING TO ARMY ARTILLERY**	**TASKING TO AF CAS**	**TASKING TO MARINE ARTILLERY**	**TASKING TO NAVAL FIRES**	**TASKING TO NAVY/USMC CAS**	**ENGAGEMENT TIME**
Status Quo Plus	*Mean: 14 min* *SD: 4 min*	*Mean: 17 min* *SD: 5 min*	*Mean: 19 min* *SD: 4 min*	*Mean: 20 min* *SD: 5 min*	*Mean: 24 min* *SD: 5 min*	+ *3 Minutes*
Centralized JFS Network	*Mean: 10 min* *SD: 5 min*	*Mean: 10 min* *SD: 5 min*	*Mean: 10 min* *SD: 5 min*	*Mean: 10 min* *SD: 5 min*	*Mean: 10 min* *SD: 5 min*	+ *3 Minutes*
Distributed JFS Network	*Mean: 7 min* *SD: 4 min*	*Mean: 7 min* *SD: 4 min*	*Mean: 7 min* *SD: 4 min*	*Mean: 7 min* *SD: 4 min*	*Mean: 7 min* *SD: 4 min*	+ *3 Minutes*

Table 11: Pairing Model Processing and Engagement Delay Assumptions

An identical target list of 1000 targets was generated for all of the simulation models. This list of target types, desired effects, locations, and request arrival times was randomly determined beforehand and then fixed for all of the simulation runs. The Target type probability was evenly distributed among the 10 options, and the targets were generated in locations that were evenly distributed across a notional battlefield. The assumption was made that Army Artillery, Marine Artillery, and Naval Fires would have similarly sized, overlapping areas of fire support capability that would permit them to collectively service 85% of the target locations. The statistics for the 1000 calls for fire are given in Table 12.

1000 Requests, Arrival Intervals Randomly Distributed 0-3 min		**Target Types**	**%**
		Troops in the Open	10%
Effects Type Requested	**%**	Entrenched Troops	11%
Harass	5%	Trucks	9%
Suppress	15%	Armored Personnel Carriers	12%
Neutralize	48%	Armor/Tanks	11%
Destroy	33%	Bunker/Hardened Structure	8%
Targets within Range of:	**%**	Logistics/Assembly Site	10%
Artillery (Army, Marine Corps) or Naval Fires	86%	Artillery Battery	9%
		C2 Site	10%
CAS (AF, Navy, USMC)	100%	SAMs/SCUDs	10%

Table 12: Pairing Model CFF Inputs

The requested effects type categories, and the distribution of those requested types, were derived from stakeholder input and Army Field Manual 6-30. To meet the request for "Harass" effects, the enemy simply needs to be concerned about the presence of enemy fires. Suppression effects on a target "limits the ability of the enemy personnel in the target area to perform their jobs." [50] To achieve the desire effect of Neutralizing a target, it must be "knocked out of action temporarily… Neutralization does not require an extensive expenditure of ammunition and is the most practical type of mission."[51] Destroy was the most severe requested effect and according to the Army, "Destruction puts a target out of action permanently." [52] Interviews with Subject Matter Experts (SMEs) determined that roughly 50% of CFFs request "Neutralize" effects, 30% request "Destroy" effects, and the remainder request primarily "Suppression" effects. The distribution of requested effects was outlined in Table 12.

The predicted effectiveness of each weapon assumed in the model is based on requested effects and target type. These weapon-target pairing effectiveness percentages are listed in Table 13 and are roughly based on Joint Munitions Effectiveness Manual (JMEM) and stakeholder/SME estimates.

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[50] Department of the Army, *Tactics, Techniques, and Procedures for Observed Fire*, Field Manual 6-30, July 1991, p. 4-9

[51] Ibid

[52] Ibid

REQUESTED EFFECT	TARGET TYPE	ARMY ARTY	AF CAS	USMC ARTY	NAVAL FIRES	NAVY/MC CAS
Harass	Troops in the Open	98%	25%	98%	96%	25%
	Entrenched Troops	60%	20%	60%	50%	20%
	Trucks	75%	40%	75%	73%	40%
	APCs	60%	45%	60%	53%	45%
	Armor	50%	45%	50%	48%	50%
	Bunker/Hardened Structure	50%	20%	50%	47%	20%
	Logistics/Assembly Site	98%	33%	98%	96%	33%
	Artillery Battery	25%	40%	25%	33%	40%
	C2 Site	94%	28%	94%	93%	28%
	SAMs/SCUDs	87%	7%	87%	85%	7%
Suppress	Troops in the Open	82%	47%	82%	35%	47%
	Entrenched Troops	41%	32%	41%	40%	32%
	Trucks	62%	47%	62%	60%	47%
	APCs	51%	49%	51%	49%	49%
	Armor	39%	48%	39%	36%	48%
	Bunker/Hardened Structure	30%	51%	30%	29%	51%
	Logistics/Assembly Site	79%	36%	79%	75%	36%
	Artillery Battery	19%	44%	19%	26%	44%
	C2 Site	77%	36%	77%	74%	36%
	SAMs/SCUDs	72%	6%	72%	71%	6%
Neutralize	Troops in the Open	73%	69%	73%	71%	69%
	Entrenched Troops	32%	41%	32%	31%	41%
	Trucks	49%	62%	49%	48%	62%
	APCs	40%	54%	40%	38%	54%
	Armor	26%	57%	26%	25%	57%
	Bunker/Hardened Structure	13%	63%	13%	13%	63%
	Logistics/Assembly Site	54%	52%	54%	52%	52%
	Artillery Battery	12%	58%	12%	14%	58%
	C2 Site	61%	52%	61%	59%	52%
	SAMs/SCUDs	59%	5%	59%	63%	5%
Destroy	Troops in the Open	51%	63%	51%	50%	63%
	Entrenched Troops	23%	49%	23%	22%	49%
	Trucks	37%	77%	37%	35%	77%
	APCs	21%	81%	21%	20%	81%
	Armor	9%	74%	9%	5%	74%
	Bunker/Hardened Structure	7%	72%	7%	26%	72%
	Logistics/Assembly Site	28%	58%	28%	27%	58%
	Artillery Battery	8%	72%	8%	15%	72%
	C2 Site	36%	63%	36%	49%	63%
	SAMs/SCUDs	46%	5%	46%	51%	5%

Table 13: Weapon-Target Pairing Effectiveness Model Input Matrix

The metric used to evaluate system performance was called the Effects Ratio. This ratio is calculated by dividing the Applied Effects (the percentage that was actually applied by the model as the target was paired with a provider) by the maximum effect possible for that target-effects pair (the largest percentage in the same row of the table defined by the target type and desired effects). For example, a “Troops in the Open” target type with a requested effect type of “Harass” that was engaged by artillery had an effects ratio of 1 (.98/.98). Engaging the same request with CAS had an effects ratio of .26 (.25/.98).

4.3.2.3 Pairing Model Results

The model results were output to a spreadsheet for analysis in MINITAB^{TM} to evaluate the pairing effectiveness for each alternative architecture. A more detailed description of the analytical results is discussed in Appendix K. The null hypothesis for all models is that there is no processing time difference caused by differences in pairing methodology or alternative systems. Analysis of variance (ANOVA) was conducted to reject or accept this hypothesis based on the simulation data.

The ANOVA results reject the null hypothesis (F=13.35, p=0.000), and indicated that at least one alternative is different from the others. Median effects ratio of the Status Quo Plus is lower than both DJFSN and CJFSN. While the middle 50% (interquartile) of observations almost completely overlap in the boxplot of the effects ratio (Figure 40), there is a difference between the alternatives.

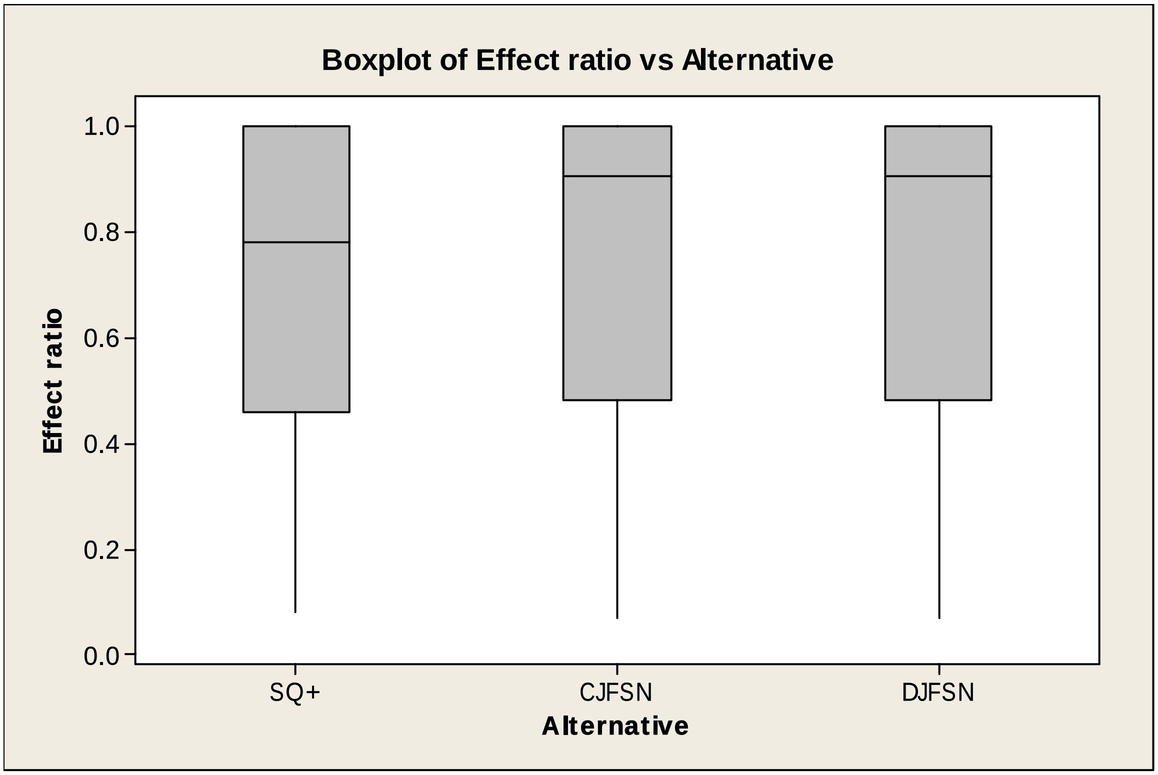


Figure 40: Statistical Means of Effects Ratios by Alternative

This overlap is primarily due to the weapons effects table used. Ground based fires, artillery and naval gun fire, were equivalent and no differentiation in the capability of air assets were made. By examining the utilization of provider assets show in Figure 41, the effect-based pairing method achieved a better median Effects Ratio by tasking more aircraft; Navy-Marine Corps CAS assets were available providers. The benefit of this pairing method is the potential for reducing the logistical requirements to support the volume of ground based artillery fire support.

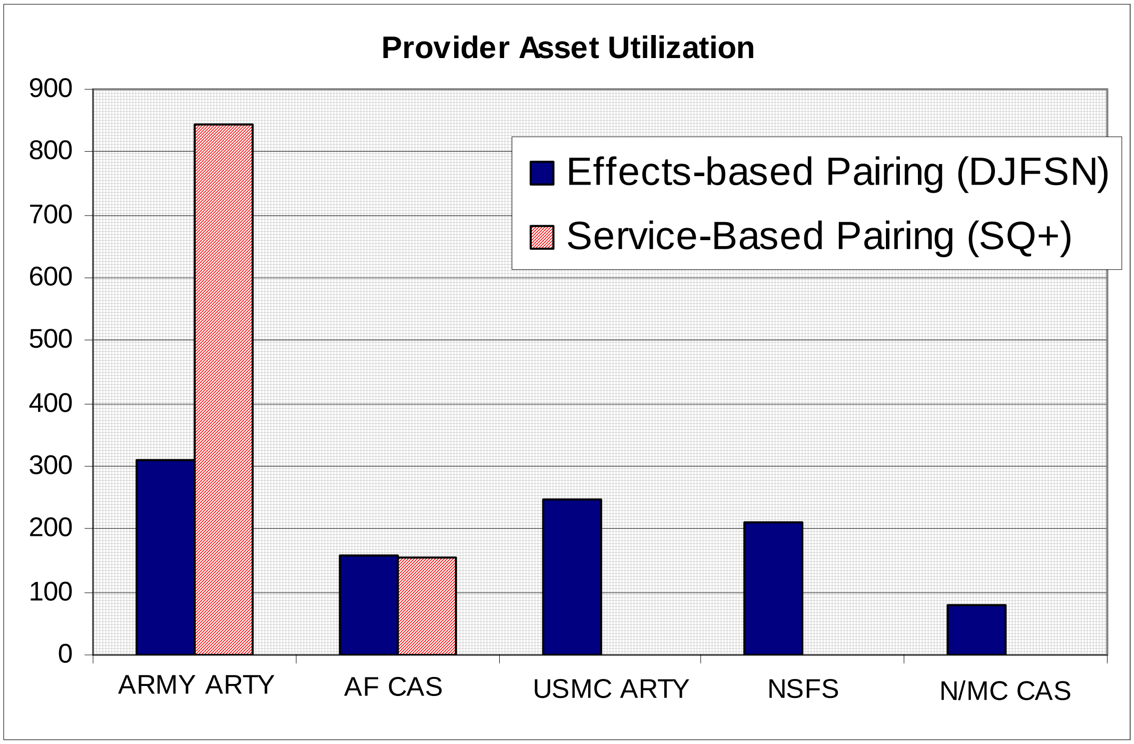


Figure 41: Provider Asset Utilization by Pairing Methodology

Considering the assumed distributions for processing and engagement times, along with the weapon effects chart, the assumption of normally distributed data was suspect. A non-parametric analysis (Kruskal-Wallis) was conducted to confirm the ANOVA results. This analysis determined that there is no difference between the CJFSN and DJFSN alternatives, but the Status Quo Plus alternative is statistically worse than the other two.

The results from this model indicate that an effects-based pairing algorithm may improve overall engagement success. With the given fixed target set and arrival rate, the differences in processing delay times between distributed and centralized processing did not adversely affect the effectiveness of the pairing process.

An additional model observation is that this relatively primitive discrete event simulation, with spreadsheet lookups, generated pairings of 1000 targets in under three minutes. This aligns with the processing delay assumptions used in the organizational alternatives model. It also indicates that a dedicated software package, using a GIG enabled database for targets and providers, could be developed with comparable results both in effects and processing time.

4.3.3 Agent-Based Performance Simulation

The Project Team consulted with the U.S. Army Training and Doctrine Analysis Command, Training and Analysis Center-Monterey (TRAC-Monterey) to assess appropriate methods to model JFS and was introduced to several modeling and simulation tools. The two best modeling alternatives were the Dynamic Allocation of Fires and Sensors (DAFS) simulation and the Map Aware Non-uniform Automata (MANA) simulation. The team chose MANA for the agent-based modeling based on its communications modeling architecture. The same scenario was tested among the team's three alternatives, with the full MANA output gathered for each alternative.

The simulation was designed to evaluate performance of the alternative system in providing operational support to a patrol in an Urban scenario. The Urban scenario was chosen as the most difficult among the available scenarios to demonstrate each alternative's effectiveness. Additional scenarios were assumed to yield similar results, and were not modeled due to time and resource constraints. Number of blue force casualties sustained was determined to indicate relative effectiveness of the fire support system.

These models and subsequent analysis produced the following conclusion: Distributed JFSN resulted in the fewest friendly force casualties. The models and analysis used to arrive at this conclusion are described in the following sections.

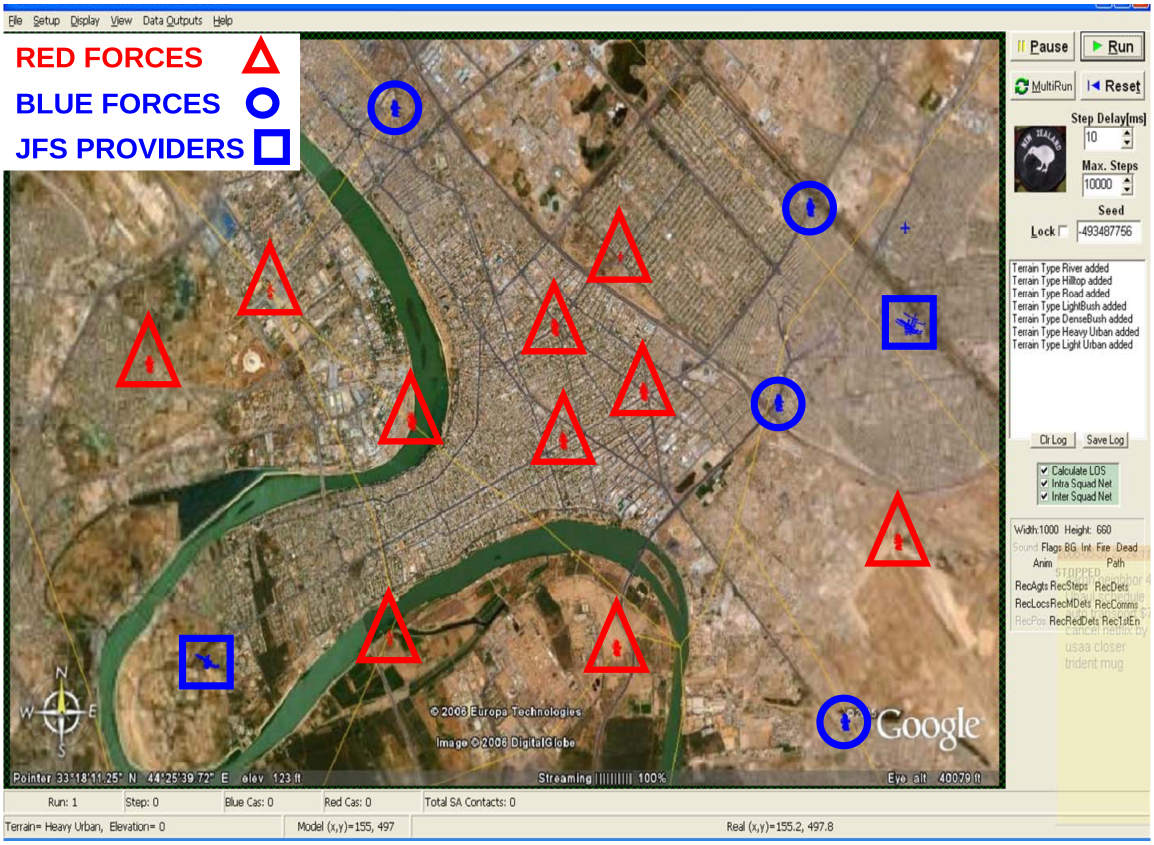
4.3.3.1 Agent-Based Model Description

MANA is an agent-based simulation. Entities (agents) are given sensor ranges, weapon performance parameters, and behavioral guidelines, and are then released in the simulation to react to conditions based on those behaviors. The user is able to shape outcomes based on an agent's propensity to engage or run from the enemy, cluster with like-minded agents, or seek cover and concealment. Macroscopic interaction and outcomes can then be analyzed based on the individual agent behaviors.

The MANA model was not intended to test pairing or deconfliction methodology, but rather to test communication schema to determine effectiveness of Joint Fire Support in a scenario. The Status Quo Plus MANA model required a fires request to route through several separate steps (based on analysis of command structure from Sections 2.2 and 3.1), while the CJFSN and DJFSN required fewer steps or communications. Aside from the communication and decision delays, the time for targets to be accurately located and ordnance to arrive on target are consistent throughout each alternative. This modeling tool does not permit best-provider pairing. This aspect was not measurable within MANA and any fire support provider which had ammunition and was within range of the target fired as soon as it was aware of a valid (hostile) target.

An urban scenario was built using downtown Baghdad as the notional geography. A company of Marines patrolled the city with an Army Battalion to the east with supporting artillery that was not previously coordinated. Marine requests for Army artillery support were routed, depending on the alternative simulated, through either the Joint Operations Center (Status Quo Plus), Joint Fires Cell (CJFSN) or directly to the artillery battery (DJFSN).

Each alternative was evaluated in the urban simulation with 44 blue (friendly) entities representing the C2, indirect fires providers, or front line troop categories. The scenario layout is shown in Figure 42. There were two Joint Fire Support providers, in the form of two Army artillery batteries of six guns each, which were able to support Marine patrols within the city. Red forces were held constant at 38 entities and consisted of unconventional forces with enemy inferior weapons, as well as 3 sniper agents with increased (superior) detection and weapons capability. The blue patrol elements required, by design, assistance outside their level of capability (i.e., Joint Fire Support) in order to neutralize the red threats and allow the unit to complete its mission (a complete patrol of the area). A detailed description of the MANA model along with information on the exact location and capability of each agent, and settings for each alternative, is contained in Appendix L.



Step Delay[ms] 10

Max. Steps 10000

Seed

Lock ☐ -493487756

```
Terrain Type River added
Terrain Type Hilltop added
Terrain Type Road added
Terrain Type LightBush added
Terrain Type DenseBush added
Terrain Type Heavy Urban added
Terrain Type Light Urban added
```

☑ Calculate LOS
☑ Intra Squad Net
☑ Inter Squad Net

Width:1000 Height: 660

Pointer 33°18'11.25" N 44°25'39.72" E elev 123 ft

Eye alt 40079 ft

Run: 1 | Step: 0 | Blue Cas: 0 | Red Cas: 0 | Total SA Contacts: 0

Terrain= Heavy Urban, Elevation= 0 | Model (x,y)=155, 497 | Real (x,y)=155.2, 497.8

Figure 42: MANA Urban Scenario Initial Layout

4.3.3.2 Agent-Based Model Assumptions

MANA is an implicit model, not an explicit, physics-based model. Sensor ranges, weapon performance, and probabilities are input by the user based on scenario assumptions. These assumptions were based on stakeholder input and the combined military experience of the team. General assumptions include friendly weapon and sensor superiority (range, probability of detection/kill) with few exceptions, enemy insurgent behaviors (propensity to avoid blue forces until able to mass fire in an ambush-style attack), and 95% reliable communications. Communications were assumed to be accurate with the exception of a sensitivity analysis performed to analyze the effect of communications problems on system performance.

The Status Quo Plus model was built with a serial call for fire format. Requests are generated at the lowest engaged forward element (a squad), and passed serially through the chain of command until it can be appropriately serviced. The CJFSN model sends all calls to the Joint Fires Cell, which then notifies providers of targets to be serviced. The DJFSN model uses a fully connected communications matrix so that all elements in the simulation are able to communicate with each other (engaged elements can talk directly with Joint Fires providers).

The Fire Support weapons used for this simulation are based on a generic, battalion- or brigade-level fire support weapon. Currently this weapon is 155mm artillery, but for the purposes of the simulation, the artillery represents a joint fires provider under direction of the brigade. This weapon is assumed to have sufficient range, accuracy and payload, with the required precision targeting and collateral damage requirements for use in an urban environment.

4.3.3.3 Agent-Based Model Results

MANA results for blue force casualties are depicted in Figure 43. These results are based on 50 runs of each alternative within the specified scenario and analyzed using MINITAB^{TM}.

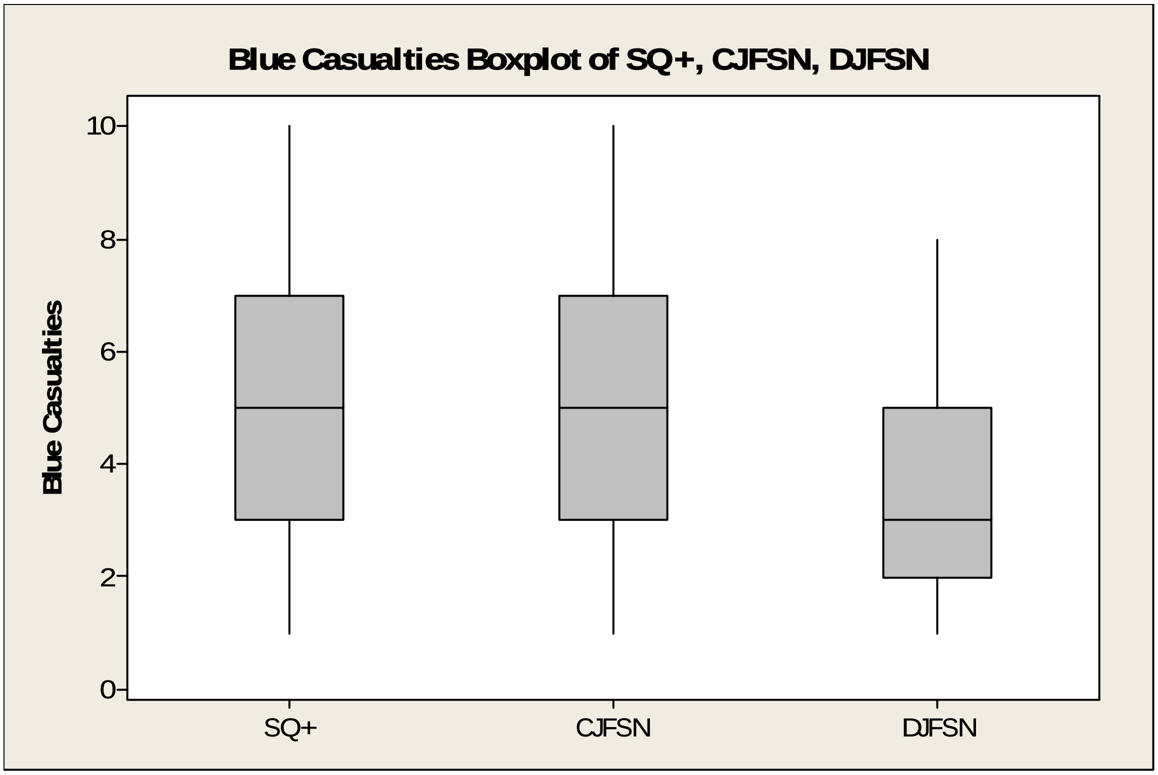


Figure 43: Blue Force Casualty Results from the MANA Simulation

Analysis of blue casualties revealed no statistically significant difference between the Status Quo Plus and the CJFSN alternatives, but a significant difference between Status Quo Plus and DJFSN alternatives. CJFSN was expected to perform better than the Status Quo Plus based on the assumptions that improved communications resulted in more rapid Joint Fire Support response, and thus fewer friendly casualties. While investigating the lack of improvement, it was discovered that the CJFSN communications simulated in the MANA model resulted in less communication between friendly elements on a direct basis. Elements communicated with the Joint Fires Cell for fire support missions, but did not communicate with each other (inter-squad) for those missions that did not require outside fire support. Thus when the battlefield environment called for fewer inorganic fire support missions the CJFSN alternative resulted in fewer communications overall, and a decrease in situational awareness. In those cases where calls for fire were frequent and necessary, blue casualties decreased and there were no differences between the DJFSN and CJFSN models.

The DJFSN alternative resulted in the fewest blue casualties. Based on the conclusions above, in a low calls-for-fire environment (organic target prosecution), situational awareness outside the squad is critical to make the most use of organic assets. In this environment it is not necessarily the Joint Fire Support process or format that facilitates fewer blue casualties, but rather the increase in communications and the resulting increase in situational awareness.

The MANA model was based on 100% communications accuracy. As a side note, sensitivity analysis was conducted within each alternative to determine the effects of degraded communications accuracy. Accuracy was decreased linearly from 100% to 98% in .2% increments. Casualties increased exponentially as communications accuracy decreased below 99% for the Status Quo Plus alternative, as shown in Figure 44. This was important to effective fire support in all alternatives, but critical to Status Quo Plus. Even a small decrement in communications accuracy resulted in extremely harmful results. Model behavior included elements reporting themselves or their position as hostile or fire support elements firing on non-existent or stale targets (targets that were either already dead or that had moved position). On the other hand, fratricide due to communication inaccuracies for both the CJFSN and DJFSN alternatives appears linear, which is a logical result of a shift from serial to parallel communications. The decrease in fratricide from distributed to centralized control can be attributed to the "check and balance" of multiple users using different communications links to get the same information from one point to another, as well as the assumed crosscheck of multiple receivers.

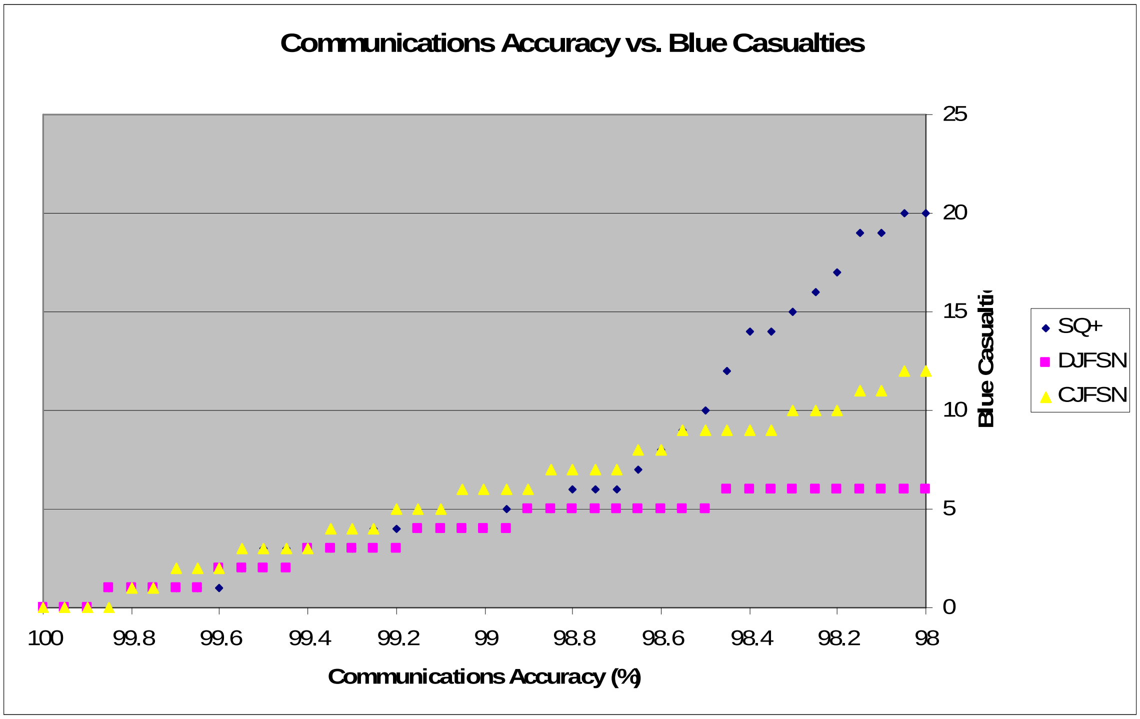


Figure 44: Communications Accuracy vs. Blue Casualties

In conclusion, the DJFSN alternative, with its associated web of communications, resulted in the fewest blue casualties (including fratricide) and best increase in situational awareness. This conclusion is valid in either a high volume call for fires environment, or an environment in which most targets are processed organically.

4.4 MODELING AND SIMULATION SUMMARY

The three proposed alternatives were evaluated based on the metrics developed to support the effective need. Table 14 summarizes the results from the modeling and simulation of the alternative architectures.

METRICS	**Alternatives**		
	SQ+	**CJFSN**	**DJFSN**
1. Avg. Processing Time for a Request to be Serviced (minutes) **(↓=better)**	**16.7**	**10.1**	**6.6**
2. Avg. Pairing Efficiency of the Target-Weapon Pairings (percent) **(↑=better)**	**78%**	**90%**	**90%**
3. Avg. Number of Systems Involved in the Request-to-Tasking Process **(↓=better)**	**10.5**	**3.7**	**3.8**
4. Avg. Number of Decision Points Involved in the Request-to-Tasking Process **(↓=better)**	**9.5**	**6.9**	**7.9**
5. Avg. Number of Steps Involved in the Request-to-Tasking Process **(↓=better)**	**12.0**	**9.2**	**10.0**
6. Avg. Number of Gaps in the Request-to-Tasking Process **(↓=better)**	**5.6**	**2.1**	**2.0**
7. Avg. Number of Blue Force Casualties **(↓=better)**	**4.9**	**5.1**	**3.5**

Table 14: Summary of Modeling and Simulation Results.

The following comparative analysis outlines the results among all alternatives with regard to each criterion previously identified:

1. Time to process a CFF request in simulation was a surrogate for proposed system processing time. Average processing time for a CFF request to be serviced was evaluated by simulation. The results rate the DJFSN as the best, followed by the CJFSN alternative, then the Status Quo Plus system.
2. Pairing efficiency with notional weapons effects in simulation was a substitute for an effects-based pairing algorithm. Pairing efficiency was evaluated by simulation. The average pairing efficiency of the Target-Weapon pairings rated CJFSN and DJFSN as the same, with the Status Quo Plus performance significantly lower.
3. A count of the systems involved is a proxy measure to count interface translation systems required, and opportunities for errors to be introduced in the tasking process. The number of systems involved in the process was evaluated with static models. The

average number of systems involved to generate a tasking rated the DJFSN as slightly better than CJFSN and both outperforming the Status Quo Plus.

4. A count of the decision points (human intervention) is a surrogate measure to evaluate operator oversight, opportunity to introduce errors, and process delays during conversion. The number of decision points involved in the process was evaluated with static models. The average decision steps involved to generate a tasking rated the DJFSN best, followed by CJFSN then Status Quo Plus.
5. A count of processing steps is a substitute for the volume of information exchanged to support tasking a provider. The number of processing steps (human or machine) involved in the process was evaluated with static models. This resulted in CJFSN as fewest steps, followed closely by DJFSN and significantly higher processing steps in the Status Quo Plus.
6. A count of the process gaps represents the number of missing digital interfaces between systems in each alternative. Process gaps were evaluated with static models. The CJFSN required the fewest followed closely by DJFSN with Status Quo Plus with a gap at nearly every decision and processing point.
7. The organizational and communications structures modeled in the MANA models assessed the number of friendly (blue) force casualties as a result of the timeliness of the response to a CFF. The DJFSN communications structure resulted in the fewest casualties, and both the CJFSN and Status Quo Plus alternatives presented a similar larger number of casualties.

Based on the modeling and simulation results alone, the DJFSN alternative offers the best performance of system objectives while fulfilling the Effective Need.

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5.0 COST ESTIMATE

A cost estimate for a system with few physical specifications is difficult, if not impossible. Regardless of the JFS alternative chosen, the physical portions of the system would include: user input devices (such as TLDHS or “Strikelink” systems), the communications equipment and architecture necessary to transmit JFS request data to higher command (RF spectrum, TCP/IP, SATCOM), the computer systems and software necessary to process, pair, display, and transmit target tasking data, and the associated systems resident on the provider platforms.

5.1 COST ESTIMATE ASSUMPTIONS

The basic assumption was that joint procurement can be more economical and effective than service-specific acquisition. The overall cost of a joint command and control system is expected to be comparable to the existing service specific C2 systems. Table 15 summarizes current C2 systems and illustrates the limited degree to which the services share systems. Shifting to a single system has potential to reduce expenditures to significantly less than the current total expended on all of these separate systems.

Service	C2 system	Contractor
Army	CPOF (part of Maneuver Control System (MCS))	General Dynamics
	FBCB2/BFT	Northrop Grumman
	ABCS	Lockheed
	GCCS-A	DISA
Navy	TBMCS	Lockheed
	GCCS-M	DISA
Air Force	TBMCS	Lockheed
	GCCS-AF	DISA
	Integrated Space Command and Control	Lockheed
Marine Corps	C2PC	Northrop Grumman

Table 15: A Selection of Service Specific Command and Control Systems

The other costs associated with continuing to operate with disparate C2 systems is the lack of interoperability. Four separate prime contractors maintain these systems, with numerous subcontractor support facilities and teams. The three separate GCCS systems are not currently interoperable, although the NECC transition plan does propose a path for future integration.[53]

This lack of interoperability leads to potential operational costs based on mission risk. For example, if time sensitive information, delayed due to translation from one services' system to another, is used to dynamically deconflict assets it could result in a higher risk of fratricide. Similarly, delays in prosecution while awaiting accurate data for deconfliction or pairing could result in lost opportunities to prosecute valid targets. The additional risk placed on ground elements when they are engaged with a hostile enemy force is unacceptable when the source of the delay is a manual translation delay from CPOF to TBMCS (for example).

5.2 COST ESTIMATE CONCLUSIONS

The materiel cost of implementing each alternative is similar. All involved elements of: computer hardware, software, data input and display devices, and radios/networking equipment. C2 software requirements for a common system (CJFSN and DJFSN) are expected to be less than continuing separate development with incremental improvements in interoperability (Status Quo Plus). The potential operational costs associated with independent systems do not support future operational concepts or a more responsive joint fire support system.

In the end, the cost of developing a common interoperable system is at least comparable to continuing the development of existing systems. The additional operational benefits of reduced fratricide risk and improved engagement opportunity provides a high return for a relatively low cost and supports development of a common command and control system.

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[53] Defense Information Systems Agency, *The NECC Provisional Technical Transition Architecture Specification*, Version 0.5.7, 12 April 2006, pp. 1-2.

6.0 RISK AND RELIABILITY

6.1 RISK ESTIMATE

The magnitude of risk was estimated by viewing all three of the proposed alternatives from the perspective of changes to DoD's current Doctrine, Organization, Training and Education, Materiel, Leadership, Personnel, and Facilities (DOTMLPF). Because some risk areas crossed DOTMLPF categories the Project Team combined certain categories for ease of discussion. The risks for the DOTMLPF categories, with respect to all three alternatives, are qualitatively evaluated below.

6.1.1 Doctrinal Risks

This category considers the interaction between the service component capabilities, the services' roles and missions, and Title 10. Because they are interrelated, especially when it comes to the individual service budgets, the proposed JFS alternatives pose challenges to the existing balance within these three areas.

The Status Quo Plus alternative was assessed to have a low risk to implementation because it does not require a significant change to existing service or joint doctrine to implement.

However, the CJSFN and DJSFN alternatives require that service capabilities, especially those outside its historical roles, are considered. This could lead to the expansion of a particular service's roles and missions and a possible redistribution of budget. As an illustration, the CJSFN and DJSFN alternatives support a functional consolidation of the ASOC and the DASC. This consolidation would put all fixed wing CAS assets under centralized control. However, Air Force doctrine for Countersea Support it is extremely limited (it is a single paragraph)[54]. So, while Air Force assets have the capability to provide Countersea Support (which could include CAS support to amphibious forces), it

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[54] Department of the Air Force, Air Force Basic Doctrine, AFDD-1, 17 November 2003, pp.45-46.

is easily argued from a funding basis that the Air Force is not resourced to fill that role and should not perform it. This dichotomy exists across most of the mission areas and affects all services in meaningful ways.

Additionally, the CJSFN and DJSFN alternatives blur the distinctions between the *supporting* and *supported* roles. The concepts of OPCON, TACON, and ADCON must become very dynamic to permit these alternatives.

Since the CJSFN and DJFSN alternatives will undergo continual rebalancing of capabilities, roles and missions, and statutory requirements, they were assessed to have high levels of risk to implementation with respect to doctrine as shown in Figure 45.

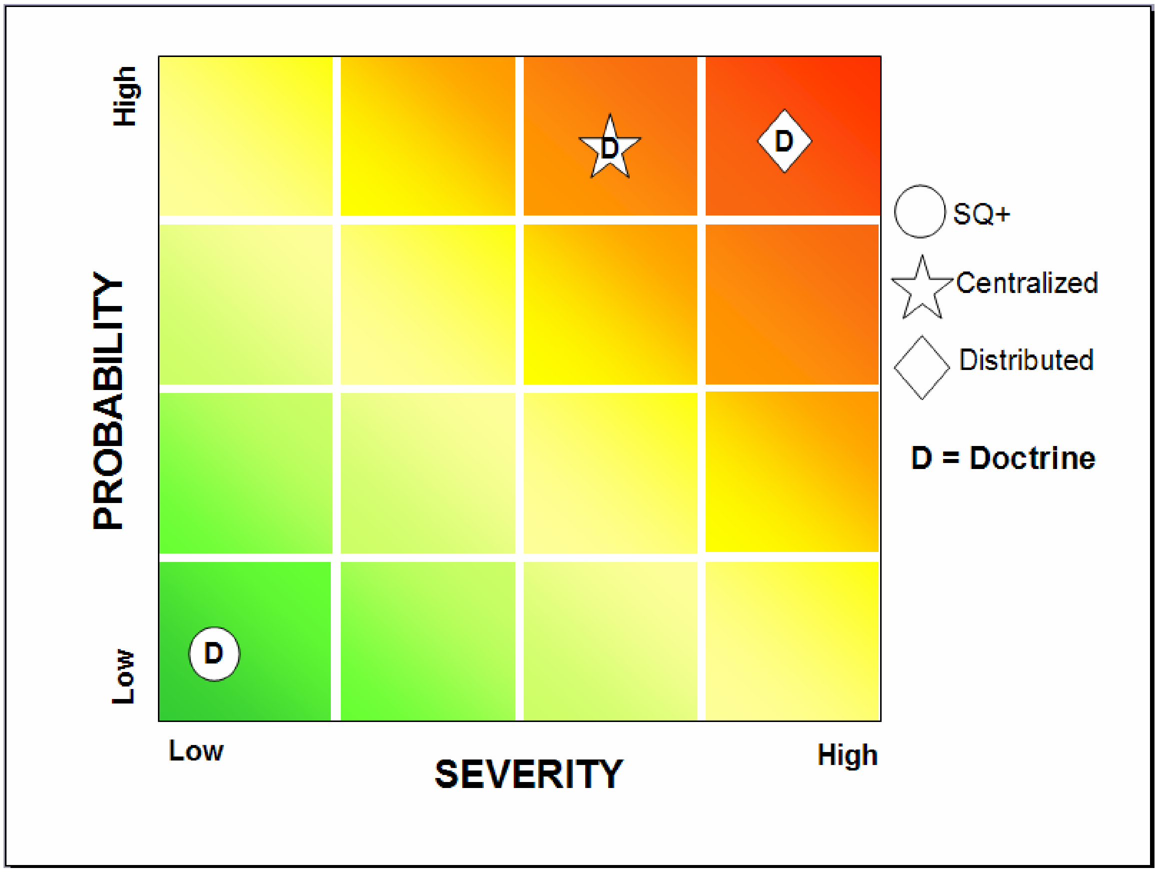


Figure 45: Doctrine Risk Chart

6.1.2 Organizational and Leadership Risks

This risk is much more complex than simply drawing a solid or dotted line on an organizational chart. This risk category considers the challenges of maintaining dynamic chains of command, even across services, and the degree of business process reengineering necessary to consolidate cross service functions. System and personnel risks are addressed separately.

The current movement within DoD is towards streamlining and consolidating military organizations away from service-based roles and towards capability-based roles and missions. While this move is in line with the effects-based joint fire support concept, it challenges established military organizational conventions.

The Status Quo Plus alternative has low risk to implementation because it does not require a significant change to current fire support organizations. Because this alternative preserves existing and duplicate functional organizations, the level of effort required to execute this strategy is low.

The CJSFN architecture was assessed to have a medium risk level due because it requires the consolidation of HQ-level organizations with similar roles. Combining the functionally similar organizations with different cultures and procedures will require extensive process engineering efforts. It does not fundamentally change the organizational construct of JFS to the same degree that the DJFSN alternative does.

The DJSFN alternative was assessed to have a high level of risk due to the significance and scope of the organizational changes required to implement it. Because Distributed JFS organizations are networked at all levels, from the field to the JOC, the dynamic chains of command and shifting levels of authority will challenge conventional leadership concepts. A transition to a Distributed JFSN organizational construct would be difficult to implement incrementally and the initial performance of the Distributed architecture will probably be less than projected until leadership style adjustments are assimilated throughout. The organization and leadership risks of each alternative are shown in Figure 46.

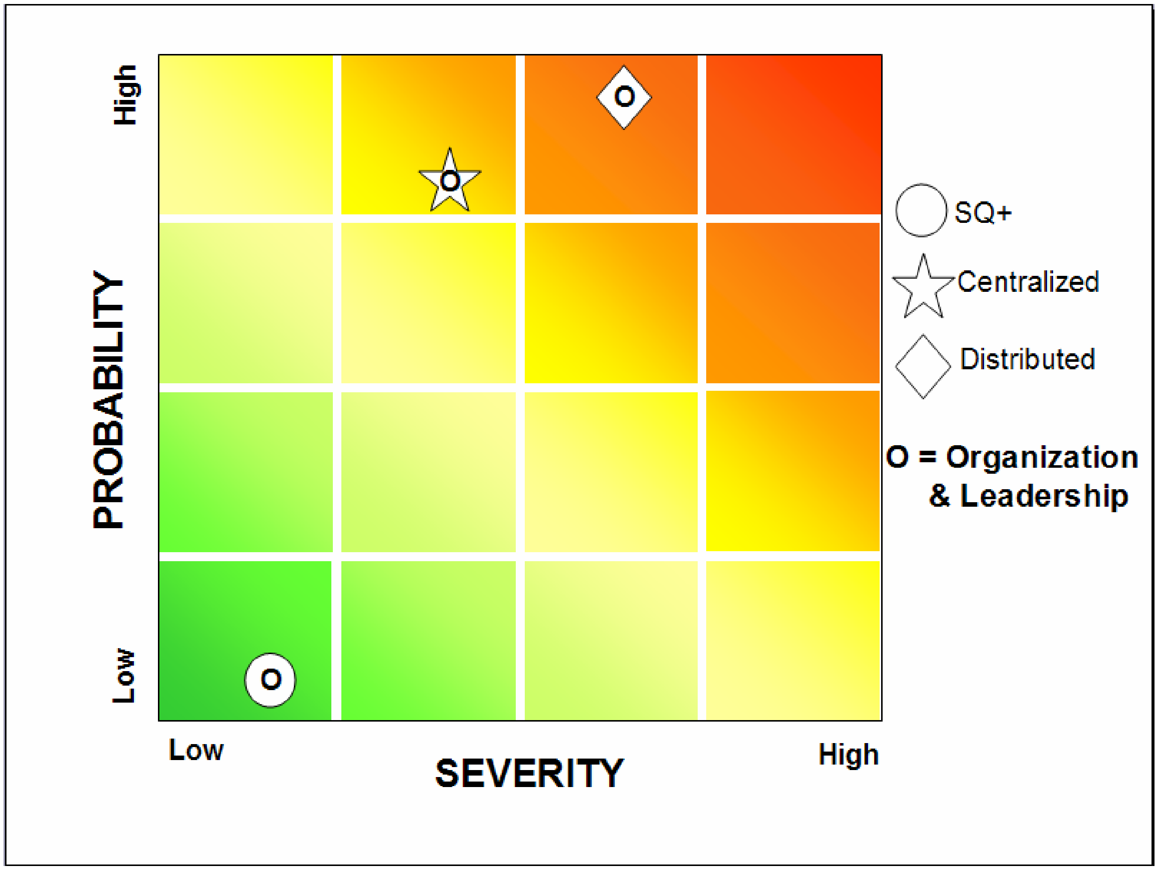


Figure 46: Organization and Leadership Risk Chart

6.1.3 Tactics and Training Risks

This category highlights the risk involved with creation and implementation of completely joint tactics and training procedures with respect to JFS. These risks include implementation at the forward observer level and at the upper-echelon levels. The Status Quo Plus alternative was assessed to have a low risk to implementation due to the limited changes from current and projected tactics and training. The service-specific improvements to JFS associated systems and procedures will incur a minimal training burden on the service components without any significant changes to tactics and only slight improvements in tactical flexibility. There will continue to be a burden for cross-service training of liaison elements in the disparate C2 systems of each service. There are no requirements to further standardize call for fire formats or data standards in the Status Quo Plus alternative, therefore those training requirements change very little.

The CJFSN alternative was assessed to have a medium risk to implementation with respect to tactics and training. The movement towards a common JFS data entry and request device and C2 system will enable standardization of warfighter training requirements across all of the services. This commonality of equipment should enable significant improvements in training quality and tactical flexibility, and the risk will be mitigated by maintaining the option to use legacy voice procedures for requesting support. One of the most significant risks to this alternative with respect to training is the development, acceptance, and implementation of a common joint call for fire format to replace the numerous service and function-specific formats used today. The changes in the routing of this request are anticipated to produce noticeable improvements in upper-echelon functions as a result of organizational consolidation moves such as the Joint Fires Cell. The simple act of consolidating cross-functional expertise should realize efficiency gains in both coordination and processing times, but also in the tactical efficiency of the request-to-provider pairings. The training risks of consolidation at this level are mitigated by virtue of the breadth of experience available for on-the-job training and learning, although there may be some tactical challenges with initial implementation and use of a common format for request for fire data.

The DJFSN alternative was assessed to incur a high level of training risk due to shifts in authority and responsibility. The ability to request and receive fire support without direct oversight and approval requires a high degree of individual proficiency. The movement towards a common JFS data entry and request device and C2 system will enable standardization of warfighter training requirements across all of the services. The training burden for tactical expertise and aptitude is shifted from a relatively small cadre of upper-echelon leaders to a very large group in the field and in combat. The responsiveness of this architecture will challenge the ability of supervisory entities to maintain tactical synergy and deconfliction of fires. A risk reduction factor of this alternative could be that the elimination of service or function specific equipment will remove the premium currently placed on training for those specialized systems. The tactics and training risks of each alternative are shown in Figure 47.

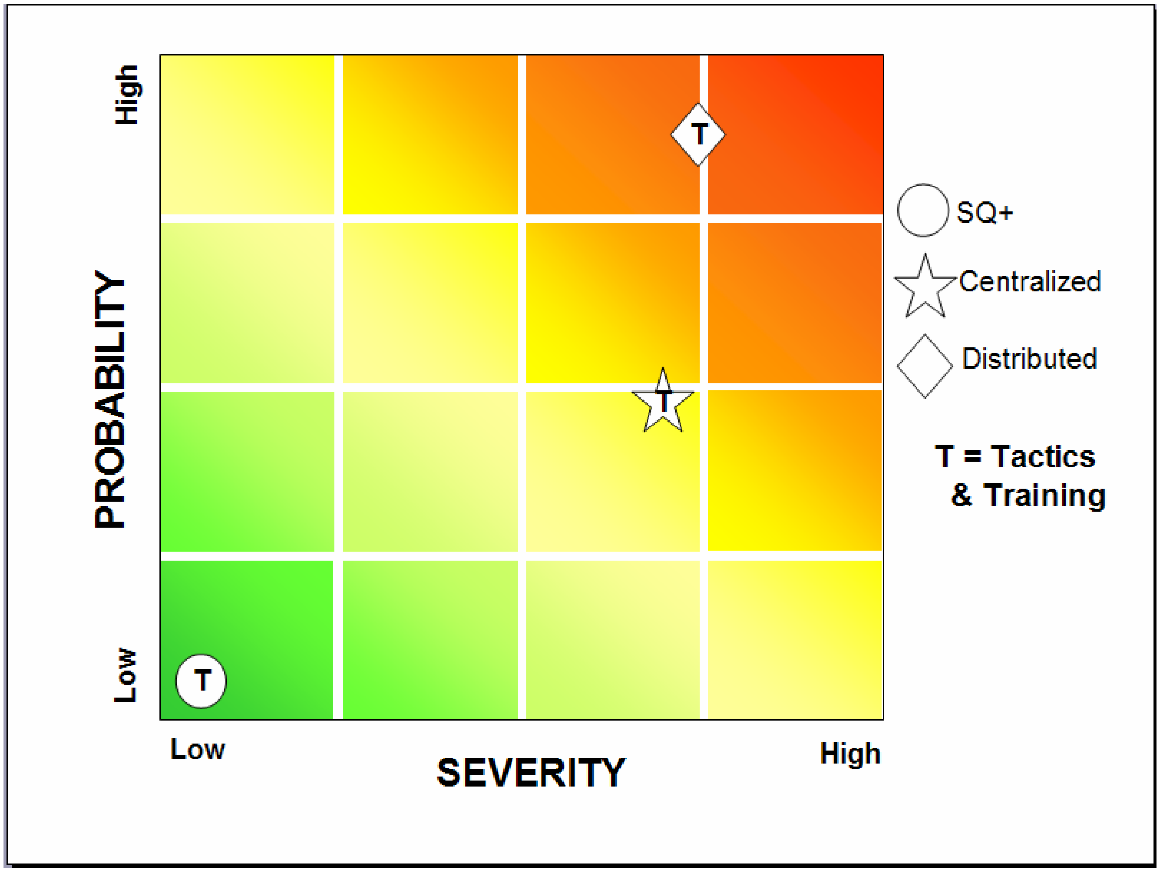


Figure 47: Tactics and Training Risk Chart

6.1.4 Materiel Risks

The main risk drivers in this area are system interoperability and the expanded vulnerability of a fully networked force. Interestingly, technical readiness levels were not determined to be a driver. The core technologies to develop fully interoperable JFS systems exist today. Interoperability challenges reside primarily with programmatic choices.

System interoperability includes the equipment which processes the call for fire directly (fielded land, sea, and air systems), the C2 systems which provide decision inputs, and the communications structure (GIG) which serves as the information conduit.

There is a continuum of interoperability that will define the materiel risks of the three alternatives. The highest level of interoperability occurs when there is complete commonality of equipment or the systems have been purposefully developed to be interoperable. On the other end of the spectrum, the lowest level of interoperability occurs when the interface between separate systems or functions is filled by a person that must combine or move data from one system to another. The interoperability required of the systems and material needed to implement the alternatives drives the risk for each.

Expanded system vulnerabilities stem from the assumption of network connectivity. All networked nodes in these joint fire support request networks can be assumed to be predictably radiating within the electromagnetic spectrum. Radiating nodes lose the advantage of concealment. Additionally, attacks against radiating nodes would likely result in a “no transmit” policy, rendering all of the proposed alternatives ineffective. This risk will have to be mitigated through technology (low power signals) and countermeasures. Since a net-enabled force was an assumed condition across all alternatives, this risk was assessed to be equal for all alternatives.

The Status Quo Plus alternative incurred low materiel risk because it accepts a low level of interoperability. Projected improvements to the separate C2 systems at upper command levels will enhance the performance of these alternatives, but the repercussions of failures in interoperability at these levels will be absorbed by personnel. While its fire support networks will require relatively faster and more efficient communications, most of the communications strain in this alternative will be across the upper organizational echelons. Incremental improvements in legacy C2 systems and currently fielded data input devices (service and function specific) will reduce this alternative’s risk.

Both the CJFSN and DJFSN alternatives were assessed to have medium levels of risk. Both of these alternatives require significant interoperability in order to function. Both alternatives require fully interoperable C2 systems, the development and DoD-wide fielding of a joint, common input data device, and a common transmission network that eliminates specialized data links, particularly across the aircraft fleets. These alternatives demand improvements in communications and networking although the requirements for the Centralized alternative are primarily on the back side of the request (in the processing and tasking areas). The network requirements for the DJFSN are riskier because connectivity must span all organizational levels and out to the "edge" with the forward observer. The materiel risks of each alternative are shown in Figure 48.

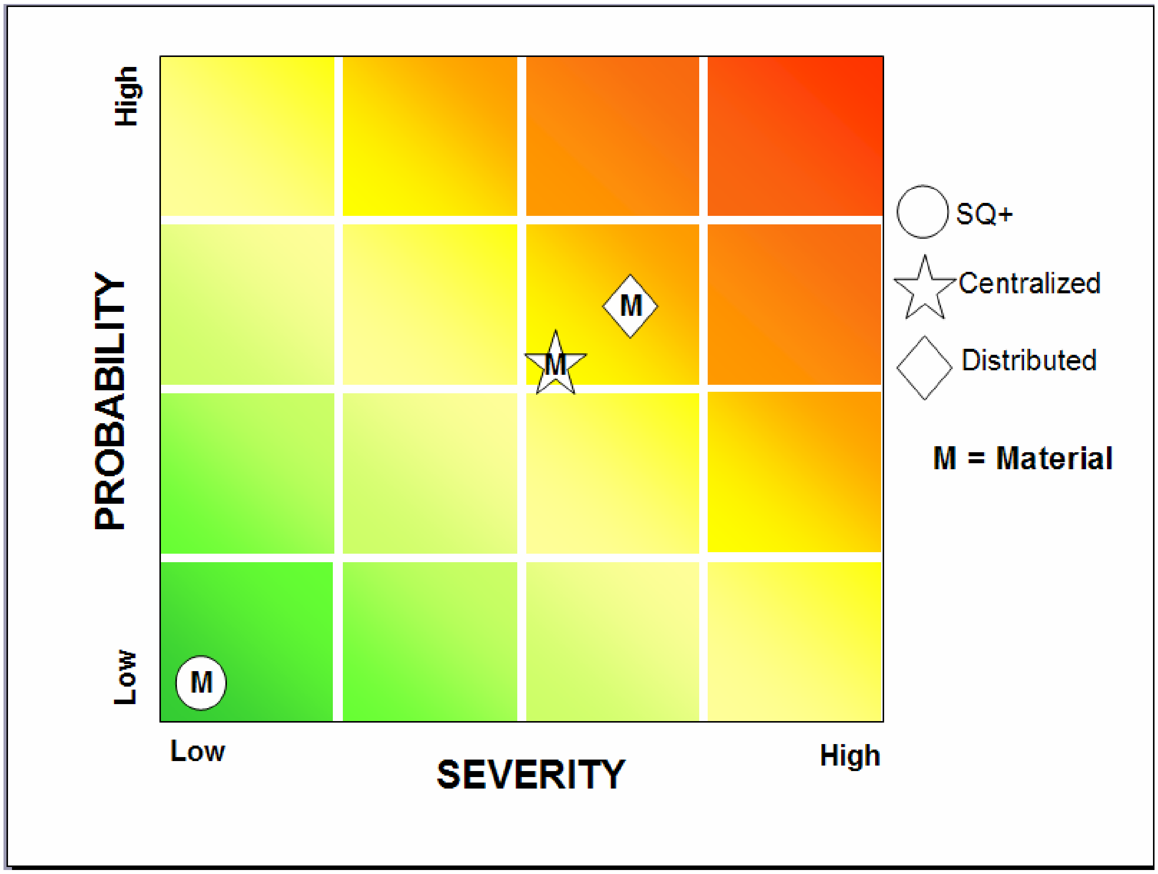


Figure 48: Materiel Risk Chart

6.1.5 Personnel and Facility Risks

The risks to implementation of these alternatives due to personnel and facility changes vary significantly. The Status Quo Plus alternative is assessed to have very little risk because the qualified personnel and appropriate facilities needed to implement this option already exist. Although there may be some challenges caused by incremental improvements of legacy systems, the risk remains small in this category.

The CJFSN concept will make significant demands on physical facilities due to the consolidation of fire support functions and personnel. This was assessed as a medium level of risk and can be mitigated by simply mixing the personnel and expertise currently segregated by function and service without combining them into one large organization.

The DJFSN alternative will incur high risk to implementation due to the fundamental personnel changes involved. The ability to transition the tactical knowledge and experience in JFS into a virtual and distributed organization at the level of proficiency required is not currently feasible. Although the relaxation of physical facility requirements helps reduce the implementation risk, the personnel productivity of virtual organizations must also meet or exceed the capability of a co-located organization. This will be very risky if a large portion of that virtual organization is on the battlefield under fire. The personnel and facilities risks of each alternative are shown in Figure 49.

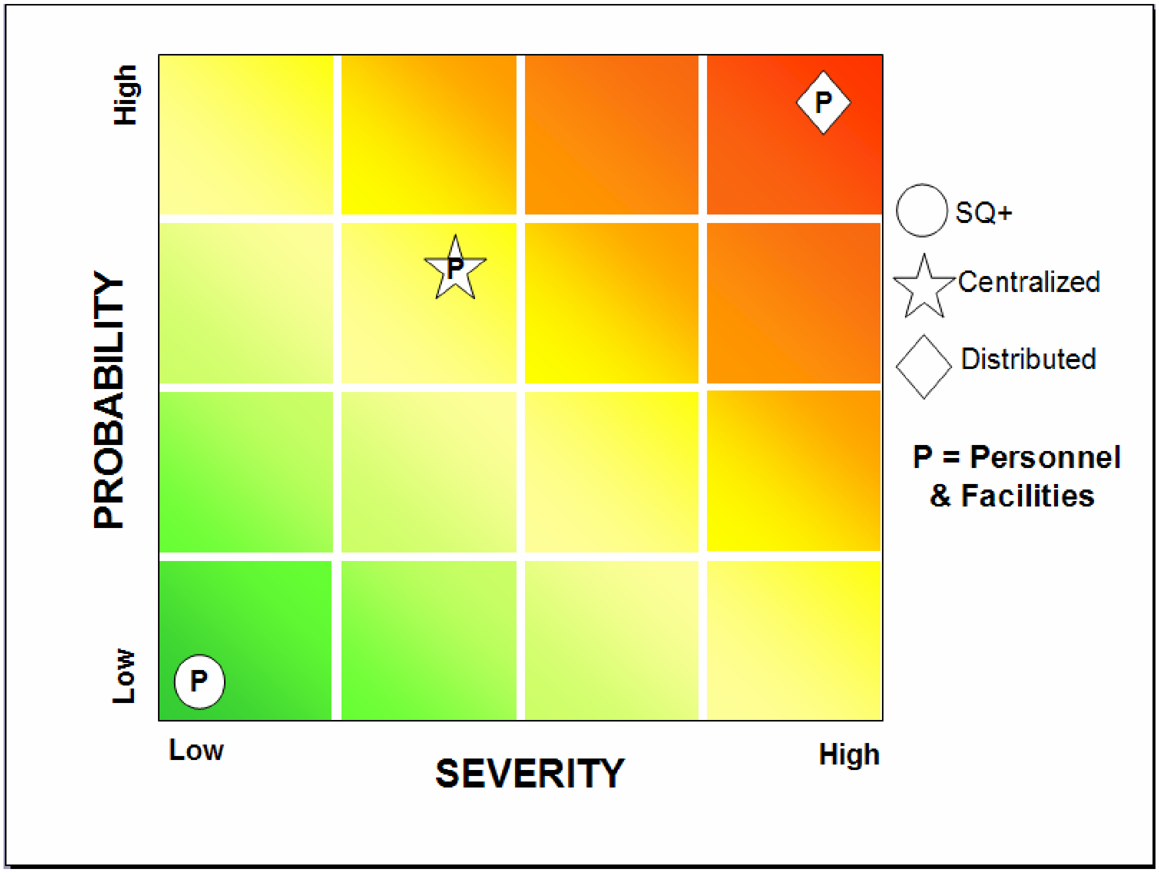


Figure 49: Personnel and Facilities Risk Chart

A summary comparison of the qualitative risk estimates of these alternatives is provided in Figure 50 and Table 16.

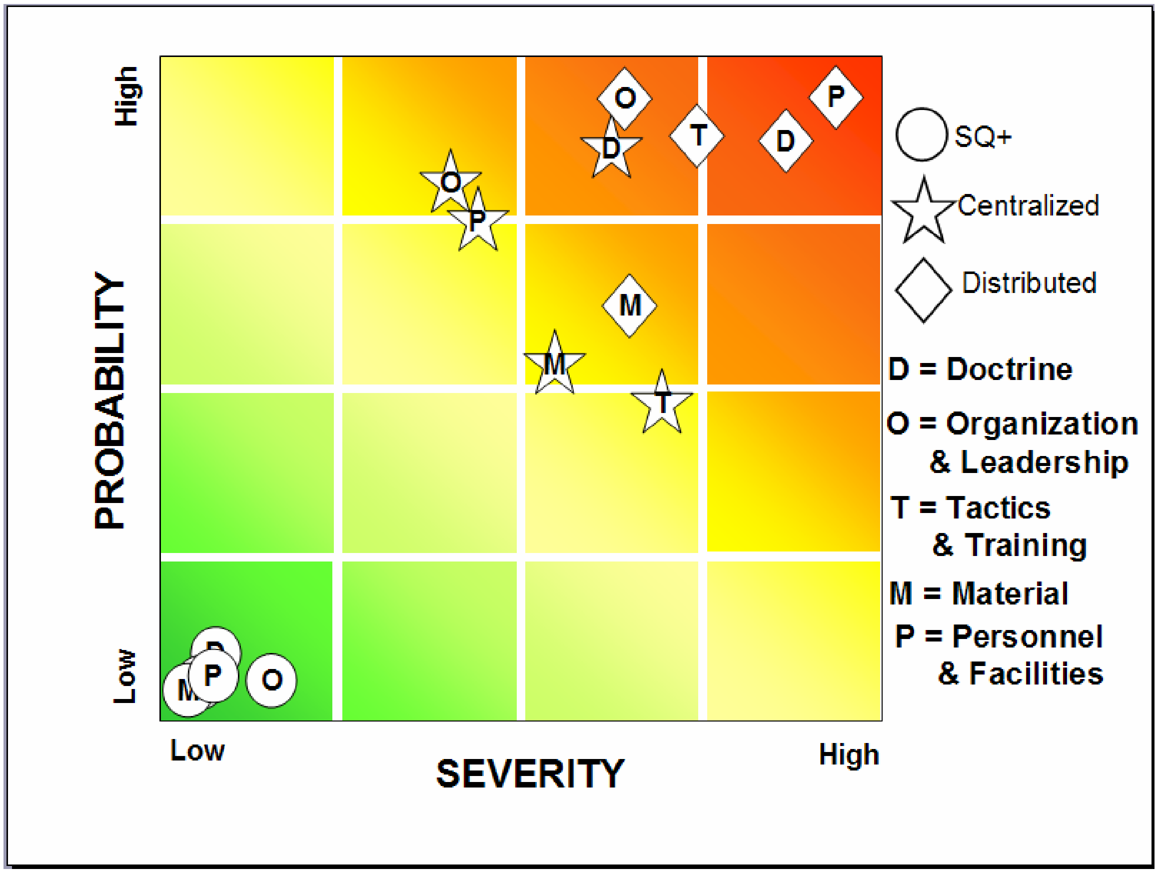
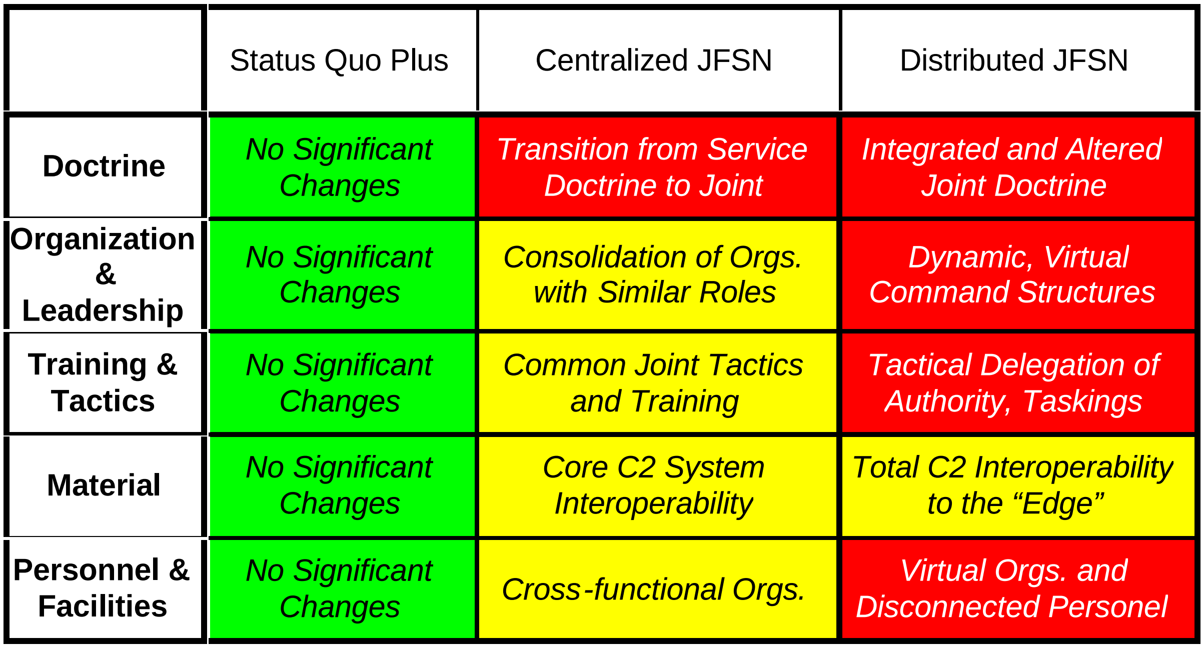


Figure 50: Summary Risk Chart



	Status Quo Plus	Centralized JFSN	Distributed JFSN
Doctrine	*No Significant Changes*	*Transition from Service Doctrine to Joint*	*Integrated and Altered Joint Doctrine*
Organization & Leadership	*No Significant Changes*	*Consolidation of Orgs. with Similar Roles*	*Dynamic, Virtual Command Structures*
Training & Tactics	*No Significant Changes*	*Common Joint Tactics and Training*	*Tactical Delegation of Authority, Taskings*
Material	*No Significant Changes*	*Core C2 System Interoperability*	*Total C2 Interoperability to the "Edge"*
Personnel & Facilities	*No Significant Changes*	*Cross-functional Orgs.*	*Virtual Orgs. and Disconnected Personel*

Table 16: Risk Across Alternatives with Respect to DOTMLPF

6.2 RELIABILITY ESTIMATE

Each alternative's performance of F2T2EA functions forms a basis for future reliability analysis. The proposed joint fires system fits the process between acquiring targets (find, fix, and track) and prosecuting them (engage and assess). Evaluating potential failure modes and mission impact of each step in the process provided insight into what failures significantly degrade overall system operation. The Project Team examined specific failure modes and assessed severity and likelihood for each alternative. These failure modes were evaluated relative to the severity of the mission and were independent of the system alternative. The likelihood of occurrence based on the alternative implemented was then evaluated. A relative risk assessment code was then assigned and color code ratings listed for each failure mode (as seen on Tables 17, 18, and 19). The list is not all inclusive and the severity is will be mission (scenario) dependent.

The definition of what constitutes a failure is necessary to evaluate the overall system. Failure to deliver available ordnance on a valid target is considered a failure of the overall fires system. Figure 51 summarizes the overall system, with potential failures listed.

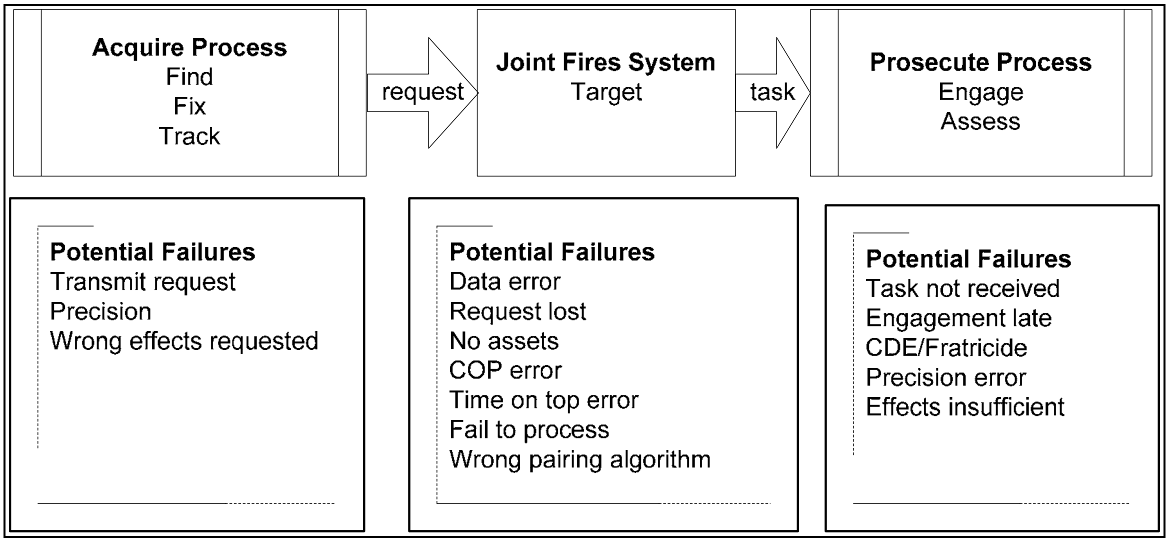


Figure 51: Overall Fires System Potential Failures

The acquire and prosecute processes are outside the scope of the system being developed, but potential failures at those interfaces are important to the overall reliability of the system. Reliability risks, failure modes and potential for mitigation are discussed below.

6.2.1 Request Process Failures

The request input from the forward observer or other engaged unit was assumed to be perfect within the team’s modeling and simulation. The main causes of errors being introduced to the system by the request are equipment failure, environmental effects, and training.

Table 17 summarizes some potential failures and proposes actions to mitigate the risk of invalid or missed requests. Equipment failures, such as the primary radio, typically result in delays in placing the CFF. Additional radios are typically available within the unit, the request can be sent to another unit for forwarding, or messengers can be sent.

Environmental effects, including radio interference, or electronic attack may prevent a call from being sent or merely delayed while an alternative communications path is found.

The final factor, human error is typically a result of insufficient training or proficiency. Correctly identifying a target while under fire can be difficult. There is a tendency to request destruction of every target. This typically is not the commander’s intent because excessive ordnance and providers could be tasked potentially missing other valid targets.

Additionally, blind reliance on targeting equipment without the experience to verify the data can lead to precision errors. Unqualified observers calling for fire on their position, not recognizing range or bearing errors, and calling from the wrong reference point will have severe implications. Tasking a qualified fire support team to respond to every call may not be feasible.

Potential Failure Mode	Potential Causes	Mission Impact	Recommendations	Results	Risk to Mission		
					SQ+	CJFSN	DJFSN
Request Not Received	FO radio failure	Valid target not nominated	Alternate comm path	Additional delay	Med	Med	Med
Request Not Received	Environment (blockage)	Valid target not nominated	Multi frequencies	Increased cost, weight or quantity of radios	Med	Med	Med
Request Not Received	Jamming	Valid target not nominated	HOJ asset tasking	Reduced providers for other missions	Med	Med	Med
Precision Error	FO precision	Precisely miss target	Reliable positioning and targeting equipment	Increased weight, possibly requires vehicle	High	Med	Med
Wrong Effects	FO training and experience	Overkill - lost opportunity to prosecute harder target	Joint training on desired effects	Expect request for overkill from all non-trained requesters	Med	Low	Low

Table 17: Potential Failures in the Acquire Process

6.2.2 Targeting Process Failures

The targeting process for each alternative is the primary system under consideration. A summary of the potential failures in this system are presented in Table 18. Equipment failures and human error account for the majority of potential problems.

Potential Failure Mode	Potential Causes	Mission Impact	Recommendations	Results	Risk to Mission		
					SQ+	CJFSN	DJFSN
Tasking Not Received	Decision authority fails to transmit	Valid target not engaged	Alert decision authority of delay	Requires (semi-) automated decision aid	High	Med	Low
Request Not Prosecuted	No assets available	Valid target not engaged	Alert decision authority.	Possible re-tasking of assets	Med	Med	Med
Request Not Prosecuted	Priority too low	Valid target not engaged	Inform FO	Possible re-tasking of assets or delay in engagement	Med	Med	Med
Request Not Prosecuted	Insufficient time	Increased risk to engaged forces	Inform FO, update TOT	Delay or cancel request	Med	Med	Med
Request Not Prosecuted	COP indicated danger close (or denied target)	Increased risk to forces	Inform FO, verify positions and update COP	Cancel request, delay in engagement if request deemed valid	Med	Low	Med
Delivery Late	Delay in asset availability	Partial Success (hit late)	Inform FO	Delay or loss of engagement	Med	Low	Low
Delivery Late	Estimated time on top too late	Failure (target departed)	Inform FO, task earliest provider	Delay or loss of engagement	Med	Med	Med
Delivery Late	Excessive pairing time	Delay in authority to task	Delegate to appropriate level	Less CDR involvement in decision process, ROE may restrict	High	Med	Low
Precision Error	Error in message transmission	Attack wrong target	Data structure design, verification of task with requester	Increased message flow, bandwidth requirements	Med	Med	Med
Wrong Effects	Pairing algorithm errors	Target requires re-attack	JFC staff periodically evaluate algorithm for current CDR intent	Variety of pairing algorithms based on ROE & CDR Intent	Low	Low	Low
Wrong Effects	Pairing algorithm errors	Target requires re-attack	Exercise evaluate algorithms	Modeling and simulation of algorithms prior to operational use	Low	Low	Low
Wrong Effects	Ordnance load not correct in COP	Overkill or under kill	Auto update weapon platform status in COP	Lost opportunity or re-attack required	Med	Med	Low
Tasking Not Received	Provider radio failure	Valid target not engaged	Alternate comm path or alternate provider	Delay in engagement or "2nd best" provider tasked	Med	Med	Low
Tasking Not Received	Environment (blockage)	Valid target not engaged	Multi frequencies	Delay in engagement or "2nd best" provider tasked	Med	Med	Med

Table 18: Potential Failures in the Joint Fires System Targeting Process

Communications system failures may prevent requests from being forwarded to the appropriate decision cell or tasking orders being sent to providers. In either case, a delay in engagement or loss of target will result. Failures in communication with the common operational database, or within the database itself will complicate the pairing and deconfliction algorithms.

Assignments to less than optimal providers or an increase in “CANTCO” responses will result. Delays in prosecution due to manual deconfliction of airspace, or increased risk of fratricide will also result. The algorithms used for pairing and deconfliction should account for the possibility of time delayed position data and the application of appropriate separation for assets and ordnance trajectories.

These pairing and deconfliction algorithms also require flexibility to meet changing Commander’s Intent and Rules Of Engagement. The correct pairing in an open desert permissive environment is not necessarily the same as a constrained urban setting even when the same assets are available. The JFC staff should periodically review the algorithm in use and promulgate changes to subordinate commands.

The message format and data structure used to share the information between the various entities should be robust enough to be virtually error free. Inadvertent bit errors that go undetected will adversely impact the engagement process. Increased risk of fratricide, collateral damage, and lost opportunities to engage targets will result.

Errors in the operational picture will increase the risk to blue and neutral forces or may negate a valid CFF. Sharing this data with coalition forces presents a significant security risk that should be addressed separately.

Unavailability of assets or an estimated engagement beyond requested response time needs to be communicated to the operational commander and the requesting unit. A decision will then be made to engage the target when an asset becomes available, cancel the request, or re-task an asset assigned to a lower priority target. The Project Team’s modeling and simulations did not consider a situation where preplanned missions were re-tasked to engage unplanned targets.

6.2.3 Prosecution Process Failures

Table 19 summarizes potential failures during the prosecution process. Project Team simulation and modeling did not take into account potential failures which include equipment failures, environment effects, and human error.

Potential Failure Mode	Potential Causes	Mission Impact	Recommendations	Results	Risk to Mission		
					SQ+	CJFSN	DJFSN
Tasking Not Received	Jamming	Valid target not engaged	HOJ asset tasking	Reduced providers for other missions	Med	Med	Med
Delivery Late	Operator intervention required or error in delivery	Increased risk to engaged forces	COP update sufficient to use auto-deconflict algorithms	Increased message flow, bandwidth requirements	Med	Med	High
Delivery Late	Manual deconfliction required	Increased risk to engaged forces	COP update with all friendly assets	Manual or auto update own unit status periodically	Med	Med	High
Precision Error	Target close to friendly/neutral types	Risk of CDE / Fratricide	Danger close range restrictions included in pairing algorithms	TTPs for engaging danger close targets still required. Limits potential providers	High	High	High
Precision Error	Targeting error at delivery	Target requires re-attack	Function of weapon-platform	Pairing algorithm consider effects based on platform-weapon effects	Med	Med	Med

Table 19: Potential Failures in the Prosecution Process

Environmental interference or jamming preventing receipt of tasking can be mitigated by tasking the “second best asset” or providing anti-jam or electronic attack assets to engage the jammer. A delay in engagement or loss of opportunity to engage the target may result.

Equipment failure of the provider will result in a non-engagement, and require the target to be re-assigned. Removal of the asset as a potential provider from the operational database should make this a single event with minimal overall system impact. Inherent inaccuracies in the targeting systems (position error, circular error probable, average miss distance, etc.) will impact the actual effectiveness and coupled with effective assessment may require re-nomination of the target for prosecution.

System errors that require human intervention will typically delay time until the target is engaged. If the CAS provider is required to deconflict airspace via voice en route to the target, the overall timeliness of response will suffer. For “Danger Close” targets, it will be required to employ tactics and procedures that are inherently more difficult and slower than a less restrictive CFF.

The overall expected risk of the above failures can be used to rank the alternatives based on relative reliability of mission success. The Acquire process rated the Status Quo Plus more likely to fail than the centralized and distributed joint fire support networks. The Target process rated the DJFSN alternative as the best, followed by the CJFSN and Status Quo Plus. The Prosecution process rated the Status Quo Plus and CJFSN as moderate to high risk, with the DJFSN even higher.

7.0 RESULTS AND CONCLUSIONS

The objective of this study was to determine a better way to perform Joint Fire Support. Specifically, the Project Team attempted to "define an operationally feasible Joint Fire Support request, coordination, and tasking architecture that maximizes rapid battlefield effects for the Commander." By taking an objective look at the concept of JFS and applying a systematic design process to the problem, the project team has identified challenges, proposed solutions, and insights for a truly "joint" fire support system in the future.

7.1 PREFERRED SYSTEM ARCHITECTURE

The Distributed alternative offers the best possible range of benefits but also comes with the highest implementation risks and challenges. Before the project team could arrive at an overall alternative recommendation, a consideration that military forces will have to continue day-to-day operations during the transition period. This constrained the risk that operational commanders would wish to take and imposed a "tipping point" for implementation. Having considered all these factors, the team chose to recommend the distributed joint fires support network as the recommended alternative. However, the project team recommended against efforts to get to that objective in one step. The Centralized alternative is a natural evolutionary step to get to a distributed system. Moving to the centralized alternative and, after that alternative is fully realized, moving to the distributed architecture is a preferred method to mitigate implementation risk.

The doctrine, organization, and materiel requirements for the DJFSN system drive the main sources of operational risk. The dynamic chains of command, a fully interoperable and common command and control system, and trusted decision making algorithms are high risk to implement; the DJFSN system fails without them. However, even though these objectives will be difficult to implement, they should remain the ultimate goals.

The Centralized Joint Fire Support Network (CJFSN) represents a stepping stone on the path to DJFSN. While CJFSN also streamlines chains of command and requires an interoperable command and control system, it remains less efficient than DJFSN because it keeps the personnel associated with decision-making at the various functional levels. These people are the key to operational risk mitigation; they can absorb the shortfalls associated with areas that do not yet meet the larger goals.

The path to implementing a fully distributed joint fire support network can be achieved by transitioning first to a centralized joint fire support network (CJFSN) and then building on that success. Development of the required doctrine, organization, and tactics changes will then allow a “top-down” implementation of the DJFSN. This “build a little, test a little” approach will mitigate the risks involved with transition from Status Quo (Plus) to a fully distributed process while also improving overall Joint Fires system performance.

The magnitude of DOTMLPF changes required to implement the DJFSN alternative compared to the centralized or status quo plus is illustrated in Figure 52.

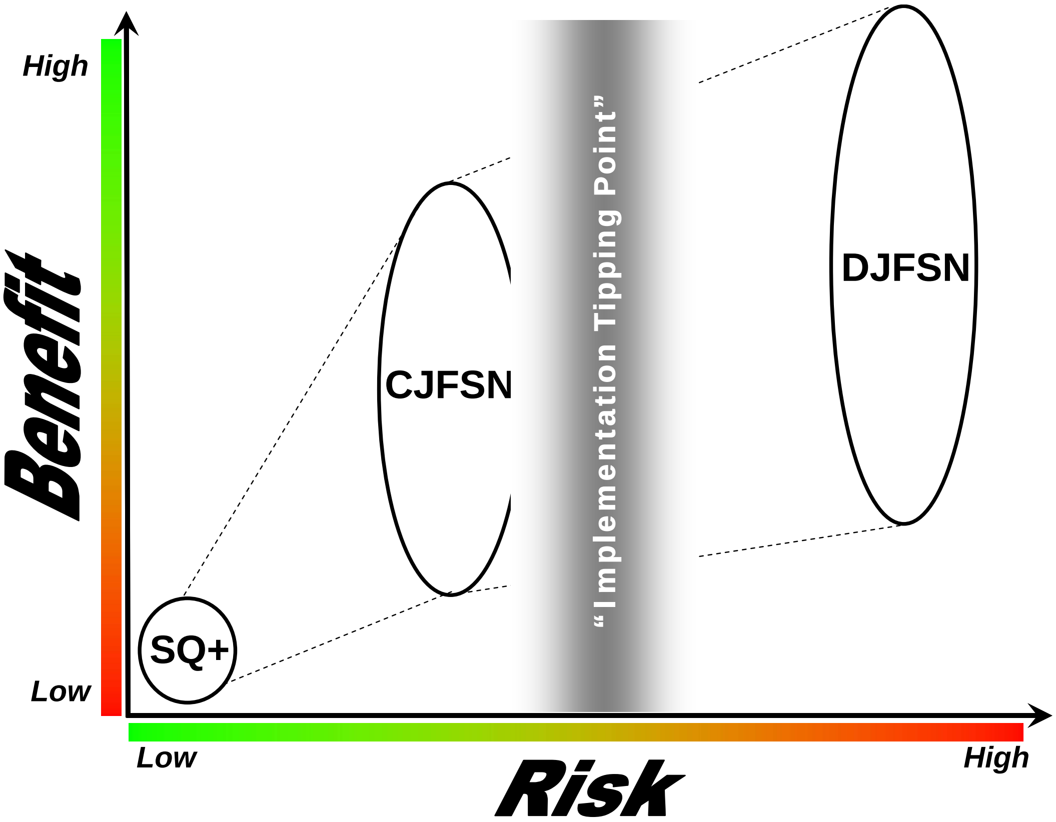


Figure 52: Potential Benefits and Risks of the Proposed Alternatives

7.2 CONCLUSIONS AND RECOMMENDATIONS

There are numerous obstacles that must be overcome if any integrated JFS system is to be deployed. Based on the team’s study of the challenges of joint fire support and the recommended implementation path from a centralized to a distributed joint fire support network, numerous recommendations were identified to enable this change. These conclusions and recommendations have been organized in the construct of the DOTMLPF model and are highlighted below.

7.2.1 Doctrinal Conclusions and Recommendations

The implementation of the DJFSN requires that service doctrine continues to evolve towards capability-based operations. Progress in this area has been significant and is likely to continue. The establishment of the JFC structure has brought an unprecedented level of flexibility to operations. And commands like

SOCOM continue to push out “the edges of the envelope” through their day-to-day operations.

> The Joint Fires Support mission area crosses the boundaries of the four Services, each bringing unique capabilities to the battle. The synergism of the mission area that has universal Tactics, Techniques and Procedures (TTPs), recognized and employed by all users, will be a force multiplier for joint operations in the future.[55]

Doctrine should also permit the services to carry more supporting roles and missions that are consistent with their capabilities and Title 10 responsibilities. In particular, doctrine should establish more developed ground and air combat support relationships among the services.

7.2.2 Organizational/Leadership Conclusions and Recommendations

Functionally equivalent organizations should be consolidated, physically or virtually, with formal organizational linkage under the JFC construct. From the perspective of the team, there are a significant number of organizations performing comparable functions. For example, the DASC and ASOC complete many of the same tasks for CAS operations. Defined organizational links will maintain clear chains of command and allow any calls-for-fire to move between the services’ decision nodes without having to transit the staffs, thereby shortening the timeline for truly effects-based decision making.

This organizational consolidation should be used as the catalyst for functional collaboration. Personnel working in these organizations will expose the interoperability issues of duplicative systems, help develop common training syllabi, and be a primary source of cross-cutting improvements. Acting on these areas is key to the “build a little, test a little” approach and overall implementation success.

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[55] U.S. Marine Corps Marine Corps Combat Development Command, Mission Area Initial Capabilities Document for Close Air Support, JROCM 095-04, 14 June 2004, p. 2.

7.2.3 Tactics and Training Conclusions and Recommendations

Develop a core syllabus of standardized, joint training for calls-for fire which is included in every service’s basic combat skills list. Where it is necessary, specialized training for fire support teams, forward observers, forward air controllers, or riverine combat teams may be developed. The expected result is a reduction of training differentiation between the services and consistent procedures between theaters. Develop a common joint tactical publication set to reinforce this core syllabus.

Develop prioritization, pairing, and deconfliction algorithms for a variety of scenarios. These automated algorithms will be used as tactical aides by the Joint Fires Cell to support rapid effects-based pairing. A robust set of algorithms that can be tailored to support the JFC intentions and operational requirements is necessary to move to the DJFSN architecture.

7.2.4 Materiel Conclusions and Recommendations

The DoD must realign to permit the development of interoperable systems. With respect to joint fires, this realignment must focus on the portfolios of programs that comprise the Command and Control systems, fielded ground, air, and ship systems, and the communications equipment which comprises the Global Information Grid. Despite the significant efforts from a roster of program executive officers, functional boards, and oversight councils, separate command and control systems still exist within a fractured community. Each service maintains multiple approaches to address common issues. This diversity extends across the entire joint fire support spectrum and is increasing each day. For example, as the “ground gets taller” with fielded combat troops operating UAVs in the battlespace, integration into the Theater Battle Management Core System (TBMCS) is not a requirement for the UAV C2 systems.

The DoD should realign the requirements, authority, and funding of the programs into a single track. One construct to do this is to use a Joint Program Executive Officer as the instrument of that change. For C2, this would be particularly difficult since the acquisition community is divided between the

Assistant Secretary of Defense for C3I and each of the services. With fully interoperable systems as the goal, all systems which process calls-for-fire should share common data standards; many of which already exist. As an example, the Joint C3 Information Exchange Data Model (JC3IEDM) developed by the Multilateral Interoperability Program (MIP) at NAVSEA is a mature standard but it has not yet been widely used outside experimental settings.

The DoD should continue investments in communications with an emphasis on providing more bandwidth to the fielded troops, ships, and aircraft. Much like the C2 discussion above, the Global Information Grid (a program managed by DISA under ASD/C3I) needs to move in step with the services' own planned networks. The Navy's ForceNet, Air Force's C2 Constellation, and Army's LandWarNet systems are attempting to capture, process, interface, and secure the ever-increasing amount of networked tactical data in the form of text, VoIP, recorded data, sensor targeting, fire control data, text command instructions, and images.[56] The command and control efficiency needed to effectively communicate the JTF commander's intent and priorities will be impossible to achieve without a robust and interoperable system.

The DoD should designate a "Center of Excellence" for the development of the family of decision algorithms necessary to support automated command and control. Throughout this thesis, the Project Team reviewed several decision algorithms that conducted various actions including prioritization, pairing, and resource deconfliction. The team concluded that no universal decision making algorithm will satisfy the full range of operational requirements. However, the majority of these algorithms will share common processes and data requirements. A centralized repository of methods and expertise should prevent needless duplication in this area.

7.2.5 Personnel and Facility Conclusions and Recommendations

The continued development of the Global Information Grid (GIG) should allow the expansion of the joint fire support concept within the US military and

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[56] Department of Defense, Joint Battle Management Command and Control (JBMC2) Roadmap, Draft Version 2.0, 22 February 2005, pp. 1-181.

allow participation of allied and coalition partners. The primary challenge to this expansion is the complexity and sensitivity of allowing allied/coalition entry into the U.S. joint "infosphere." The GIG should deliver, as advertised, a "plug and fight" interoperability, that enables allied and coalition partners to connect on an as needed basis. [57]

A coherent and unambiguous common operational picture requires that sensors reliably and clearly identify and track targets within the complex battlespace. Future C4ISR systems will have to support a rapid detection and precise location of blue forces and red targets for a shared common view linked to the operational command decision maker, who determines the joint fire of choice in an integrated, dynamic fire support plan.[58] As technology integrates more information into the user's hands, data analysis/discrimination will be slowed by necessary human intervention. Information overload will occur. Battle management aids will have to be developed to avoid inefficiency of the human in the loop stymied with information overload. [59]

The reliance on voice communications permeates current JFS practices, affecting Fire Support Coordination Agencies (FSCAs) and related elements. As the military develops advances in joint fires capabilities the reliance on automated data may bring with it overcrowding of some RF spectrums as well as new requirements for increased information security that result in longer data transfer times.[60]

The DJFSN requires a real time operational picture of targets and providers. Additionally, blue, gray and white positions should be known with sufficient accuracy to prevent fratricide and collateral damage. Effective IPB communicated to all fire providers is needed to set no-fire or restricted zones where higher authority permission is required to engage (due to presence of SOF, coalition forces, critical infrastructure, political targets etc.).

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[57] US JFCOM, Global Information Grid, 15 August 2001, p. 7.

[58] U.S. Marine Corps Marine Corps Combat Development Command, Mission Area Initial Capabilities Document for Close Air Support, JROCM 095-04, 14 June 2004, p. 34.

[59] Ibid

[60] U.S. Marine Corps Marine Corps Combat Development Command, Mission Area Initial Capabilities Document for Close Air Support, JROCM 095-04, 14 June 2004, p. 34.

7.3 AREAS FOR FURTHER STUDY

During the course of this study, the Project Team identified several areas for further study.

7.3.1 Doctrine

Title 10 US Code mandated separation of some service functions was cited as a reason for lack of interoperability between services during several stakeholder interviews.

An operator's review of 10USC revealed flaws in the arguments and apparent support for several of the team's recommendations. According to 10USC, the Secretary of Defense shall take action to eliminate duplication in the Department of Defense[61]. Additionally, matters of joint concern shall be coordinated between the Army, Air Force, and Navy[62]. In joint operations, airspace management and deconfliction of manned aircraft, unmanned vehicles, and ordnance are matters of joint concern. Coordination between USMC, Army, and Air Force for tactics and equipment used by landing forces is also required.[63] With regard to the acquisition of systems, the JROC has a responsibility to assist CJCS in assessing joint military requirements.[64] The team proposes that a common command and control system should be a "joint military requirement". Title 10 also states the Assistant Secretary of Defense for C3I "shall have as his principal duty the overall supervision of command, control, communications, and intelligence affairs of the Department of Defense." [65] Establishing a Joint PEO under ASD/C3I may be the catalyst to develop a common joint command and control system.

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[61] House of Representatives, "10USC125(a)", [http://www.access.gpo.gov/uscode/index.html], Nov06

[62] House of Representatives, "10USC5062(c)", [http://www.access.gpo.gov/uscode/index.html], Nov06

[63] House of Representatives, "10USC5063(b)", [http://www.access.gpo.gov/uscode/index.html], Nov06

[64] House of Representatives, "10USC181", [http://www.access.gpo.gov/uscode/index.html], Nov06

[65] House of Representatives, "10USC138(3A)", [http://www.access.gpo.gov/uscode/index.html], Nov06

The requirement for separately developed and managed systems within the component services appears to be more a matter of “the way we’ve always done it” than public law. A more detailed review of the legal requirements to enable more efficient, effective, and economical operation stated in 10USC125 which we believe is needed. These doctrine changes will also affect the distribution of budget between the services and how they organize, train, and equip the force.

7.3.2 Organization and Leadership

The requirement for dynamic allocation of assets to prevent fratricide presents significant challenges to the decision makers. The complication of a manned weapon occupying the same volume of space as unguided weapons and the expected proliferation of small unmanned aerial vehicles necessitates additional coordination measures. The various methods of deconfliction and development of a model to overcome the organizational challenges of implementing ‘joint engagement zones’ for fires support requires further analysis.

7.3.3 Tactics and Training

The priority of the targets, and the desired effects against those targets, determines the fire support assets that should be tasked against them. On a dynamic battlefield with rapidly moving targets, exceptionally mobile blue forces, and quickly shifting objectives, this aspect of fire support integration becomes extremely difficult to manually accomplish. The final DJFSN system should have a pairing algorithm that can be tailored to the commander’s intent. Development of a variety of these pairing algorithms to support a range of operating environments, an assortment of ROE environments will be required. Parallel development of these algorithms for testing and use at the joint fires support cell will improve the processing time and help build the confidence during the transition to a distributed networked system.

7.3.4 Materiel

As the services move towards more restrictive ROE and precision guided munitions, the capability to accurately locate the target is critical. Otherwise precise misses result from PGM on errant targeting information. An alternative method of tasking a targeting sensor (a remote UAV for instance) that operates in conjunction with a ground based fires asset may replace or enhance the active range finder carried by each ground unit. BDA assets should also be tasked as part of the joint fire support system. The assumption that the requester was in position to conduct BDA may not always hold true. Consideration to employ manned aircraft as weapons delivery and BDA, or tasking a sensor asset to accomplish the assessment should be part of the decision process.

Continued development of the Global Information Grid was an initial assumption for all three alternatives considered. The information data structures, exchange formats, and interfaces with existing and developing systems require oversight and evaluation. The common operational picture assumed to exist is predicated on systematic integrated development of various command and control systems.

7.3.5 Personnel and Facilities

The consolidation of the various service specific functional entities under the centralized system requires further analysis. Physical and functional layout and organization of this new functional component should be designed and networked based on a human resources based analysis.

Commonality of training syllabus, collocation of facilities or cross-service exchange of instructors should be evaluated.

APPENDIX A. JFIIT SYSTEMS INTEROPERABILITY

Joint Forces Interoperability and Integration Team Systems Matrix shown in Table 20 identify capabilities, limitations, and interoperability of various weapon platforms and the command and control equipment across the Services.

	APPLICATION & NETWORK LEVEL																
AIRCRAFT	**Pro[4]**		**Message Standard**												**Header Stand.**		
	Combat Track II	**SADL**	**LINK-16 MIL-STD-6016**	**STANAG 5516 Tactical Data Exchange**	**MIL-STD-3011(JRE)**	**XML-CoT**	**AFAPD**	**MTS TIDPS/ SDN-C2103-442 17 OCT 94**	**VMF TIDP-FTE R2 (VMF)**	**VMF TIDP-FTE R6 (VMF +ACAS)**	**VMF TIDP-FTE R6 w/imagery message**	**VMF MIL-STD-6017**	**VMF MIL-STD-6017 w/Imagery Message**	**VMF MIL-STD-6017A**	**MIL-STD-2045-47001B**	**MIL-STD-2045-47001C**	**MIL-STD-2045-47001D**
AH-1W																	
AH-1Z												**P^1**					**P^1**
AH-64D							**P^2**										
A-10		**P^1**								**P^1**							
A/V-8B								**X**							**P^1**	**P^1**	
F/A-18 A+/C/D, F/A-18 E/F [22-24] F/A-18 E/F [25&up]			**O^1**						**X**						**X**		
F/A-18 A+/C/D,			**O^1**						**X**	**X**					**X**		
F/A-18 E/F [25&up]			**O^1**						**X**		**X**				**X**		
F/A-18 A+/C/D, F/A-18 E/F [22-24] F/A-18 E/F [25&up]			**O^1**										**P^1**		**P^1**		
F/A-18 E/F [25&up]			**O^1**										**P^1**				**P^1**
F-16C, Block 25/30/32		**X**															
F-16CG, Block 40/42			**P^1**				**X**										
F-16CJ, Block 50/52			**X**				**X**										
AC-130H	**X**					**X**											
AC-130U	**X**					**X**											
F-15E			**X**														
B-1	**X**		**P^1**														
B-2			**X**		**X**												
B-52	**X**		**P^1**				**P^1**							**P^1**			**P^1**
F/A-22			**P^3**														
F-35			**P^1**									**P^1**					**P^1**
JTAC GROUND SYSTEMS																	
TLDHS							**X**	**X**	**X**	**X**	**P^1**	**P^1**			**X**	**X**	
BAO w/Gateway			**P^1**			**X**											
TACP-M wo/Raider							**X**	**X**	**X**	**X**	**P^1**	**P^1**			**X**	**X**	
TACP-M w/ Raider		**P^1**	**P^1**		**P^1**		**X**	**X**	**X**	**X**	**P^1**	**P^1**			**X**	**X**	

Table 20: JFIIT's Interoperability and Capability Matrix

AIRCRAFT	PHYSICAL/SIGNAL LEVEL									
	Radio						Physical & Signal Standards			
	JTIDS/ MIDS Terminal (R/T)	ARC-210 R/T 1824	ARC-210 R/T 1851 (Warrior)	ARC-210 R/T 1851B (5th Gen)	AMF JTRS	AN/PRC-117F(or equivalent)	LINK-16 MIL-STD-6016	STANAG 4175 Tchnical Characteristics of th	MIL-STD-3011(JRE)	UHF Amplitude Modulation
AH-1W										
AH-1Z				P^{1}						
AH-64D										
A-10										
A/V-8B			P^{1}							X
F/A-18 A+/C/D, F/A-18 E/F [22-24] F/A-18 E/F [25&up]	O^{1}	X					O^{1}			X
F/A-18 A+/C/D,	O^{1}	X					O^{1}			X
F/A-18 E/F [25&up]	O^{1}	X					O^{1}			X
F/A-18 A+/C/D, F/A-18 E/F [22-24] F/A-18 E/F [25&up]	O^{1}	P^{1}					O^{1}			P^{1}
F/A-18 E/F [25&up]	O^{1}				P^{1}		O^{1}			P^{1}
F-16C, Block 25/30/32										
F-16CG, Block 40/42							P^{1}			X
F-16CJ, Block 50/52										X
AC-130H										
AC-130U										
F-15E	X						X			
B-1	P^{1}						P^{1}			
B-2	X						X		X	
B-52	P^{1}		?				P^{1}			P^{1}
F/A-22	P^{3}						P^{3}			
F-35							P^{1}			P^{1}
JTAC GROUND SYSTEMS										
TLDHS						X				X
BAO w/Gateway						X	P^{1}			X
TACP-M wo/Raider						X			X	X
TACP-M w/ Raider	X					X	X		X	X

X = Existing	O^{3}=Installed but not planned to support JTAC to Aircraft CAS		
P^{1}=Program/Service Planned	Prop^{4} = Proprietary Specification		
P^{2}=Installed, ICD w/ Strikelink Pl 🟦	Combat Track II Protocol	🟧	BAO Kit Protocol Stack
P^{3}=Program /Service Planned fo 🟨	SADL Protocol	🟩	Traditional Modem-Based Protocols
Chuck Cratsley 757-203-4492 🟪	JTIDS/Link-16 Related Stds	▨	Primary System Configuration Item
USJFCOM J89			

Table 20: JFIIT’s Interoperability and Capability Matrix (cont.)

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APPENDIX B. JOINT FIRE SUPPORT REQUEST DATA FORMATS

The Project Team asserted that the call-for-fire data requirements are constant across the services. The team has reviewed the primary methods to complete a call for fire for various types of providers to ensure the data contained in these different requests is essentially static.

For artillery calls for fire, a normal call for fire consists of six elements: Observer identification, Warning Order (which includes the type of mission, the size of the element to fire for effect, and the method of target location), Target Location, Target Description, Method of engagement, and Method of fire and control. These elements are transmitted by voice communication in three parts, with each part being read back to the originator to ensure accurate transmission.

If an artillery call for fire is completed within AFATDS, the basic data entry screen requires the input of the observer identification, unit composition, ammunition type requested, target location, target type guidance, and map version used in the handheld terminal. By design, these data elements correspond directly to the items required for a verbal call for fire.

Requests for CAS are completed via a DD Form 1972 Air Strike Request and a “9-line” engagement message. (Due to widely varying equipment baselines in the aircraft fleet, there is no parallel to an AFATDS-like system.) While there at least 21 different versions of the 9-line, the data contained in the different versions are basically static and compare very closely with the data elements needed for artillery requests. From Table 21, the core data elements (contained in >50% of the formats) are evident

	Call for Fire Formats																					
JFIRE Variables	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**Total**
Target location / coordinates	x	x		x	x	x	x	x		x	x		x	x	x	x	x			x	x	16
Callsign: Observer ID / aircraft / JTAC	x	x		x	x	x	x	x		x		x		x	x	x		x	x			14
Target description	x	x		x		x	x			x			x	x	x	x	x			x	x	13
Method of engagement / type of ordnance	x			x	x			x		x	x	x	x		x			x	x			11
Heading to target / direction		x	x	x				x	x	x				x	x					x	x	10
Clearance / method or type of control	x	x		x	x			x		x			x			x				x	x	10
Friendly position													x	x	x	x	x			x	x	7
Distance to target			x						x					x	x					x	x	6
Authentication		x		x	x							x						x	x			6
Abort code												x	x		x			x	x	x		6
Time-on-target / Time-to-target						x					x			x						x	x	5
Number and type of aircraft											x	x			x			x	x			5
Mission Number												x			x			x	x	x		5
Mark type														x	x	x				x	x	5
Target Elevation														x	x		x			x	x	5
Weather / hazards													x				x			x	x	4
Threats in the target area													x				x			x	x	4
Remarks												x	x		x	x						4
Position of aircraft												x			x			x	x			4
Play time												x			x			x	x			4
Initial Point														x	x					x	x	4
Egress direction / instructions														x	x						x	3
Restrictions													x		x							2
Artillery (max ordnanace / gun-to-target line)							x						x									2
Target area description								x														1
Intelligence / situation update													x									1
Ground commanders initials																						0

Table 21: Close Air Support Call for Fire Format (From[66])

As a result of this analysis, the team felt confident in assuming the data required to engage a target was not significantly different based on the mode of engagement.

Simplicity under combat conditions is a characteristic of the above formats. However, these simple data structures aren't sufficient to describe the battlespace for C2 Automated Information Systems.

The Joint Consultation Command and Control Information Exchange Data Model (JC3IEDM) was developed by the Multilateral Interoperability Program (MIP) at NAVSEA, Dahlgren, VA. The JC3IEDM is essentially a pre-negotiated data structure to share Command, Control, and Communications (C3) data between 28 participating nations. This robust data structure of over 2000 elements would permit a very high degree of data interoperability between participating nations. If fully implemented, the JC3IEDM would require extensive changes to or replacement of existing equipment and software. JC3IEDM implements an eXtensible Mark-up Language (XML) format and would require much more bandwidth than current ASCII text-based equipment. While the

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[66] D. C. Clayton, Air Combat Command USAF Weapons Review, Winter 2005, "Close Air Support Briefings for the Future: Alterations to the 9-line", p. 40

JC3IEDM construct is on the interoperability path of many of the major C2 systems, the hardware at the edges, such as the data links onboard aircraft or in handheld data terminals, will probably not capitalize on it.

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APPENDIX C. CURRENT JFS COORDINATION AND DECISION-MAKING COMPLEXITY

Figures 53 through 55 are additional examples of the challenges in requesting fie support outside of traditional service coordination channels in the current system.

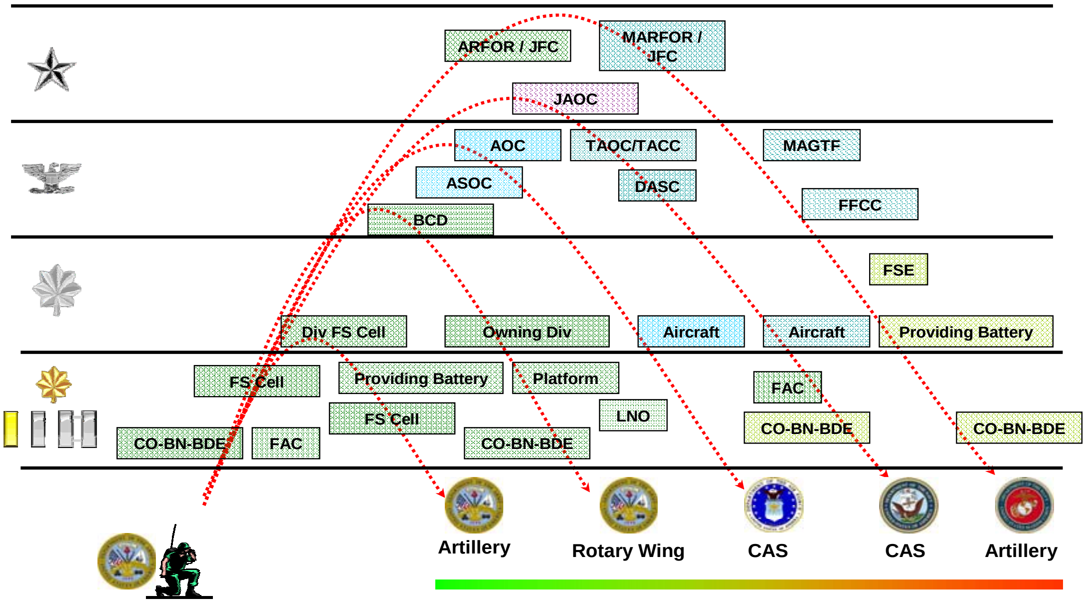

Figure 53: Army Soldier Requesting Fire Support

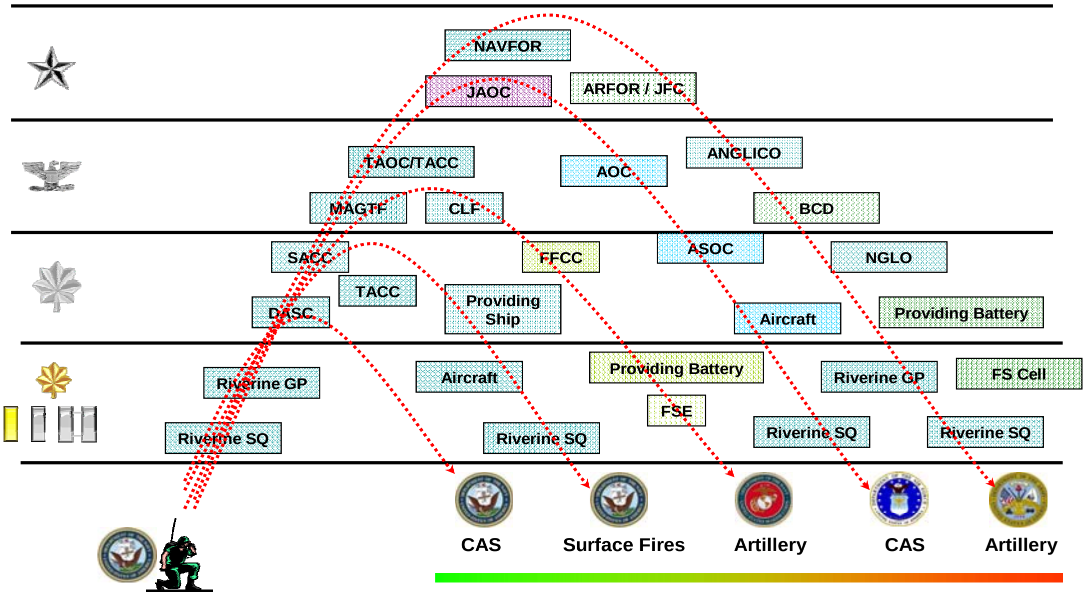

Figure 54: Navy Sailor Requesting Fire Support

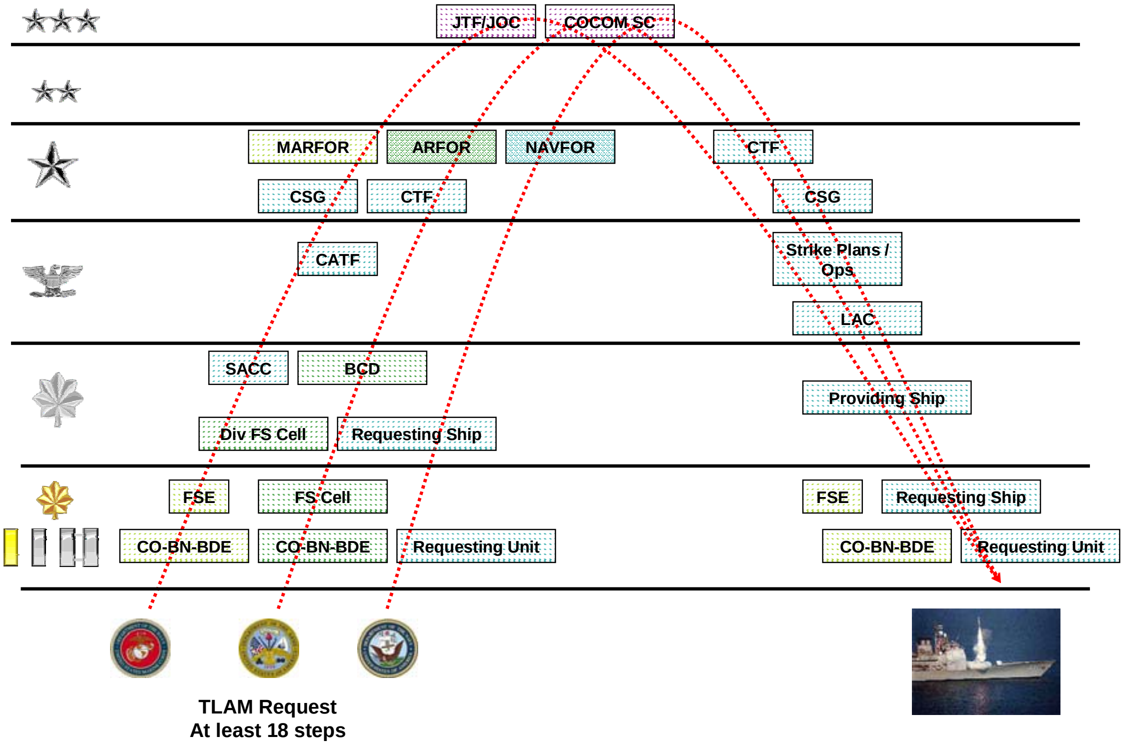

Figure 55: TLAM Request Processing

APPENDIX D. INPUT-OUTPUT MODELING PROCESS

The first consideration when attempting to characterize any system with an Input-Output (I-O) Model is to determine the intended outputs. The systems engineering process inputs combine the customer's requirements and the project constraints. The controllable inputs determine what is needed to start the process in order for the outputs to be achieved. The controllable inputs must be able to shorten the fire support tasking cycle by having the capability to task a request expeditiously. Controllable inputs apply to areas that can be controlled by the human interface with the system. These include, but are not limited to: training, C2, and the type, number, placement, and grouping of targeting sensors for a specific operation, in addition to tactics and logistics.

Uncontrollable inputs are those mostly environmental characteristics that influence the performance of the system. They are inevitable factors such as geography, climate, and topography. The uncontrollable inputs of our system often detract from the intended outputs. The proposed fire support system solution must be able to operate a range of dynamic environments from force-on-force, to rear area support and urban combat.

By-products of the systems process are unintentional or incidental outputs that have a positive or negative effect on achieving the overall goal of the system. Some of the by-products that have been identified by the Project Team include such things as sensor failure and enemy responses. The I-O Model helps provide information on the performance characteristics of the system and relates to how well the system will work in its intended environment. Once the outputs have been generated and bounded, the analysts can begin to make a determination of the effective need of the client and goals that satisfy this need.

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APPENDIX E. FUNCTIONAL FLOW ANALYSIS

The functional flow of items through the proposed system was deliberately decomposed into smaller steps as outlined in Figures 56 through 61.

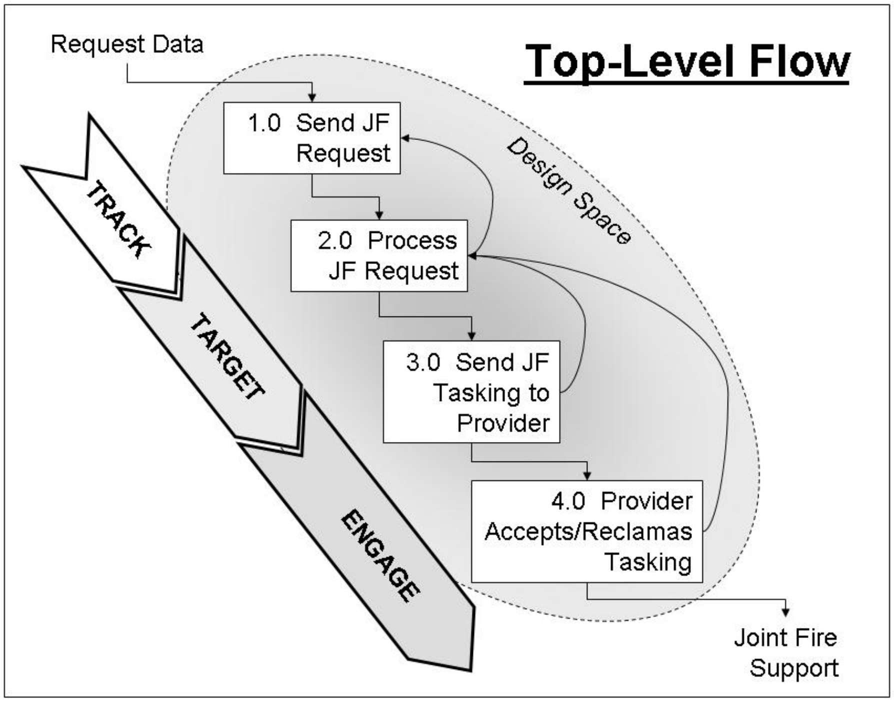

Figure 56: Proposed System Decomposition

Second-level Functions

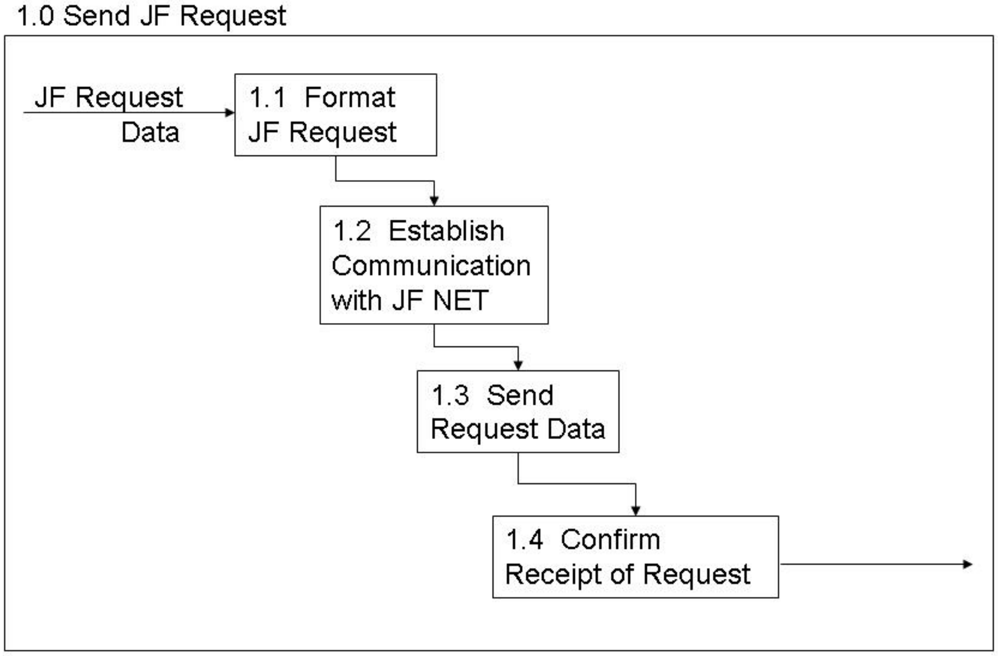

Figure 57: Send JF Request Sub-functions

Second-level Functions

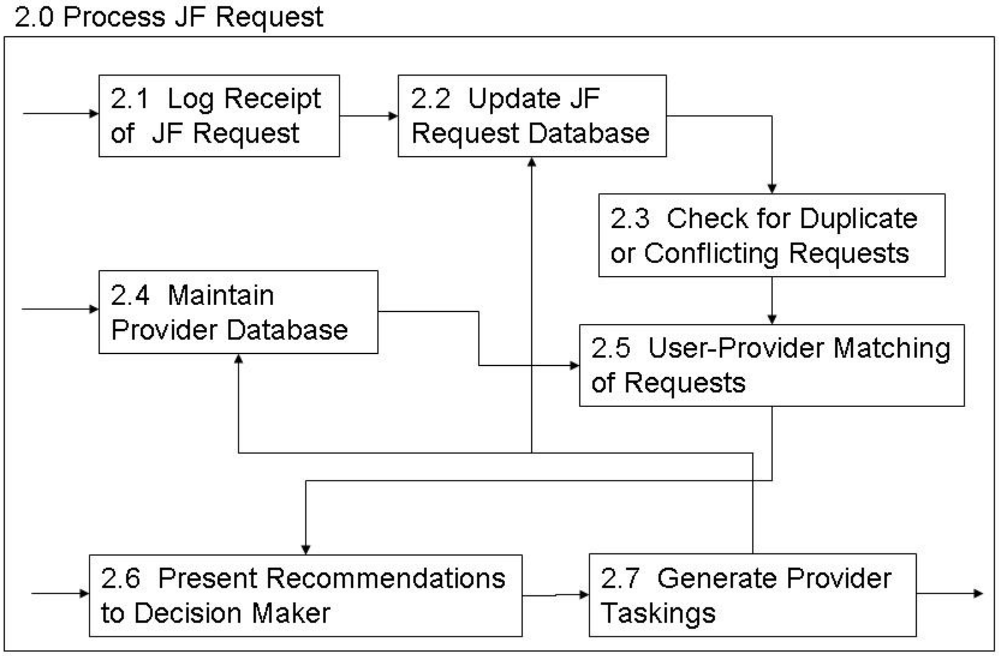

Figure 58: Process JF Request Sub-functions

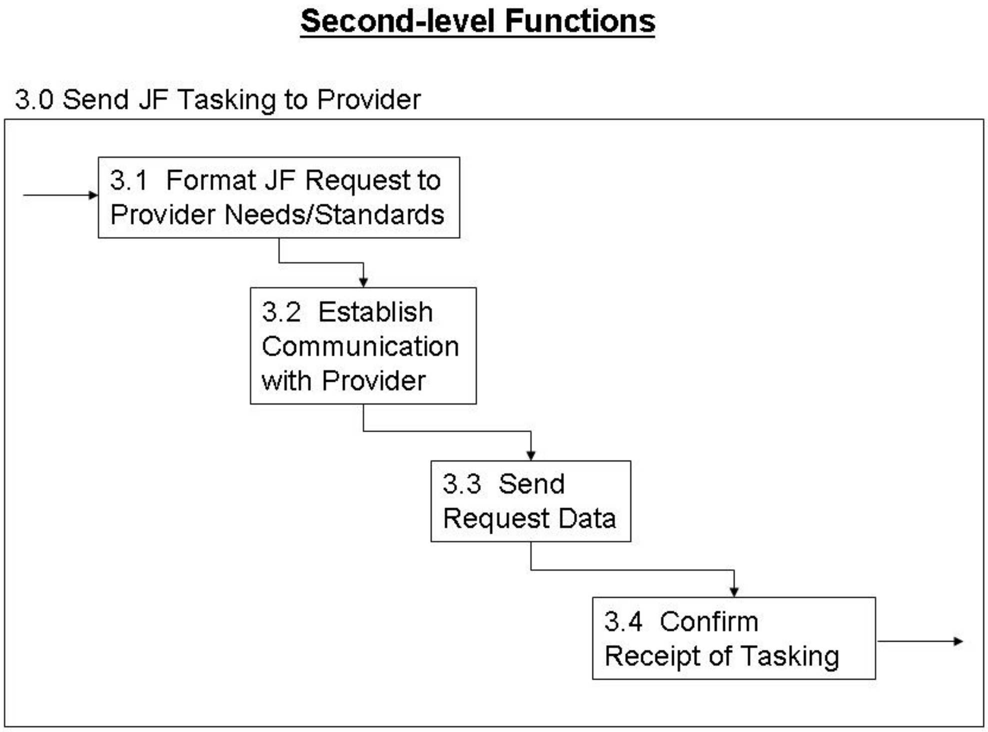

Figure 59: Send JF Tasking Sub-functions

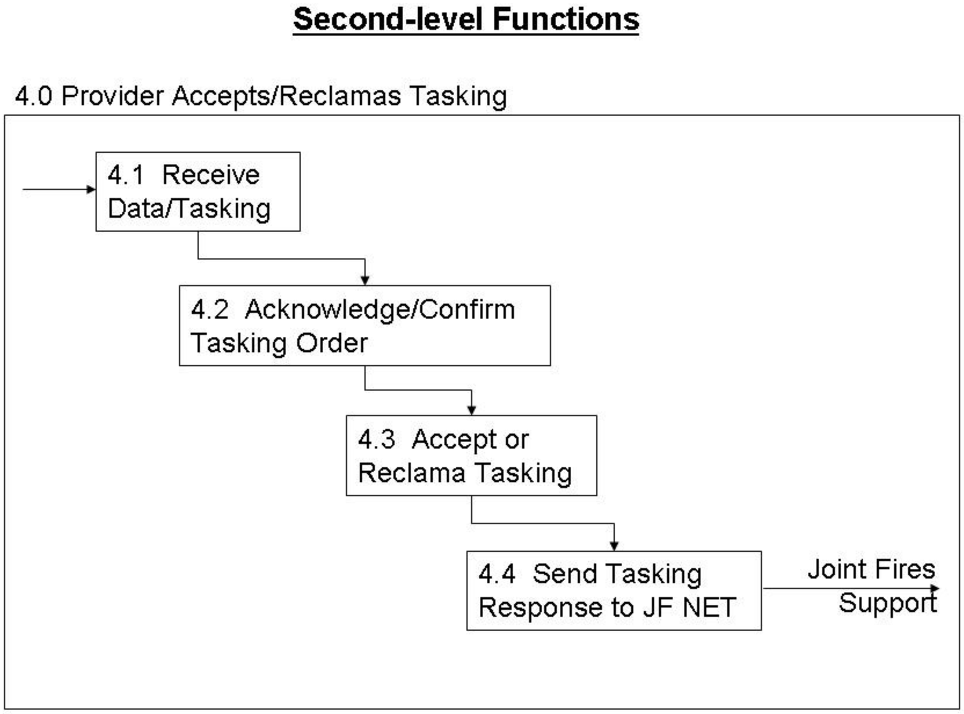

Figure 60: Provider Tasking Sub-functions

Third-level Functions

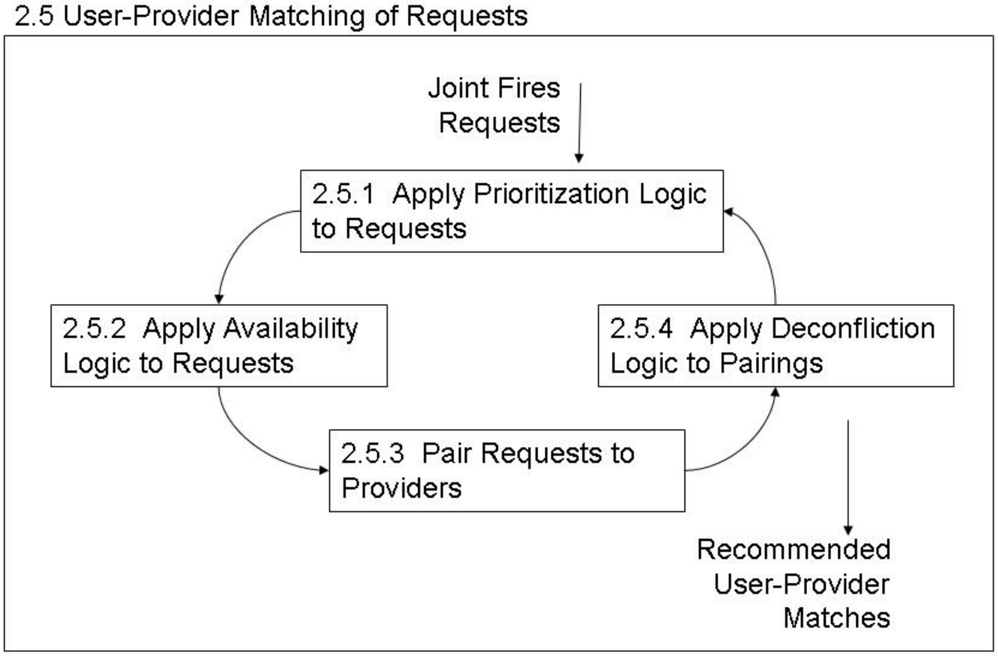

Figure 61: Request-Provider Pairing Sub-functions

APPENDIX F. STAKEHOLDER ANALYSIS AND SUPPORTING DATA

Stakeholder analysis enables the designer to identify the system's effective need as well as critical assumptions and constraints of the defined problem. These may come from a variety of sources and might include assumptions ranging from strategic to tactical. While time and money are the most typical constraints, there are also physical, legal, environmental, social and technological constraints that may be relevant and must be considered.

The Project Team began identifying stakeholders who would determine the system requirements, scope and bound the problem, and be involved in the entire process of definition, development, and deployment of the solution. Stakeholder analysis has several sub steps that include: (1) identifying stakeholders; (2) conducting interviews with stakeholders; (3) identifying stakeholders' needs, wants, and desires for the proposed system; (4) consolidating information.

Stakeholders can be separated into five major categories. Each category identifies a unique function and perspective that the specific stakeholders in that category provided the team. These five categories are:

1. Decision Makers
2. Clients
3. Sponsors
4. Users
5. Analysts

For the proposed Joint Fires in 2020 system, the following stakeholders were identified with respect to these five categories:

Decision makers have the authority to make impacting and final project decisions when multiple design choices are available. Because the purpose of the proposed future systems includes the weapon effectiveness of Joint military assets, the practical primary decision maker is: the Joint Fires Integration and Interoperability Team (JFIIT).

Clients are agencies or groups of people that will have substantial input as to the development of the solution set. They include Combatant Commanders (COCOMs) and each of the armed services.

Sponsors are offices or groups of people that provide financial support, which may include technical support or support in the form of special studies or specialized information, and include the Naval Postgraduate School (NPS).

Users are agencies or groups of people that will actually use the system that is developed. Practical users include Operators (all U.S. military) and defense contractors.

Finally, the project team **analysts** will evaluate the effective need and assist in determining the projected performance of various system alternatives. These include the SEA-10 Joint Fires Project Team and NPS faculty, staff and students.

Based on efforts to identify the stakeholders, the team traveled to visit and discuss JFS with the organizations described below. The following excerpts are trip report e-mails sent by members of the team immediately after each stakeholder visit. Each trip report describes the significant events and knowledge gained on each trip.

Stakeholders:	**US Marine Corps AFATDS Training Center** **AFATDS Software Development Project Manager**
Location:	**Fort Sill, Oklahoma, May 2006**
Audience:	**Joint Fire Support in 2020 Team & Advisors**
Author:	**Maj Tyler Gabriel**

> Overall, the short visit to Fort Sill, OK was incredibly helpful in all respects and I honestly believe that we have saved weeks or months of project effort by making this short trip. The amount of information we received was enormous and the insight into customer needs and stakeholder inputs we gained during our tabletop discussions with the Marines there gave us a whole new perspective on our Joint Fires project concept.
>
> On Thursday morning, we met with the USMC contingent on Fort Sill responsible for training Marines on the AFATDS system. Officers and Senior Marine NCOs spent about 1½ hours just describing and demonstrating AFATDS, EMT (Effects Management Tool), PSSSOF (Precision Strike System, SOF), C2PC, JTCW, and the MRT/TLDHS (AKA Strikelink), a new piece of

hardware/software that has recently joined the AFATDS system of systems. After a thorough review of how a Marine (or Army GI, or possible Riverine sailor) actually makes a call for fire using the AFATDS family of equipment, and how that request gets sent, processed, approved, prioritized, allocated, tasked, serviced, and assessed, they spent the next 2 ½ hours answering our questions about stakeholder needs and helping us to understand where the current systems are not meeting those needs. All of these Marines have recently returned from OIF and had actual experience interfacing the AFATDS and NFCS systems aboard a ship in the Persian Gulf. We also talked briefly about one recent application of the AFATDS technology, a rapid anti-mortar counter-fire capability, which has direct tie-in to the efficiency/timeliness of the technology in place and the advantages of the rapid responsiveness. This was a very productive meeting, and we learned a lot about the current system architecture and interaction, as well as programs that are in development and/or in limited fielding.

Thursday afternoon, we met with the program requirements manager for the AFATDS software for 4 hours. After seeing the operation of the current equipment with the USMC, we were able to pepper him with informed questions about the Joint Fires process and the requirements process that generated, and continues to refine, the AFATDS system. Of note, the AFATDS system, as a ‘System of Record’ designation, is by mandate projected to be THE primary mechanism for fire support in both the USA and USMC until around 2016. The next block software cycle, due out later this year, will move to a Windows OS (instead of the Unix OS it is on now), will include XML capability in addition to its current VMF/USMTF (Variable Message Format/US Message Text Format) messaging capability, and it will also be able to provide a specific deconfliction ‘tunnel’ for planned shells/rockets/missiles to aid in better deconfliction with airborne aircraft (and civil air as in the case of Iraq). The first version of AFATDS was fielded in 1996, so it has been in refinement and development for 10 years, making it an established and refined program that has incorporated 10 years of customer inputs to get to the functionality that it has today. One important aspect of AFATDS that we learned from both the Marines and the software program manager is the 2 different functions, tactical and technical, in the same software/hardware package. The technical function is the side of the software that computes exactly where to point the tubes/MRLS (essentially a weapon system component), and the tactical function is the side of the software that prioritizes, allocates, and tasks based on commander’s guidance. An important part of the AFATDS software that we discussed with the software program manager in detail was the compatibility issues with other existing systems. AFATDS is currently able to communicate directly to over 60 other systems using its VMF/USMTF message format. Several other systems, including JADOCS (Joint Advanced Deep Operations Coordinated System…simply renamed from ADOCS to generate funding) which should soon be supplanted by WEEMC (Web-Enabled Execution Management Capability), and the upcoming Net-Enabled Command Capability (NECC) were discussed. We had a great discussion of the shortcomings of AFATDS and all of the other Joint Fires-related software and the TTP/doctrinal disconnects. Interestingly, it appears the AFATDS systems wasn't originally developed using a systems engineering process. Only after 10 years of customer feedback have they managed to provide a system that meets the customer's (ground unit) effective needs…mostly.

"Take Aways"- The AFATDS system seems to be already doing exactly what the Army and Marines want it to do for organic indirect fires (mortar, arty, rockets, etc), but the Joint Fire Support request system starts breaking apart once it tries to leave the ground commander's purview (i.e. CAS, Naval Fires). This is where all of the advantages of this digital request format are lost by human-in-the-loop hurdles, which means that there has been little or no quantifiable improvement in CAS/NSF during the decade between Desert Storm and OIF/now. This is where Shawn and I think we should focus our analysis…there is an effective need here for customers across all of the services.

Stakeholder:	**Joint Fires Integration and Interoperability Team**
Location:	**Eglin AFB, Florida, June 2006**
Audience:	**Joint Fire Support in 2020 Team & Advisors**
Author:	**LCDR Matt Bartel**

The trip to JFIIT went well.

As for the briefs and the briefers: overall impression is that these guys are the single joint source. Nobody else is working on a joint picture that they could think of. There are a slew of civilians and contractors on staff, and only a few military (the CO, LCOL Ringler, and a few enlisted folks). The contractors are almost exclusively folks involved in joint fires (Marine FACs, former A-10 driver, Naval Aviators, and Intel). They (JFIIT) are the result of combining the CID (Combat Identification, think BlueForce Tracker, etc), and the Joint Fires folks commissioned by JFCOM. About 140 total personnel. They've done some research, with a lot of it at the National Training Center. We are invited to the next NTC event, August 12-15. The data they've collected, however, doesn't seem very useful from a modeling perspective...they monitor communications and layer each units SA to a ground truth (reality) to see how well the picture is being relayed up and down the chain. Here’s a rundown of the briefs:

Intro from LCOL Ringler: Welcomed us and offered all his resources...really looking to help us in any way he can. Changing command in a month or two, but guaranteed his replacement would have the same attitude. Asked about other organizations, he said: CNA (Center for Naval Analysis)...should have lots of data/info, JFCOM (POC pending), JAGO offices (Joint Air Ground Operations)...never heard of them, and look at the Marine Corps lessons learned on Joint Fires (I'm looking into this...it should be unclas). As far as data for the models, they have anecdotal info (interviews and surveys, with a big one finishing next month), but not much we can directly plug into our model, and no model of their own to simulate joint fires...their "model" is collecting data at live fire and exercise events to give performance feedback. Steve Mechum (Intel guy who coordinated for us) said he'd look at finding what we're looking for.

Ron Spock - Laser Rangefinder Quicklook method: At first I thought this brief wouldn’t be useful, but it turned out to be insightful. There are 5 laser rangefinders currently in use...they didn't recognize my weak attempt at describing the Strikelink LRF/tablet system. The five are: LLDR (Northrop Grumman product with Thermal and Video), the Mk 7 (most widely used), the Viper 2 (no longer manufactured), the Vector 21 (replacement unit for Viper 2), and the LH-40/41 (limited manufacture). All of these produced a mean error of 6-175 meters due primarily to the magnetic compass. JFIIT devised a method to improve to 5-40 meters mean error using the "Quicklook" method (using a known fixed point to determine declination and improve the coordinates passed). When I asked about digitized/automated systems, they said "bad data fast is still bad data". We eventually got around to the point that nearly every transmission of coordinate data is transmitted by voice. This brief also raised the point of joint fires also being joint ISR (in other words joint target location…USAF unit finds target for Army unit to be engaged by Army MLRS). Their biggest emphasis for future trends was CDA/CDE (collateral damage analysis/estimate); smaller and smaller warheads to attack a target due to political correctness.

Mike Higgins/Tim Finn (Tim Finn wrote quite a bit of the Joint Fires pubs) - JBMC2 (they used this acronym quite a bit at JFIIT). Like almost all the briefers, the emphasis is on JCAS...little integration of artillery/indirect fires, and no integration of NSFS. They had only a limited knowledge of current and planned Naval weapons like ERGM and the Rail Gun. This brief brought forward one of the biggest lessons learned (from my perspective): a major part of our analysis should go into the politics of the current problem (the major reason the military is not "joint")...and that is Title 10. I'll be honest and say I don't know a whole lot about it, but every brief mentioned that service parochialism and Title 10 are the major roadblocks to truly joint fires. It doesn't allow for the interoperability necessary for close coordination. It took them a year to do the analysis of JCAS problems, but the data is summarized in two excel spreadsheets that have more data than we could process in the time there...all the holes between aircraft and systems (who can't talk to whom, etc). Great data. Also mentioned talking to the Military Operational Research Society (MORS) for more data. They also spoke of a CJTFEX (Combined Joint Task Force Exercise) 04-02. They spent millions of dollars putting SA-6's and Scuds in the North Carolina countryside for "Joint Fires"...the targets were found by national assets, but the information never made it to the trigger pullers (they mostly faulted the Navy, who was in overall command, for not processing and relaying the info). Again, a great ISR tie-in. They recommended analyzing Joint Vision 2010 and 2020 for the discrepancy between what's been mandated and what's possible, especially in the realm of the F-35 JSF (hard joint requirements that conflict with service requirements). Tim also took the time to explain exactly how you go from user to provider (in a generic sense): Ideally you have a TACP (Tactical Air Control Party) who is a JTAC (Joint Terminal Air Controller)...could be officer (FAC qualified) or could be enlisted. They submit a voice request to the USAF Air Request Net, proposed to become the Joint Request Net. This request is then sometimes transferred to a form DD 1972 to go through Army channels for indirect fires. The coordination happens at the DASC (Direct Air Support Center, USMC) or ASOC (Air Support Operations Center, USA). The question of allocation or prioritization seemed very fuzzy, and I wasn't convinced of a standard approach aside from commander's prerogative. The joint coordination seems missing entirely once you leave the CAS arena...they mentioned AFATDS use by both the Army and the Marines.

Scot Chiasson (A-10 Driver) - Joint Fires Model. The Joint Fires "Model" is actually a UML representation of the kill chain. He presented the F2T2EA kill chain, and the presentation does an outstanding job of dissecting it. He also showed us another kill chain, D3A (Decide, Detect, Deliver and Assess). I obviously like the way we're going better (F2T2EA). His presentation explains target selection within this kill chain, including the allocation of assets for TST and on-call fires. Good explanation, but not a model in the sense of what we're going to need to do. Brought up the urgent need for MOE's and MOP's, and he referred me to "Annex

A"...lots of time/Pk/etc metrics that'll be on SharePoint shortly. When pressed for an allocation scheme, he referenced AFATDS and the way it handles calls for fire. He said there was an automated process for allocation that the commander can tailor with intent...maybe Tyler and Shawn know more on this.

On the technology side of things, they mentioned Link 16 is not currently compatible for CAS (you have to enter an air target at 0 altitude to point out a ground target). A neat system they mentioned was Rover 3, a system that allows the JTAC to see exactly where the aircraft's sensors are pointing (a video display of what the pilot is looking at in his FLIR/etc).

Col Andy Balding (USMC, Ret) gave a brief on training and the plan for future JTAC...doesn't look good. The capacity is barely there to maintain the requirements as it is, and the plan is to double output. Major roadblock is aircraft sorties for live fire training. Again mentioned Title 10 roadblocks to integration. Extensive brief on the T part of DOTMLPF.

Overall the trip was beneficial and provided good insight to the communications and breakdown of Joint Fires between the services.

Stakeholders: **Various Air Force, Army, Navy, and Marine Corps personnel and Professors**
Location: **Naval Post Graduate School Monterey, California, July 2006.**
Audience: **Joint Fire Support in 2020 Advisors & Team**
Author: **LT Spencer Nordgran**

The Joint Fire Support in 2020 held its interim Project review in July, 2006. This meeting was held to get expert faculty and student input from experienced personnel in the area of Joint Fires, Fires, and Systems Engineering. Numerous personnel from the Army, Marine Corps, and Navy, as well as several professors and retired flag rank military personnel were in attendance. The meeting was very successful and allowed the opportunity to meet subject matter experts in several joint fire areas to assist in the scoping and bounding of the project. The following questions and comments were addressed:

1. Maj Che’ Bolden
    - -Are you using kinetic or non-kinetic fires?
    - -Organic/non-organic?
    - -Request is it from a human or will you include UAV’s etc.
    - -Who’s doing tracking?
        - -electronic
        - -human

-May want to start at lowest level. USMC uses battalion level.

2. MAJ Tony Knight
   - -Guy on the ground already knows what he wants.
   - -Multi Asset (possible thesis topic).
   - -How are you going to positively identify a 1500 yard target (UAC, UCAV, etc.)?
3. MAJ Tom Stoner
   - -How are you going to encompass TST stuff?
   - -Caution separating request from process.
   - -What will JTF's role be?
4. Admiral Mike Jones
   - -What type of C4I is being proposed?
5. Tom Pugsley
   - -Is someone waving the flag and making the big push for what the priorities should be?
6. MAJ Ty Neuman
   - -2015 and on doesn't matter the ordnance/platform, all electronic, link/architecture should be able to drop on target and be adaptable for new technology.
7. MAJ Mike Shewfelt
   - -Direct/indirect support, everything initially falls into general support or general category then it will be prioritized, ordered, etc. (intended plan for the 2015 time frame).
8. Phil Acquaro
   - -Collateral damage estimates, are you looking at it?
   - -JCA, what is the effect, do you use regional, multi-regional, etc?
9. Prof. Langford
   - -Problem, increased vulnerability to mission completeness, quicker response & effective use of weapons?

All of these personnel were experienced in Joint Fires or Systems Engineering. A lecture was given on the scope and current direction (at the time) of the Joint Fire Support in 2020. Although some of the questions were outside the bounds of the Joint Fire support in 2020 project, the input was vital and the information was very helpful in considering issues in these specific areas.

Stakeholder:	**National Fire Control Symposium**
Location:	**Tucson, Arizona, July 2006**
Audience:	**Joint Fire Support in 2020 Team & Advisors**
Author:	**Maj Brian Peters**

Overall: We all should have gone to this symposium. Not only would we all be on the same page for what we learned, we could have worked with a few more of the technical people at the conference at a deeper level. Aspects of our project are being completed by many other organizations within the services. All of them really seem “to get” the issue at hand, even if there doesn’t seem to be any overarching leadership to focus the effort.

Leo and I were puzzled at the lack of military representation at the symposium. Besides the two of us, there were maybe 5 other military in a crowd of 200+ contractors, government civilians, etc. If there were any government “decision makers” in the crowd (military Program Managers, PEOs, HQ staffers), they were keeping a low profile.

This forum yielded very valuable information and contacts for our project. We’ll break down some of the key contacts/projects so you can all get an idea where we can leverage their efforts to fill some of our gaps. While we signed up to get a copy of all the briefings/papers (in a few weeks), we’ll have to follow up with most of these contacts individually if we want information sooner…

Service Perspectives

The sessions started with overviews from the Army, Navy, and Air Force. Interesting that all these visions shared the idea that munitions will be controlled all the way to impact, not just release.

The Navy perspective was given by Edmund Anderson (PEO for Navy Strike Weapons). edmund.anderson@navy.mil He related a vision for using networked fires to launch (and control) an SM-6 / Harpoon-3 to the limit of its range, not just to the limit of the ship’s control (effectively doubling the range). The scenarios he described match the components of ours. His office has demos planned for ’09 and ’10 … too late to be of real value for us. However, he does have a program office that is interested in our conclusions.

The Air Force perspective included a laydown of AFRL’s priorities

The Army perspective was very adamant to maintain the person-in-the-loop. Army requirements documents will continue to force decisions made by humans over automation. We should keep that in mind for our efforts. TLDHS, AFATDS, etc will remain a centerpiece of the Army effort. (The Marine Corps briefs later reinforce this link).

Advanced Technologies for Fire Control

Most of the briefings in this section of the symposium were guided-sensor, small-munition combinations. Many of the weapons have been tested on some scale so data about data link rates etc. can be collected although we probably aren't going to do any big models of the bandwidth required.

The most useful project information from this section is from:

Dr. Piali De (Piali_De@raytheon.com)… she has real world experiment data for CAS and artillery support. She recently completed an exercise with the Marine Corps where all fires requests/support were analyzed. I'll get a copy of their experiment results and her briefing slides. These are something we should all talk about. (file: PDENFCS06 paper.pdf)

Michelle Adams (Michelle.L.Adams@navy.mil) … She has a number of very valuable pieces of information. 1) The LANCE-NFCS 2005 demonstration results. This is an AFATDS/NFCS multi-national exercise. In particular, they used a common XML message to do all the targeting information –much like we have talked about. 2) New acronym: JC3IEDM – The Joint Consultation Command and Control Information Exchange Data Model. It's common, XML-based and part of a very large data standardization effort. This is the "9-line streamlining" effort we talked about. (file: FileControlSymposium_Brief.ppt)

James Matts / James Cech (cechjv@navsea.navy.mil) - Naval Integrated Fire Control System. More NFCS exercises … Useful source documents for how the Navy intends to migrate NFCS. Mr. Cech (an NPS grad) also made a pitch to ask him to come out to be a guest speaker. I'll forward his information to Prof. Solitario.

Chris Shoaf (Chris.shoaf@navy.mil) NFCS Joint Test Threads and Architecture documents.

Combat Identification Session

This session contained multiple briefings regarding various LADAR/LIDAR sensor programs.

Joint Air and Missile Defense Session

Two interesting items from this session.

One, a Lockheed presentation took a different tack at the coordination problem (a different way to look at networking).

Two, three engineers from Raytheon developed an EXCELLENT construct to move from the requirements views to the data flows. We'll have to show you on slides, it would take too long to describe here.

Network Enhanced Fire Control Session

While all the briefers at this symposium had the big “Network Ring” in the sky, only a few briefers talked about what made it up.

Three briefers from MIT Lincoln Labs headed by Dr. Steven Davidson have some excellent source material for the topic. Mr. Roop Ganguly and Jeff McLamb gave briefings on what would be the beginnings of a requirements analysis for the network. (files: Ganguly – AND – with notes.pdf , McLamb – Early Operator – with notes.pdf)

We spoke at length with Dr. Davidson. He would like to be involved in our work as we progress. He certainly seemed willing to help us out.

Also, the Marine Corps Roadmap was laid out by Thomas Irwin. We’ll get his briefing in the next few days and review it with our group. Bottom line: more connectivity with AFATDS, abandoning all competing programs. God Bless the Marine Corps for picking a single service direction and moving toward it.

Stakeholders: **Various Army/Marine Corps personnel**
Location: **Naval Post Graduate School Monterey, California, August 2006**
Audience: **Joint Fire Support in 2020 Advisors & Team**
Author: **LT Spencer Nordgran**

The Project Team held a stakeholder input session in Bullard Hall in August of 2006. The purpose of the meeting was to collect stakeholder needs and requirements, as well as receive feedback on the group’s work. Some of the relevant questions/comments from the meeting were:

1. How are you defining deconfliction? The deconfliction between both air assets and ground assets was addressed. In addition, the deconfliction between field artillery, CAS, and other munitions with special forces was addressed.

(Earl Richardson, USMC/Capt/Infantry)

2. Recommend Modeling using CBS or JCATS. These systems were discussed but with the close proximity of TRAC Monterey it was decided that MANA or DAFS would be the best for the project based on modeling support.

(MAJ Chris Wade, BCTC, FT Leavenworth)

Iraq and Afghanistan is a slow process on the watch floor for Joint Fires, recommend automation of process as much as possible. Discussion on the need to automate the majority of the process was held. However, the need for the man in the loop was discussed, as well. The concern was that top level military personnel would want a person to give final authority to give the feeling of human control of release authority.

(MAJ Tom Stoner, Army Special Forces)

On the watch floor if there is nothing on the grid, watch floor personnel want to bomb it. This is unacceptable to special forces because they are there, but they will not show up on grid. Therefore, requires a Special Forces authorization before release authority is granted for Joint Fires. The discussion was that even though we have a good idea where personnel are at all times the special forces are in areas that are only understood by special forces personnel. Therefore, they must be present and must give authority prior to any release of weapons. In addition, the JAG usually has a cut on the release authorization.

(MAJ Tom Stoner, Army Special Forces)

Will the system of systems be compatible with emerging Doctrine? The discussion was about what doctrine is provided and how it compares between joint doctrine and each service doctrine. It was determined that there may need to be new doctrine written to address the new system or systems.

(MAJ Tom Stoner, Army Special Forces)

Recommend a Joint Fires Operating Center(s) with all services in control of launch authority in a central location. The discussion was that all fires should go to one location. This would allow for all service authority to be able to determine the need or ability to provide fires. This would also allow for optimization of weapons and limit fratricide because all necessary personnel would be available for consultation, if necessary. This includes a special forces contingent.

(MAJ Tom Stoner, Army Special Forces)

Battalion Commander won't want the company commander making the decision to fire in case a new company is approaching the area. The discussion was about the ability of the lowest man to have authority to call for fires and the ability for the company commander to support. This led to the ability of the company commander to hold the big picture. If he can see the same operating picture as the battalion commander and he is trained this may or may not be an issue.

(Earl Richardson, USMC/CPT/infantry)

All of these personnel were experienced in either the Iraq and/or Afghanistan theaters. Discussion was brought forward in each of these areas and considered in the approach to solving the issues with Joint Fire Support in 2020.

Stakeholders: National Training Center
Joint Fires Integration and Interoperability Team
Air Warrior Operations
Joint Fires Coordination Measures JT&E
Joint Air to Ground Operations Group
Location: Fort Irwin, California, October 2006
Nellis AFB, Nevada, October 2006
Audience: Joint Fire Support in 2020 Advisors & Team
Author: Maj Tyler Gabriel

The SEA-10 Joint Fires trip to Fort Irwin and Nellis AFB was informative and provided us with a perspective of the fires request process that we hadn't seen before. The coordination process, especially the process for artillery fires as it exists now, was significantly different, operationally, than we had researched. The coordination and insight that we gleaned from our interaction with the JFIIT team was very useful determining the users, providers, and C2 stakeholders in our proposed system.

FORT IRWIN, CA – National Training Center (NTC)

We observed the JFIIT team was involved in data collection in the field and through the use of the instrumented range equipment. The JFIIT team had between 20-30 folks there who were involved monitoring every part of the exercise. They paired each of us up with a JFIIT Observer and took us out into the field each day. Our team took turns going out into the field or monitoring the exercise from the instrumentation rooms on post so that every one of us got to see the exercise from both perspectives. The scenario at NTC has changed dramatically from when I was there as a participant however, and the pace of the 'action' was slow. The scenario was a 'spin-up' for future operations in Iraq (SRO) and although there was opportunity for fire support requests (almost exclusively counter-fire), they were few and the coordination process was not necessarily doctrinal. Additionally, there were much fewer trained requesters in the current system (about six per brigade) compared to the fully netted force we were considering.

The units in the field suffered from pretty severe training and manning issues that hampered both their actual connectivity and their organizational responsibilities. In conversations/interviews with the exercise players, the biggest issues that prevent timely fire support are the coordination process/oversight and deconfliction issues. Hampering their ability to do either was a pretty broad range of technical competence…some of the units (Battalions) had most of their C2 systems operating (CPOF, AFATDS, etc) but many of the units had only partial connectivity. It appeared that the problems were mostly training issues, but the systems were so diverse that there was a high training requirement for each of them. The process that was used by the NTC participants to request CAS was ad hoc and didn't utilize their available resources…they were finally able to find a surrogate DD Form 1972 request within the AFATDS system and use that to request support. However, there was no feedback from "higher" that told the requesting unit the status of their request. In conversations with the Air Force TACP (JTACs) in the field, they are plagued by a lack of SA on the status of requests. Their problem wasn't in making contact with higher, but with getting any sort of feedback on what happened to their request after it was sent. As a result, they adopted a 'shotgun' approach to requests for CAS…they'd request through several avenues and with repetition and hope that one of the requests would get through. From our perspective back at the Division TOC and notional ASOC, only some of the requests were making it up to the ASOC, and the feedback on the status of the requests was going back to the Brigade…the info/SA was stuck there.

Although AFATDS was designed to be a system of record, it has MAJOR loopholes in it which allow users to bypass the automation features that are designed specifically to assist them. This led to ad hoc and non-doctrinal usage of all aspects of the current system. I especially noticed that there were no example templates in the HELP section of the software.

An interesting observation was that, with very few exceptions, the communication of fire support requests and coordination was almost exclusively done via voice (radio or VoIP phones). Although systems like CPOF are built to maintain a COP that makes the coordination process easier and faster, the technical problems experienced by these units prevented this enabling technology from working.

We gathered data on the requests for CAS and the timelines involved with each request. We observed the equipment currently in use and the portions of each of the systems that are actually being used and the portions that are not (either due to difficulty, training, or connectivity). We also had a discussion with LtCol Ell (JFIIT leader at NTC) about the fire support process and he offered his insight from the exercise and suggestions for our project. ASR (air support request) data for NTC is posted on SharePoint.

NELLIS AFB, NV – Air Warrior, Joint T&E, Red Flag

The Project Team visited the AF unit that supports the NTC exercises with CAS assets and is the keeper of the lessons learned from NTC's ground-air interactions. We were able to observe another days worth of air support via the instrumented system. We were able to hear the conversations between the JTAC on the ground and pilots overhead and follow their discussions of targeting using the force tracker and imagery overlay. In team meetings with the Air Warrior staff (LtCol Barks ad Maj Spechler) we discussed our proposed system and its compatibility with the CAS process and future trends in CAS. They pointed out the dangers of coordinate specific weapons (JDAM, JSOW, etc) in the CAS role and said that at least 90% of NTC's fratricide incidents (blue air dropping on blue forces) are due to these types of weapons being used in CAS. They also told us that the responses for calls for CAS are dependent on the quality of the request and the information in it. We attended a post-flight debrief of a CAS engagement and garnered lessons learned from the coordination and deconfliction of fires. There seemed to be some concern about overall tasking authority, especially as it related to the ASOC's ability to task. The concern wasn't whether the ASOC had the authority to task CAS assets, but instead centered on the quality of the decisions made by this tasking authority. As it applies to our project, the take-away is in the quality of the tasking and whether the tasking reflects the ground truth about what is really going on in the AO. In our proposed system, there seems to be a significant need for a man-in-the-loop who will be able to QC the tasking orders against the latest AO update. The concern for us is to design a system that is reliable, or more to the point, a system that the providers trust to give them the best tasking.

We visited the Joint Test and Evaluation program for Joint Fires Coordination Measures as well and discussed the Joint Fires Area concept that is soon to be released. The JFAs are 3-D areas that are intended to replace "kill boxes" and include coordination and authorization for fires. The T&E program is about 2/3 complete and they discussed and provided us with a draft version of their TTP product. They had some interesting insights on the processing piece of the coordination that we can take into our conceptual model. One of the most unique points for me was a discussion of the processing of requests…should the processing be focused on the "who chooses" or on the "how to choose" the target-provider pairings?

We also visited the Joint Air to Ground Operations Group (JAGOG) and the 6th Combat Training Squadron to discuss the processing of requests and the training of Joint Tactical Air Controllers (JTACs) and Joint Forward Observers (JFOs). We met with LtCol Ehmig and Maj Oberdieck, who was working in the ASOC during the high-intensity conflict phase of OIF and he shared some really interesting insights on CAS based on that experience. In collaboration with several other agencies, they are developing JAGC2 (Joint Air-Ground Coordination Cell) concept to try to move towards collaboration instead of deconfliction. This concept has some interesting implications for our project…if we can refine our proposed system to integrate fires smartly, then we won't have to deconflict the fire supporters from each other. We discussed in detail the current systems for tracking and coordinating fire support requests, especially JADOCS, and we now have a working knowledge of how JADOCS is used in theater (and Red Flag exercises) to coordinate/deconflict fires from targets.

Overall, this multi-stop trip was very informative and, despite the lower-than-expected level of activity at NTC, allowed us the opportunity to gather some valuable data and discuss aspects of our proposed system with some key stakeholders.

APPENDIX G. GENERATION OF ALTERNATIVE ARCHITECTURES

The initial steps taken to generate alternatives were built upon both the functional analysis and the needs analysis. The functional analysis was analyzed and several areas were identified for assessment. Among these functions were: send request, process request, task request, and send tasking.

Based on feedback from the stakeholders and continuing advances in communications capabilities, three possibilities arose for sending requests and sending tasking orders: they could continue to be sent via voice, they could be sent as a digital data packet via a point-to-point transmission, or they could be sent as a digital data packet via a network broadcast transmission. Each of these possibilities has advantages and disadvantages. The primary advantage of continuing to use voice requests and tasking orders is in the simplicity and ease of use. Our stakeholders, especially the stakeholders that send the requests, identified numerous tactical situations that would favor the use of voice transmissions over data. A time-critical situation involving friendly troops engaged with the enemy in close proximity, what is called a “Troops In Contact” (TIC) situation, would tend to favor a simple voice transmission over a data entry task, regardless of the simplicity of the data/request entry device. The added benefit of a voice transmission is the ability to discern contextual messages in the voices of the parties involved. The strain, panic, or stress in an individual’s voice can relay tremendous non-verbal information to another human, but those subtle messages would be lost by any sort of automated translation of voice to data.

The digital data packet method holds tremendous promise due to its relative speed, accuracy, and flexibility. Unlike a voice transmission, a data transmission will be able to send all of the available target information in less than a second. Additionally, a data transmission can be used to send graphical data, such as imagery, as well as text data.

The transmission method of these data packets defines the other two options for sending requests. A digital point-to-point, similar to a fax transmission or an e-mail, has the advantage of being targeted to a particular recipient. The communication procedure for this type of transmission dictates that positive feedback is required from the recipient that a transmission was received. This trait would be vital to a system where “lost” requests have life or death consequences. Additionally, a point-to-point transfer system would not suffer from the “information overload” of a system where numerous broadcast-style messages are being sent to everyone.

On the other hand, a network broadcast transmission would allow for better information fusion into a COP if the system was able to organize the vast amounts of information being sent at any one time. A broadcast transmission may provide advantages in provider pairing however because of the transparency of the target information to all interested entities.

The processing of a request for fire was conceived in several different ways. The traditional processing method, where the request is acknowledged as “received” and then tracked throughout the remainder of the pairing and tasking process, was one alternative for this function. Another option was to “post” the request to an electronic database like a virtual “bulletin board.” The request processing function and the assignment of a fire support provider are intertwined, but the methodology options to determine the pairings of the requests with the providers is a unique function with numerous options. Several alternative concepts were conceived for the pairing motivations: pairings based on target type and predicted effectiveness, pairings based on predicted response time, pairings based on resource efficiency, pairings based on organizations, and pairings based on a combination of these measures. Any determination of the “quality” of the request and provider pairings would have to be made in the context of the priority scheme applied to the tasking. Also, the pairings should obviously be selected between *possible* providers, not simply the *available* providers. If the target is spatially out of range of the weapon, then that weapon is effectively not available. Any pairing of available providers would also need to maintain an accurate, up-to-date database or list of providers and their current status.

A pairing of requests with providers based on the effectiveness of provider's weapons was one of the most obvious methods. A fire support request, regardless of format, would specify to some degree the type of target and the effects desired on the target. Based on that target information and historical weapons effects data, such as the Joint Munitions Effectiveness Manual (JMEM), the expected effectiveness of each potential provider could be assessed. The available provider with the greatest potential to meet the requested target effects is selected and tasked to service that request. It is important to note that the selection is made only between the providers that are available at the time the request is received and processed.

Another possible pairing doctrine was to choose the provider that can service the request the soonest. A selection in this method would have to account for the variations in tactics across the diverse weapon system possibilities. For instance, the engagement time for an artillery unit ready for tasking is on the order of a few minutes from tasking to weapon impact but would be substantially longer if there were JFA deconfliction delays. On the other hand, CAS aircraft may arrive in the target area very quickly, but the pre-engagement coordination and deconfliction would surely add several additional minutes before weapons impact. Assumptions would have to be made concerning the responsiveness of a potential fire support provider based on their range to the target and their reported status. These assumptions would be used to select the most responsive fire support provider.

From the perspective of the JFC, one of the key stakeholders in any proposed JFS system, a viable pairing methodology would be one that optimized the available resources. If given the choice between using provider A's 2 bombs or provider B's 24 artillery shells to produce similar desired effects, the most efficient provider to pair with that request would be A. Each weapon system's expendable ordnance could be assessed for availability and difficulty to re-supply, and that data would be used to select between available providers.

A pairing technique that aligned requests with providers based on weapons system organization or type is in widespread use today by those that request the fire support. One of the two possible options for this pairing scheme involves the service component of the requesting entity. If the requester is Army, the preferred provider might be Army, followed by Air Force, the Marines, and the Navy. Another possible prioritization option could be based entirely on the target and provider weapon system type, i.e., CAS is preferred for vehicle targets and artillery is preferred for troop targets. A combination of these two priority schemes is another option. For example, if the requester is a Marine Corps TACP, then the preferred pairing priority might be: Marine artillery, Marine CAS, Navy CAS, naval surface fires, Air Force CAS, Army Artillery. The asset paired to that request would be selected based on weapon system preference, which may or may not be a surrogate for expected weapon performance against a particular target.

These pairing prioritizations could also be combined in various fashions to create a pairing methodology that fuses these options. This appears to be the method preferred by the existing target and provider decision aides.

Based on these options for the functions of our proposed system, the Project Team combined them in such a way to create many distinct options for the conceptual JFS system, five of which were considered at length. Two of the five alternatives that were considered were determined to be infeasible: the “Status Quo” alternative and the “Net-centric, Man-portable Joint Fires” alternative.

STATUS QUO ALTERNATIVE

One viable alternative is to do nothing and keep JFS in the state that it is in now (2006). In this alternative, the predominant method of sending requests and receiving tasking orders is via voice, not data. The selection of the best provider for the target is completed by the requester with little to no knowledge of what is available beyond the resources at their control. The pairing, if the request is routed to higher headquarters, is made without a complete understanding of which assets are truly available and not just on the ATO or the map. The stakeholders have expressed a need to improve the system for JFS, therefore maintaining the current state of affairs in not a feasible option.

NET-CENTRIC, MAN-PORTABLE JOINT FIRES ALTERNATIVE

In this alternative, each soldier is equipped with a man portable weapon system that fulfills his fire support needs and minimizes the likelihood that he will ever have to request external fire support for any reason.

Each troop carries with them a multi-purpose, guided, variable yield weapon system that obviates the need for traditional heavy fire support weapon systems. Each element of this future force is also linked wirelessly to all of the other elements in the theater of operations and/or in the battle area. These links allow for remote targeting of these future weapons so that one soldier/sensor can call on the weapons of many other troops after expending his weapon.

A key enabler to this concept is the total situational awareness of the spatial relationships between blue forces, non-combatants, observed red forces, and blue weapons and their associated effects. Pairing of joint fire support requests would be accomplished by the requester using a simple selection based on shortest service time.

The Project Team’s research determined that the technology risks to overcome would make this alternative infeasible. Even the most optimistic predictions of weapon technology in 2020 do not meet the technical requirements of this proposed alternative.

The three alternatives that were analyzed and compared were the Status Quo Plus, the Centralized Joint Fire Support Network, and the Distributed Joint Fire Support Network. These are discussed in detail in chapter 3 of this report.

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APPENDIX H. GENERATION OF NEEDED JFS SYSTEM ATTRIBUTES

A functional breakdown of a Joint Fires system was accomplished using a dendritic approach. This branching led to the development of system metrics based on needs defined by the stakeholders as seen below.

1. **Function: Coordination**
    1.1. How many organizations are involved in a decision?
        1.1.1. Improved horizontal and vertical integration
            1.1.1.1. Metric: Count process gaps
            1.1.1.2. Metric: Count organizations involved
    1.2. Does the system provide effective decision support?
        1.2.1. Deconfliction and Pairing
            1.2.1.1. Metric: Subjective assessment
    1.3. Does the system provide clear SA to the decision maker?
        1.3.1. Improved Situational Awareness
            1.3.1.1. Metric: Subjective assessment
    1.4. Is there a human in the loop at the right place?
        1.4.1. Reduce risk of fratricide
            1.4.1.1. Metric: Count decision points
    1.5. Do all component commanders have access to the same information?
        1.5.1. Reduce C2 duplication
            1.5.1.1. Metric: Count of systems involved
    1.6. Does the system streamline operations?
        1.6.1. Standardized process
            1.6.1.1. Metric: Subjective assessment

2. **Function: Processing**
    2.1. Are pairings based on JFC assets or service specific assets?
        2.1.1. Effects based
            2.1.1.1. Metric: Pairing efficiency (model)
            2.1.1.2. Metric: Number of pairing algorithms available to CJTF
    2.2. Does the system reduce overall time to task providers?
        2.2.1. Improve processing rate and response time
            2.2.1.1. Metric: Average processing time (model)
    2.3. Does the system provide robust communications architecture to the ground element?
        2.3.1. Request methods
            2.3.1.1. Metric: Count of number of communications paths from FO to HQ unit
            2.3.1.2. Metric: Average availability of each communications system
    2.4. How many CFF requests types are required?
        2.4.1. Common training, tactics, procedures
            2.4.1.1. Metric: Subjective assessment

- 2.5. Does the system provide correct information for engagement by the tasked weapon system/provider?
  - 2.5.1. Tasking methods
    - 2.5.1.1. Metric: Number of compatible weapon control system tasking formats
- 2.6. Does the system evaluate target priorities according to commander's intent?
  - 2.6.1. Prioritization methods
    - 2.6.1.1. Metric: Tailored prioritization algorithms available to CJTF
- 2.7. Does the system provide air and ground space deconfliction according to commander's intent and current operational guidance?
  - 2.7.1. Deconfliction methods
    - 2.7.1.1. Metric: Tailored deconfliction algorithms available to CJTF

3. Function: Operationally Feasible

- 3.1. Is the system scalable through a wide variety of future scenarios?
  - 3.1.1. Shift from organic to joint support
    - 3.1.1.1. Metric: Subjective assessment
- 3.2. Does the system provide adequate backup?
  - 3.2.1. Redundancy
    - 3.2.1.1. Metric: Count number systems involved
    - 3.2.1.2. Metric: Count number of communication paths available
- 3.3. Is the joint fire support system compatible with current and future (weapon/targeting/communication) systems?
  - 3.3.1. Interoperable
    - 3.3.1.1. Metric: Subjective assessment
    - 3.3.1.2. Metric: Number of open architecture interface standards
- 3.4. Does the joint fire support system meet the operational availability required by the ground forces commander?
  - 3.4.1. Availability
    - 3.4.1.1. Metric: Assessment of availability of physical sub-systems
- 3.5. Are the human to machine interfaces user friendly?
  - 3.5.1. Usability
    - 3.5.1.1. Metric: Human Factors usability study of physical sub-systems
- 3.6. What level of logistics support is required to operate the joint fire support system during expected operations?
  - 3.6.1. Sustainable
    - 3.6.1.1. Metric: Logistics analysis of physical sub-systems
- 3.7. Does the joint fire support system provide support to the ground forces commander throughout the duration of the operation/mission?
  - 3.7.1. Reliable
    - 3.7.1.1. Metric: Reliability analysis of physical sub-systems

APPENDIX I. MODELING OF JFS PROCESS AND COMMUNICATIONS

The following pages that include Tables 22 through 25 fully outline the modeling results described in the Qualitative Modeling Section.

Status Quo Plus

	Action	Air Gap?	Processing Delay?	AFATDS	NFCS	Weapon Control System	SINCGARS (HF)	EPLRS	VHF/UHF/HF Radio	Secure Phone	Various strikelinks	C2PC	CPOF	FBCB2/BFT	GCCS-A	GCCS-AF	GCCS-M	TBMCS
Marine-Marine Arty																		
Marine	Generate Request		1	x			x	x										
FSE (CO)	Decision		1	x			x	x				x						
BN-REGT-BDE	Coordination		1	x			x	x				x						
FSCC	Decision, Tasking		1	x			x	x				x					x	
Providing Battery	Tasking, Engage, Coord	1	1	x		x	x	x				x					x	
FSE (CO)	Coordination	1	1	x			x	x				x						
BN-REGT-BDE	Info			x			x	x				x						
Marine	Info			x			x	x										
	8	2	6															6
Marine-Army Arty																		
Marine	Generate Request		1	x			x	x										
FSE (CO)	Coordination	1	1	x			x	x				x						
BN-REGT-BDE	Coordination		1	x			x	x		x		x						
FSCC	Coordination		1	x						x		x						
MAGTF	Coordination	1	1							x		x					x	
MARFOR/ JFC	Coordination		1							x		x					x	
ARFOR / JFC	Coordination	1	1	x						x			x	x	x			
ANGLICO	Coordination		1	x						x		x	x	x	x		x	
BCD	Decision, Tasking		1	x						x			x	x	x			
Providing Battery	Tasking, Engage, Coord	1	1	x		x	x	x		x			x	x				
FSE (CO)	Coordination	1	1	x			x	x				x						
BN-REGT-BDE	Info			x			x	x				x						
Marine	Info			x			x	x										
	13	5	11															10
Marine-MC/Navy CAS																		
Marine	Generate Request		1	x			x	x										
BN-REGT-BDE	Coordination	1	1	x			x	x				x						
FSE (CO)	Coordination	1	1	x			x		x	x		x						
DASC	Decision, Tasking	1	1				x		x	x		x					x	x
TACC	Coordination	1	1						x	x	x	x					x	x
Platform	Tasking, Engage, Coord	1	1						x		x							
FAC	Coordination	1	1				x		x	x		x						
BN-REGT-BDE	Info						x	x				x						
Marine	Info						x	x										
	9	6	7															9
Marine-AF CAS																		
Marine	Generate Request		1	x			x	x										
BN-REGT-BDE	Coordination	1	1	x			x	x				x						
FSE (CO)	Coordination	1	1	x			x		x	x		x						
DASC	Coordination	1	1				x		x	x		x					x	x
TAOC/TACC	Coordination		1						x	x		x					x	x
JAOC/AOC	Coordination		1						x	x						x		x
ASOC	Decision, Tasking	1	1						x	x	x					x		x
Platform	Tasking, Engage, Coord	1	1						x	x	x							
FAC	Coordination	1	1				x		x	x		x						
BN-REGT-BDE	Info						x	x				x						
Marine	Info						x	x										
	11	6	9															10
Marine-NSF																		
Marine	Generate Request		1	x			x	x										
FSE (CO)	Decision	1	1	x			x	x				x						
BN-REGT-BDE	Coordination	1	1	x			x		x	x		x						
FSCC	Coordination	1	1	x					x	x		x						
SACC	Decision, Tasking	1	1	x	x				x	x		x					x	x
CATF, CLF, CTF	Coordination	1	1		x	x			x	x							x	x
Providing Ship	Tasking, Engage, Coord		1	x	x				x	x							x	x
FO	Coordination	1	1	x			x	x	x			x						
BN-REGT-BDE	Info			x			x	x				x						
Marine	Info			x			x	x										
	10	6	8															10

Average # of Steps 10.2
Average # of Air Gaps 5.0
Average # of Process Delays 6.8
Average # of Systems Needed 9.0

Centralized Command and Control

	Action	Air Gap?	Processing Delay?	Data/Voice Integrated Device	Weapon Control System	JTRS / JTIDS compatible radio (for direct Land/Air Comms)	JC2 (tailored)
Marine	Generate Request		1	x			x
FSCC	Decision, Tasking		1	x			x
Providing Battery	Tasking, Engage, Coordination	1	1	x	x		x
Marine	Coordinate			x			x
BN-REGT-BDE	Info (Can Negate)		1	x			x
	5	1	4				3
Marine	Generate Request		1	x			x
FSCC/BCD	Decision, Tasking		1	x			x
Providing Battery	Tasking, Engage, Coordination	1	1	x	x		x
Marine	Coordinate			x			x
MAGTF	Info (Can Negate)		1				x
MARFOR/ JFC	Info (Can Negate)		1				x
ARFOR / JFC	Info (Can Negate)		1				x
BN-REGT-BDE	Info (Can Negate)		1				x
ANGLICO	Obsolete						
FSE (CO)	Obsolete						
	8	1	7				3
Marine	Generate Request		1	x			x
FAC	Forward Request	1	1	x		x	x
DASC/TACC	Decision, Tasking		1				x
Platform	Tasking, Engage, Coordination		1			x	x
FAC	Coordinate	1		x		x	x
Marine	Info (Can Negate)		1	x			x
BN-REGT-BDE	Info (Can Negate)		1				x
	7	2	6				3
Marine	Generate Request		1	x			x
FAC	Forward Request	1	1	x		x	x
DASC/TACC/ASOC	Decision, Tasking		1				x
Platform	Tasking, Engage, Coordination		1			x	x
FAC	Coordinate	1		x		x	x
Marine	Info (Can Negate)		1	x			x
BN-REGT-BDE	Info (Can Negate)		1				x
AOC	Info (Can Negate)		1				
	8	2	7				3
Marine	Generate Request		1	x			x
FSCC/SACC	Decision, Tasking	1	1	x			x
Providing Ship	Tasking, Engage, Coordination		1	x			x
Marine	Coordinate			x			x
CATF, CLF, CTF	Info (Can Negate)		1				x
BN-REGT-BDE	Info (Can Negate)		1				x
	6	1	5				3

Average # of Steps 6.8
Average # of Air Gaps 1.4
Average # of Process Delays 4.8
Average # of Systems Needed 3.0

Distributed Command and Control

	Action	Air Gap?	Processing Delay?	Data/Voice Handheld Set	Weapon Control System	JTRS / JTIDS compatible radio (for direct Land/Air Comms)	JC2 (tailored)
Marine	Generate Request		1	x			x
Decision Algorithm	Decision, Tasking		1	x			x
Providing Battery	Tasking, Engage, Coordination	1	1	x	x		x
Marine	Coordinate			x			x
BN-REGT-BDE	Info (Can Negate)		1	x			x
FSCC	Info (Can Negate)		1				
	6	1	5				3
Marine	Generate Request		1	x			x
Decision Algorithm	Decision, Tasking		1	x			x
Providing Battery	Tasking, Engage, Coordination	1	1	x	x		x
Marine	Coordinate			x			x
FSCC/BCD	Info (Can Negate)		1				x
MAGTF	Info (Can Negate)		1				x
MARFOR/ JFC	Info (Can Negate)		1				x
ARFOR / JFC	Info (Can Negate)		1				x
BN-REGT-BDE	Info (Can Negate)		1				x
ANGLICO	Obsolete						
FSE (CO)	Obsolete						
	9	1	8				3
Marine	Generate Request		1	x			x
FAC	Forward Request		1	x		x	x
Decision Algorithm	Decision, Tasking		1				x
Platform	Tasking, Engage, Coordination		1			x	x
FAC	Coordinate	1		x		x	x
Marine	Info (Can Negate)		1	x			x
BN-REGT-BDE	Info (Can Negate)		1				x
DASC/TACC	Info (Can Negate)		1				x
	8	1	7				3
Marine	Generate Request		1	x			x
FAC	Forward Request	1	1	x		x	x
Decision Algorithm	Decision, Tasking		1				x
Platform	Tasking, Engage, Coordination		1			x	x
FAC	Coordinate	1		x		x	x
Marine	Info (Can Negate)		1	x			x
BN-REGT-BDE	Info (Can Negate)		1				x
AOC	Info (Can Negate)		1				x
DASC/TACC/ASOC	Info (Can Negate)		1				x
	9	2	8				3
Marine	Generate Request		1	x			x
Decision Algorithm	Decision, Tasking	1	1	x			x
Providing Ship	Tasking, Engage, Coordination		1	x	x		x
Marine	Coordinate			x			x
CATF, CLF, CTF	Info (Can Negate)		1				x
BN-REGT-BDE	Info (Can Negate)		1				x
FSCC/SACC	Info (Can Negate)		1				x
	7	1	6				3

Average # of Steps 7.8
Average # of Air Gaps 1.2
Average # of Process Delays 5.7
Average # of Systems Needed 3.0

Table 22: Urban CFF Request

Status Quo Plus

	Action	Air Gap?	Processing Delay?	AFATDS	NFCS	Weapon Control System	SINCGARS (HF)	EPLRS	VHF/UHF/HF Radio	Secure Phone	Various strikelinks	C2PC	CPOF	FBCB2/BFT	GCCS-A	GCCS-AF	GCCS-M	TBMCS
Army-Marine Artillery																		
Soldier	Generate Request		1	x			x	x						x				
CO-BN-BDE	Coordination	1	1	x			x	x					x	x				
FS Cell	Coordination		1	x			x	x					x	x				
Div FSE	Coordination	1	1	x			x	x					x		x			
BCD	Coordination	1	1	x			x	x		x			x		x			
ARFOR / JFC	Coordination		1							x			x		x			
MARFOR/ JFC	Coordination	1	1							x		x					x	x
MAGTF	Coordination	1	1		x		x	x		x							x	x
FFCC	Decision, Tasking	1	1	x	x		x	x				x					x	x
Providing Battery	Tasking, Engage, Coordination	1	1		x	x	x	x				x						
FS Cell	Coordination	1	1	x			x	x					x	x				
CO-BN-BDE	Info			x			x	x					x	x				
Soldier	Info			x			x	x						x				
	13	8	11															12
Army-Army Artillery																		
Soldier	Generate Request		1	x			x	x						x				
CO-BN-BDE	Coordination	1	1	x			x	x					x	x				
FS Cell	Coordination		1	x			x	x						x				
Div FS Cell / FSE	Decision, Tasking	1	1	x			x	x					x	x	x			
Providing Battery	Tasking, Engage, Coordination	1	1	x		x	x	x					x	x				
FS Cell	Coordination		1	x			x	x						x				
CO-BN-BDE	Info			x			x	x					x	x				
Soldier	Info			x			x	x						x				
	8	3	6															7
Army-Army Rotary Wing																		
Soldier	Generate Request		1	x			x	x						x				
CO-BN-BDE	Coordination	1	1	x			x	x					x	x				
FS Cell	Coordination	1	1	x			x	x	x	x			x	x				
Div FS Cell	Coordination	1	1				x	x	x	x			x	x	x			
BCD / FSE	Decision, Tasking		1				x	x	x	x			x	x	x			
Owning Division	Coordination		1				x	x	x	x			x	x				
Army Rotary Wing	Tasking, Engage, Coordination	1	1						x		x			x				
LNO	Coordination		1				x	x	x				x	x				
CO-BN-BDE	Info						x	x					x	x				
Soldier	Info						x	x						x				
	10	4	8															9
Army-Navy CAS																		
Soldier	Generate Request		1	x			x	x						x				
CO-BN-BDE	Coordination	1	1	x			x	x					x	x				
FAC	Coordination	1	1	x			x	x	x				x	x				
ASOC	Coordination	1	1						x	x						x		x
JAOC/AOC	Coordination		1							x						x		x
TAOC/TACC	Coordination	1	1							x		x					x	x
DASC	Decision, Tasking	1	1						x	x	x	x					x	x
Platform	Tasking, Engage, Coordination		1						x		x							
FAC	Coordination	1	1				x	x	x				x	x				
CO-BN-BDE	Info						x	x					x	x				
Soldier	Info						x	x						x				
	11	6	9															12
Army-AF CAS																		
Soldier	Generate Request		1	x			x	x						x				
CO-BN-BDE	Coordination	1	1	x			x	x					x	x				
FAC	Coordination	1	1				x	x	x				x	x				
ASOC	Decision, Tasking	1	1						x		x					x		x
Platform	Tasking, Engage, Coordination		1						x		x					x		x
FAC	Coordination	1	1				x	x	x				x	x				
CO-BN-BDE	Info						x	x					x	x				
Soldier	Info						x	x						x				
	8	4	6															9
	Average # of Steps	10.0																
	Average # of Air Gaps	4.2																
	Average # of Process Delays	8.0																
	Average # of Systems Needed	9.8																

Centralized Command and Control

	Action	Air Gap?	Processing Delay?	Data/Voice Handheld Set	Weapon Control System	JTRS / JTIDS compatible radio (for direct Land/Air Comms)	JC2 (tailored)
Soldier	Generate Request		1	x			x
FSCC/BCD	Decision, Tasking		1	x			x
Providing Battery	Tasking, Engage, Coordination	1	1	x	x		x
Soldier	Coordination			x			x
ARFOR / JFC	Info (Can Negate)		1				x
MARFOR/ JFC	Info (Can Negate)		1				x
MAGTF	Info (Can Negate)		1				x
FS Cell	Info (Can Negate)		1				x
Div FSE	Info (Can Negate)		1				x
CO-BN-BDE	Info (Can Negate)		1				x
	10	1	9				3
Soldier	Generate Request		1	x			x
Div FS Cell / FSE	Decision, Tasking		1	x			x
Providing Battery	Tasking, Engage, Coordination	1	1	x	x		x
Soldier	Coordination			x			x
CO-BN-BDE	Info (Can Negate)		1	x			x
FS Cell	Info (Can Negate)		1	x			x
	6	1	5				3
Soldier	Generate Request		1	x			x
BCD / FSE	Decision, Tasking	1	1	x		x	x
Owning Division	Decision, Tasking		1	x		x	x
Army Rotary Wing	Tasking, Engage, Coordination	1	1				x
LNO	Coordination			x		x	x
Soldier	Info			x			x
CO-BN-BDE	Info (Can Negate)		1	x		x	x
Div FS Cell	Info (Can Negate)		1	x		x	x
BCD / FSE	Info (Can Negate)		1	x		x	x
	9	2	7				3
Soldier	Generate Request		1	x			x
FAC	Coordination	1	1	x		x	x
ASOC/DASC	Decision, Tasking	1	1	x		x	x
Platform	Tasking, Engage, Coordination	1	1			x	x
FAC	Coordination			x		x	x
Soldier	Info			x			x
JAOC/AOC	Info (Can Negate)		1			x	x
TACC	Info (Can Negate)		1			x	x
CO-BN-BDE	Info (Can Negate)		1	x		x	x
	9	3	7				3
Soldier	Generate Request		1	x			x
FAC	Forward Request	1	1	x		x	x
ASOC	Decision, Tasking	1	1			x	x
Platform	Tasking, Engage, Coordination	1	1			x	x
FAC	Coordination			x		x	x
CO-BN-BDE	Info (Can Negate)		1	x		x	x
Soldier	Info			x			x
	7	3	5				3
	Average # of Steps	8.2					
	Average # of Air Gaps	1.7					
	Average # of Process Delays	6.6					
	Average # of Systems Needed	3.0					

Distributed Command and Control

	Action	Air Gap?	Processing Delay?	Data/Voice Handheld Set	Weapon Control System	JTRS / JTIDS compatible radio (for direct Land/Air Comms)	JC2 (tailored)
Soldier	Generate Request		1	x			x
Decision Algorithm	Decision, Tasking		1	x			x
Providing Battery	Tasking, Engage, Coordination	1	1	x	x		x
Soldier	Coordination			x			x
FSCC/BCD	Info (Can Negate)		1	x			x
ARFOR / JFC	Info (Can Negate)		1				x
MARFOR/ JFC	Info (Can Negate)		1				x
MAGTF	Info (Can Negate)		1				x
FS Cell	Info (Can Negate)		1				x
Div FSE	Info (Can Negate)		1				x
CO-BN-BDE	Info (Can Negate)		1				x
	11	1	10				3
Soldier	Generate Request		1	x			x
Decision Algorithm	Decision, Tasking		1	x			x
Providing Battery	Tasking, Engage, Coordination	1	1	x	x		x
Soldier	Coordination			x			x
CO-BN-BDE	Info (Can Negate)		1	x			x
FS Cell	Info (Can Negate)		1	x			x
Div FS Cell / FSE	Info (Can Negate)		1	x			x
	7	1	6				3
Soldier	Generate Request		1	x			x
Decision Algorithm	Decision, Tasking	1	1	x		x	x
Army Rotary Wing	Tasking, Engage, Coordination	1	1	x		x	x
LNO	Coordination			x		x	x
Soldier	Info			x			x
BCD / FSE	Info (Can Negate)		1	x		x	x
Owning Division	Info (Can Negate)		1	x		x	x
CO-BN-BDE	Info (Can Negate)		1	x		x	x
Div FS Cell	Info (Can Negate)		1	x		x	x
BCD / FSE	Info (Can Negate)		1	x		x	x
	10	2	8				3
Soldier	Generate Request		1	x			x
Decision Algorithm	Coordination	1	1	x		x	x
Platform	Tasking, Engage, Coordination	1	1			x	x
FAC	Coordination	1		x		x	x
Soldier	Info			x			x
ASOC/DASC	Info (Can Negate)					x	x
JAOC/AOC	Info (Can Negate)		1			x	x
TACC	Info (Can Negate)		1			x	x
CO-BN-BDE	Info (Can Negate)		1	x		x	x
	9	3	6				3
Soldier	Generate Request		1	x			x
Decision Algorithm	Decision, Tasking	1	1	x		x	x
Platform	Tasking, Engage, Coordination	1	1			x	x
FAC	Coordination	1	1	x		x	x
ASOC	Info (Can Negate)		1			x	x
CO-BN-BDE	Info (Can Negate)		1	x		x	x
Soldier	Info			x			x
	7	3	6				3
	Average # of Steps	8.8					
	Average # of Air Gaps	1.7					
	Average # of Process Delays	7.2					
	Average # of Systems Needed	3.0					

Table 23: Rear Area Army CFF Request

Status Quo Plus

	Action	Air Gap?	Processing Delay?	AFATDS	NFCS	Weapon Control System	SINCGARS (HF)	EPLRS	VHF/UHF/HF Radio	Secure Phone	Various strikelinks	C2PC	CPOF	FBCB2/BFT	GCCS-A	GCCS-AF	GCCS-M	TBMCS
Riverine-Marine Arty																		
Riverine Sq	Generate Request	1	1		x		x	x										
Riverine Group	Coordination	1	1		x		x	x	x	x							x	x
SACC	Coordination		1	x	x				x	x							x	x
CLF	Coordination		1							x							x	x
FSCC	Tasking	1	1	x	x				x	x		x					x	x
Providing Battery	Tasking, Engage, Coordination	1	1	x		x						x						
Riverine Group	Coordination	1	1		x		x	x	x	x							x	x
Riverine Sq	Coordination		1		x		x	x										
	8	5	8															10
Riverine-Army Arty																		
Riverine Sq	Generate Request		1		x		x	x										
Riverine Group	Coordination	1	1		x		x	x	x	x							x	x
SACC	Coordination	1	1	x	x				x	x							x	x
CLF	Coordination		1							x							x	x
CTF	Coordination		1							x							x	x
NAVFOR/JOC	Coordination		1							x							x	x
ARFOR/JOC	Coordination	1	1							x			x	x	x			
BCD	Tasking	1	1	x			x	x	x	x			x	x	x			
Providing Battery	Tasking, Engage, Coordination	1	1	x		x	x	x					x	x				
Div FSE	Coordination		1	x			x	x					x	x				
Riverine Group	Coordination	1	1		x		x	x	x	x							x	x
Riverine Sq	Coordination		1		x		x	x										
	12	6	12															12
Riverine-MC/Navy CAS																		
Riverine Sq	Generate Request		1		x		x	x										
Riverine Group	Coordination	1	1		x		x	x	x	x							x	x
DASC	Coordination	1	1						x	x	x						x	x
TACC	Tasking		1						x	x	x						x	x
Platform	Tasking, Engage, Coordination	1	1						x		x							x
Riverine Group	Coordination	1	1		x		x	x	x	x							x	x
Riverine Sq	Coordination		1		x		x	x										
	7	4	7															8
Riverine-AF CAS																		
Riverine Sq	Generate Request		1		x		x	x										
Riverine Group	Coordination	1	1		x		x	x	x	x							x	x
DASC	Coordination	1	1						x	x							x	x
TACC	Coordination		1						x	x							x	x
AOC/JAOC	Coordination	1	1						x	x						x		x
ASOC	Tasking	1	1						x	x	x					x		x
Platform	Tasking, Engage, Coordination		1						x		x							
Riverine Group	Coordination	1	1		x		x	x	x	x							x	x
Riverine Sq	Coordination		1		x		x	x										
	9	5	9															9
Riverine-NSF																		
Riverine Sq	Generate Request		1		x		x	x										
Riverine Gp	Coordination	1	1		x		x	x	x	x							x	x
SACC	Coordination		1	x	x				x	x							x	x
CTF	Tasking	1	1							x							x	x
Providing Ship	Tasking, Engage, Coordination	1	1		x	x	x	x	x	x							x	x
Riverine Gp	Coordination	1	1		x		x	x	x	x							x	x
Riverine Sq	Coordination		1		x		x	x										
	7	4	7															9

Average # of Steps	8.6
Average # of Air Gaps	4.8
Average # of Process Delays	7.2
Average # of Systems Needed	9.6

Centralized Command and Control

	Action	Air Gap?	Processing Delay?	Data/Voice Integrated Device	Weapon Control System	JTRS / JTIDS compatible radio (for direct Land/Air Comms)	JC2 (tailored)
Riverine Sq	Generate Request		1	x		x	x
FSCC	Decision, Tasking	1	1	x		x	x
Providing Battery	Tasking, Engage, Coordination	1	1	x	x	x	x
CLF	Info (Can Negate)		1			x	x
SACC	Info (Can Negate)		1			x	x
Riverine Group	Info (Can Negate)	1	1	x		x	x
Riverine Sq	Coordination		1	x		x	x
	7	3	7				4
Riverine Sq	Generate Request		1	x		x	x
SACC/BCD	Decision, Tasking			x		x	x
Providing Battery	Tasking, Engage, Coordination			x	x	x	x
CLF	Info (Can Negate)					x	x
CTF	Info (Can Negate)					x	x
NAVFOR/JOC	Info (Can Negate)					x	x
ARFOR/JOC	Info (Can Negate)					x	x
Div FSE	Info (Can Negate)			x		x	x
Riverine Group	Info (Can Negate)			x		x	x
Riverine Sq	Coordination			x		x	x
	10	0	1				4
Riverine Sq	Generate Request		1	x		x	x
TACC	Tasking	1	1	x		x	x
Platform	Tasking, Engage, Coordination	1	1		x	x	x
DASC	Coordination		1			x	x
Riverine Group	Info (Can Negate)	1	1	x		x	x
Riverine Sq	Info (Can Negate)		1	x		x	x
	6	3	6				4
Riverine Sq	Generate Request		1	x			x
TACC/ASOC	Tasking	1	1	x		x	x
Platform	Tasking, Engage, Coordination	1	1		x	x	x
Riverine Sq	Coordination	1	1	x		x	x
DASC	Info (Can Negate)		1	x		x	x
JAOC/AOC	Info (Can Negate)		1			x	x
Riverine Group	Info (Can Negate)		1			x	x
	7	3	7				4
Riverine Sq	Generate Request		1	x		x	x
SACC	Decision, Tasking	1	1	x		x	x
Providing Ship	Tasking, Engage, Coordination	1	1	x	x	x	x
Riverine Sq	Coordination		1	x		x	x
CTF	Info (Can Negate)		1				x
Riverine Gp	Info (Can Negate)		1	x		x	x
	6	2	6				3

Average # of Steps	7.2
Average # of Air Gaps	2.2
Average # of Process Delays	4.5
Average # of Systems Needed	3.8

Distributed Command and Control

	Action	Air Gap?	Processing Delay?	Data/Voice Handheld Set	Weapon Control System	JTRS / JTIDS compatible radio (for direct Land/Air Comms)	JC2 (tailored)
Riverine Sq	Generate Request		1	x			x
Decision Algorithm	Decision, Tasking		1	x			x
Providing Battery	Tasking, Engage, Coordination	1	1	x	x	x	x
CLF	Info (Can Negate)		1			x	x
SACC	Info (Can Negate)		1			x	x
Riverine Group	Info (Can Negate)		1	x		x	x
Riverine Sq	Coordination	1	1	x			x
FSCC	Info (Can Negate)		1	x		x	x
	8	2	8				4
Riverine Sq	Generate Request		1	x		x	x
Decision Algorithm	Decision, Tasking		1	x			x
Providing Battery	Tasking, Engage, Coordination	1	1	x	x	x	x
SACC	Info (Can Negate)		1	x		x	x
CLF	Info (Can Negate)		1			x	x
CTF	Info (Can Negate)		1			x	x
NAVFOR/JOC	Info (Can Negate)		1			x	x
ARFOR/JOC	Info (Can Negate)		1			x	x
Div FSE	Info (Can Negate)		1	x		x	x
Riverine Group	Info (Can Negate)		1	x		x	x
Riverine Sq	Coordination	1	1	x		x	x
	11	2	11				4
Riverine Sq	Generate Request		1	x		x	x
Decision Algorithm	Tasking		1	x			x
Platform	Tasking, Engage, Coordination	1	1		x	x	x
DASC	Info (Can Negate)		1			x	x
Riverine Group	Info (Can Negate)		1	x		x	x
Riverine Sq	Coordination	1	1	x		x	x
TACC	Info (Can Negate)		1				
	7	2	7				4
Riverine Sq	Generate Request		1	x			x
Decision Algorithm	Decision, Tasking		1	x			x
Platform	Tasking, Engage, Coordination	1	1		x	x	x
Riverine Sq	Coordination	1	1	x		x	x
DASC	Info (Can Negate)		1	x		x	x
JAOC/AOC	Info (Can Negate)		1			x	x
Riverine Group	Info (Can Negate)		1			x	x
TACC/ASOC	Info (Can Negate)		1	x		x	x
	8	2	8				4
Riverine Sq	Generate Request		1	x		x	x
Decision Algorithm	Decision, Tasking		1	x		x	x
Providing Ship	Tasking, Engage, Coordination	1	1	x	x	x	x
Riverine Sq	Coordination	1	1	x		x	x
CTF	Info (Can Negate)		1				x
Riverine Gp	Info (Can Negate)		1	x		x	x
SACC	Info (Can Negate)		1			x	x
	7	2	7				4

Average # of Steps	8.2
Average # of Air Gaps	2.0
Average # of Process Delays	6.8
Average # of Systems Needed	4.0

Table 24: Navy Riverine CFF Request

Status Quo Plus

Marine requesting TLAM

	Action	Air Gap?	Processing Delay?	AFATDS	NFCS	Weapon Control System	SINCGARS (HF)	EPLRS	VHF/UHF/HF Radio	Secure Phone/Data Channel	Various strikelinks	C2PC	CPOF	FBCB2/BFT	GCCS-A	GCCS-AF	GCCS-M	TBMCS	Other National Means
Marine	Generate Request		1	x			x	x											
BN-REGT-BDE	Coordination	1	1	x			x	x				x							
FSE	Coordination	1	1	x			x	x	x			x							
SACC	Coordination	1	1	x	x				x	x							x	x	
CATF	Coordination		1						x	x							x	x	
CSG	Coordination		1						x	x							x	x	
CTF	Coordination		1						x	x							x	x	
JFC / JOC	Coordination	1	1							x		x	x		x	x	x	x	
COCOM SC	Coordination	1	1							x									x
NCA	Decision		1							x									x
COCOM SC	Tasking	1	1							x									x
JFC / JOC	Coordination	1	1						x	x		x	x		x	x	x	x	
CTF / TSC	Coordination		1						x	x							x	x	
CSG	Coordination		1						x	x							x	x	
Strike Plans / Strike Ops	Coordination		1			x				x							x	x	
LAC	Coordination	1	1			x				x							x	x	
Providing Ship	Tasking, Engage, Coordination		1		x		x	x	x	x							x	x	
FSE	Info			x			x	x	x			x							
BN-REGT-BDE	Info			x			x	x				x							
Marine	Info			x			x	x											
	20	8	17																14
Soldier	Generate Request		1	x			x	x						x					
CO-BN-BDE	Coordination	1	1	x			x	x					x	x					
FS Cell	Coordination	1	1	x			x	x	x	x			x	x	x				
BCD	Coordination	1	1	x	x				x	x			x						
ARFOR	Coordination		1	x	x				x	x			x						
JFC / JOC	Coordination	1	1							x							x	x	
COCOM SC	Coordination	1	1							x									x
NCA	Decision		1							x									x
COCOM SC	Tasking	1	1							x									x
JFC / JOC	Coordination	1	1							x							x	x	
CTF / TSC	Coordination		1						x	x							x	x	
CSG	Coordination		1						x	x							x	x	
Strike Plans / Strike Ops	Coordination	1	1			x				x							x	x	
LAC	Coordination	1	1			x				x							x	x	
Providing Ship	Tasking, Engage, Coordination		1	x	x	x	x	x	x	x							x	x	
ANGLICO	Info			x	x				x	x			x				x	x	
CO-BN-BDE	Info			x			x	x					x	x					
Soldier	Info			x			x	x						x					
	18	9	15																13

Average # of Steps	19.0
Average # of Air Gaps	8.5
Average # of Process Delays	16.0
Average # of Systems Needed	13.5

Centralized Command and Control

	Action	Air Gap?	Processing Delay?	Data/Voice Integrated Device	Weapon Control System	Secure Phone/Data Channel	JC2 (tailored)	Other National Means
Marine	Generate Request		1	x			x	
SACC	Coordination	1	1	x		x	x	
CTF	Coordination		1			x	x	
JFC / JOC	Coordination		1			x	x	
COCOM SC	Coordination	1	1			x	x	x
NCA	Decision		1			x	x	x
COCOM SC	Tasking		1			x	x	x
JFC / JOC	Coordination		1			x	x	
CTF / TSC	Coordination		1			x	x	
Strike Plans / Strike Ops	Coordination		1		x	x	x	
LAC	Coordination	1	1		x	x	x	
Providing Ship	Tasking, Engage, Coordination		1	x	x	x	x	
FSE	Info			x			x	
BN-REGT-BDE	Info			x			x	
Marine	Info			x			x	
	15	3	12					5
Soldier	Generate Request		1	x			x	
BCD	Coordination	1	1	x		x	x	
JFC / JOC	Coordination		1			x	x	
COCOM SC	Coordination	1	1					x
NCA	Decision		1					x
COCOM SC	Tasking		1					x
JFC / JOC	Coordination		1			x	x	x
Strike Plans / Strike Ops	Coordination		1		x	x	x	
LAC	Coordination	1	1	x	x		x	
Providing Ship	Tasking, Engage, Coordination		1	x	x		x	
ARFOR	Info (Can Negate)		1	x			x	
ANGLICO	Info			x				
CO-BN-BDE	Info			x				
Soldier	Info			x				
	14	3	11					5

Average # of Steps	14.5
Average # of Air Gaps	3.0
Average # of Process Delays	11.5
Average # of Systems Needed	5.0

Distributed Command and Control

	Action	Air Gap?	Processing Delay?	Data/Voice Integrated Device	Weapon Control System	Secure Phone/Data Channel	JC2 (tailored)	Other National Means
Marine	Generate Request		1	x			x	
Decision Algorithm	Coordination	1	1	x		x	x	
JFC / JOC	Coordination		1			x	x	
COCOM SC	Coordination	1	1			x	x	x
NCA	Decision		1			x	x	x
COCOM SC	Tasking		1			x	x	x
JFC / JOC	Coordination		1			x	x	
Strike Plans / Strike Ops	Coordination		1		x	x	x	
LAC	Coordination	1	1		x	x	x	
Providing Ship	Tasking, Engage, Coordination		1	x	x	x	x	
CTF	Info (Can Negate)		1					
SACC	Info (Can Negate)		1					
FSE	Info			x			x	
BN-REGT-BDE	Info			x			x	
Marine	Info			x			x	
	15	3	12					5
Soldier	Generate Request		1	x			x	
Decision Algorithm	Coordination	1	1	x		x	x	
JFC / JOC	Coordination		1			x	x	
COCOM SC	Coordination	1	1					
NCA	Decision		1					x
COCOM SC	Tasking		1					x
JFC / JOC	Coordination		1			x	x	x
Strike Plans / Strike Ops	Coordination		1		x	x	x	
LAC	Coordination	1	1	x	x	x	x	
Providing Ship	Tasking, Engage, Coordination		1	x	x	x	x	
ARFOR	Info (Can Negate)		1			x	x	
BCD	Info (Can Negate)		1			x	x	
ANGLICO	Info					x	x	
CO-BN-BDE	Info			x		x	x	
Soldier	Info			x			x	
	15	3	12					5

Average # of Steps	15.0
Average # of Air Gaps	3.0
Average # of Process Delays	12.0
Average # of Systems Needed	5.0

Table 25: High Value Target CFF Request

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APPENDIX J. EXTEND MODELING ORGANIZATIONAL ALTERNATIVES

Connectivity

Perfect connectivity between communication systems was assumed. All transmissions were received but delayed by a random distribution with the average delay based on historical data and Project Team concurrence.

Weapons

Each organization had some fires capability. This organic capability could be mortars, artillery, missiles, or assigned aircraft (fixed or rotary). Differentiation of weapons would not provide additional insight at this level of abstraction. Therefore, a target designated for brigade engagement was engaged by the brigade, without distinguishing between an artillery battery and attack helicopters.

Target Sets

Targets were generated to arrive randomly and assigned to the correct provider. A limit of two hundred targets, with a Poisson arrival process (2 minutes average) was used to ensure that overall processing delays were not due to the available fire provider assets. Targets were assigned a target type based on a notional pairing process. The system, at some point depending on the alternative, would match a provider to each target. Table 26 summarizes the target–provider pairing ratios and the provider resource limits used in each simulation.

Delays for pairing and deconfliction are based on alternative systems, and are addressed individually. The same assets are available and transmission time from requester to next organization is the same in all three alternatives. Total number of targets was limited to prevent running out of assets, but aircraft were made available at a rate of 2 per every 40 minutes to simulate close air support on the ATO. Targets assigned to aircraft would wait “in the queue” until an asset arrived to service them.

Target type	Probability	Provider	Assets
0	50%	Company	60
1	20%	Battalion	120
2	15%	Brigade	96
3	7%	Naval Fires	30
4	8%	Close Air Support	2 / 40 minutes

Table 26: Target Probability Distribution

COMMON COMPONENTS

Fire Support Unit

The fire support unit represented an asset with weapons that could provide fires. Each unit consisted of a time delay to process the request and task the weapon system; and an engagement delay. Simultaneous engagements were allowed based on multiple units or provider assets at this level. Figure 62 shows the layout of the fires support unit process.

Tasking delay (XDelayIn) and engagement delay (EngDelayIn) were alternative dependent numbers which set the center peak of the distributions in the random generator blocks. TaskingOut was used to capture the tasking order generation time in the model so that weapon engagements were not included in the overall system performance comparisons.

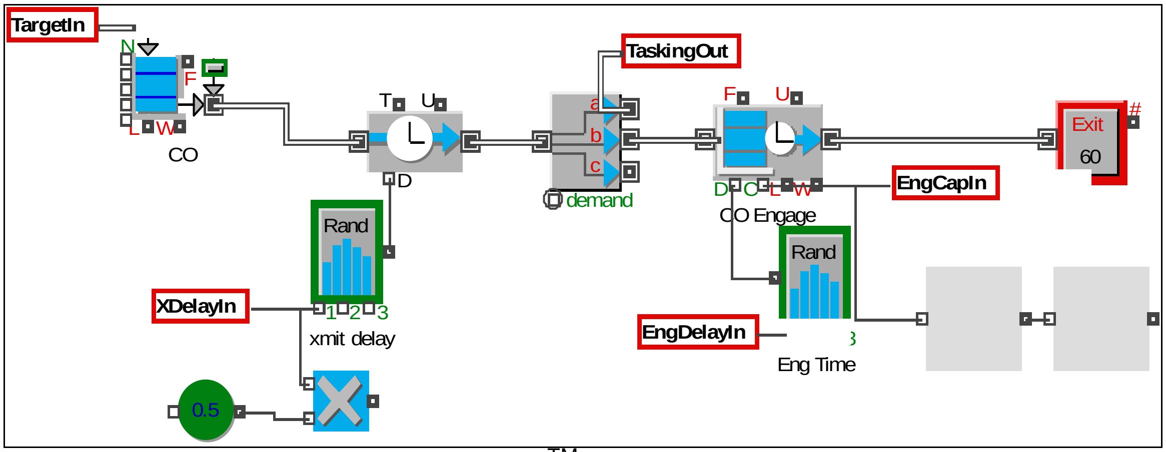

Figure 62: EXTEND6^{TM} Fires Support Unit Flow

Targets were generated with a Poisson process with a mean of 2 minutes as shown in Figure 63. Target type was randomly assigned using a fixed distribution, and time stamped with time generated. The system then processed the requests depending on the organization of each alternative and forwards tasking to the “catch block”. Total time delay through each system by target type was output for analysis.

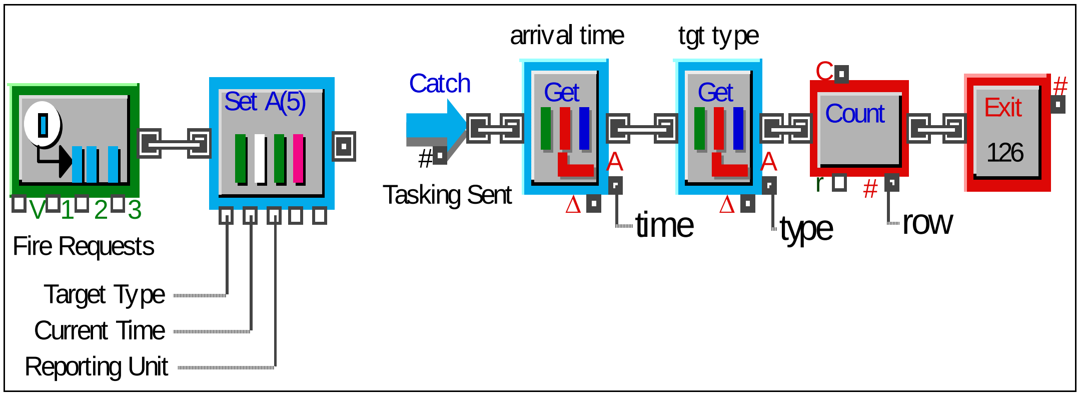

Figure 63: EXTEND6^{TM} Request Input – Tasking Output Flow

STATUS QUO PLUS

The Status Quo Plus processing structure was a linear process based on current command structure and was connected as shown in Figure 64. Requests are received at the company, processed to determine if company assets can provide support and were either tasked or forwarded to battalion for support. The battalion and brigade were similar, with a longer delay time for processing the request. Targets not engaged by the brigade were forwarded for Air or Naval Fires to the DASC, ASOC, or Joint Fires Cell for final tasking. These final tasking processes were combined in the simulation by assuming similar delays and processing capabilities for each of these organizations

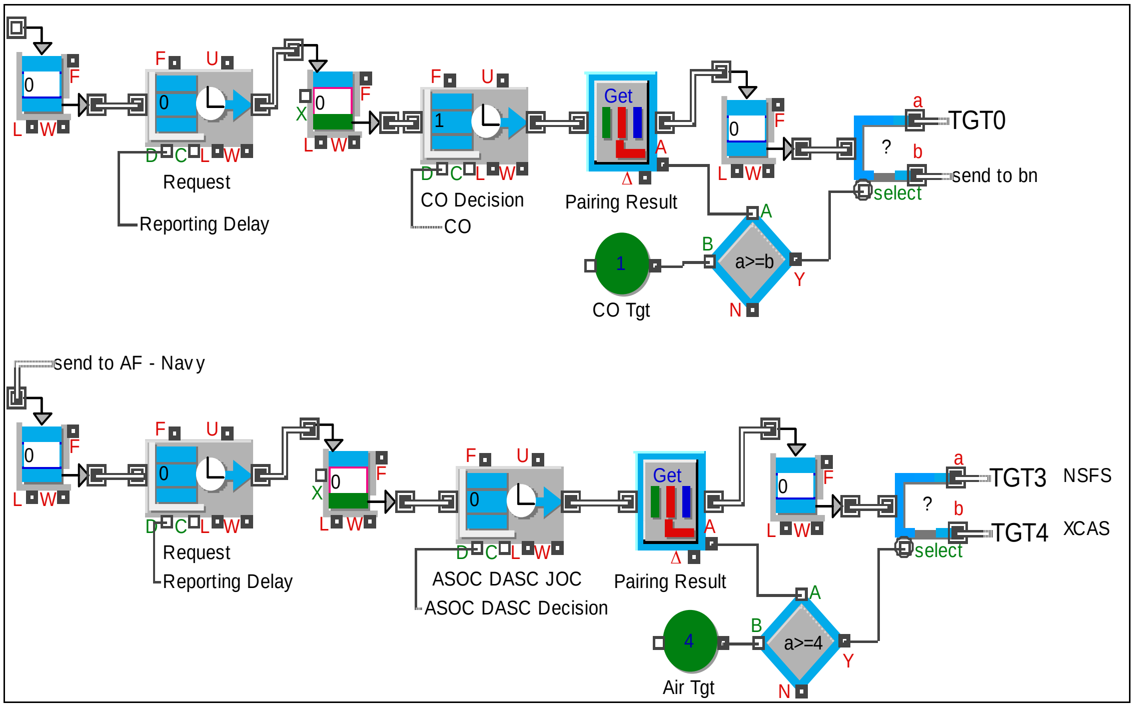

Figure 64: Status Quo Plus Flow Diagram

CENTRALIZED JOINT FIRE SUPPORT NETWORK

The centralized processing alternative was modeled by two sequential delays and a prioritization queue as shown in Figure 65. The requests were generated and placed in the queue on the left until they were transmitted to the Joint Fires Coordination Cell. The reporting delay was consistent for all requests.

At the Joint Fires Coordination Cell, requests were prioritized, paired, deconflicted and authorized for tasking. The tasking was then set to the appropriate unit for engagement. This tasking delay time was estimated at 5 minutes to complete with 12 simultaneous requests allowed. Tasking from the headquarters unit to the provider included conversion of the tasking into the appropriate format (NFCS, AFATDS, 9-line, etc.) and transmission to the fires provider is contained within each fire support unit block separately.

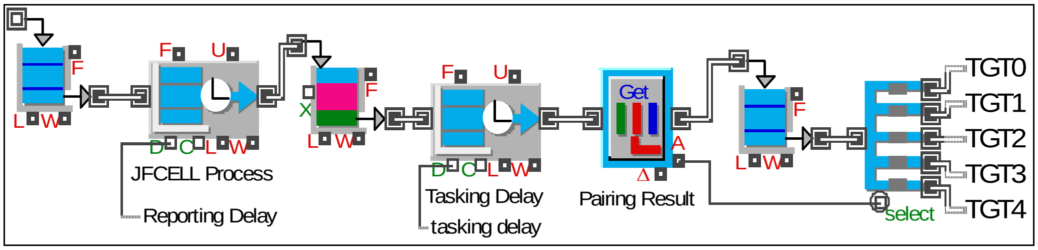

Figure 65: Centralized Process

DISTRIBUTED JOINT FIRE SUPPORT NETWORK

The distributed processing alternative was modeled by two sequential delays and a prioritization queue as shown in Figure 66. The requests were generated and placed in the queue on the left until they were transmitted to the GIG. The reporting delay remained the same for all requests.

At the GIG, requests were prioritized, in this case sorted by target type, highest number first. Concur 2 Shoot represented the composite delay for all potential providers to receive the data, bid on the data, concur on bids and finally task the applicable unit. The tasking was then set to the appropriate unit for engagement tasking, conversion delays for headquarters to provider contained in the fires support unit block separately.

The pairing delay time was highly dependent on quantity of participants and bandwidth availability to pass the various messages between stations. The Project Team agreed on a 3 minute delay by assuming that brigade and senior headquarters units (or equivalent) were nominating their assets (including subordinate commands) to reach a recommended pairing. To push to fully decentralized processing, with “every soldier a sensor” would rapidly increase the quantity of messages. It was deemed ‘not likely’ by the team to meet a three minute delay with this quantity of units by 2020.

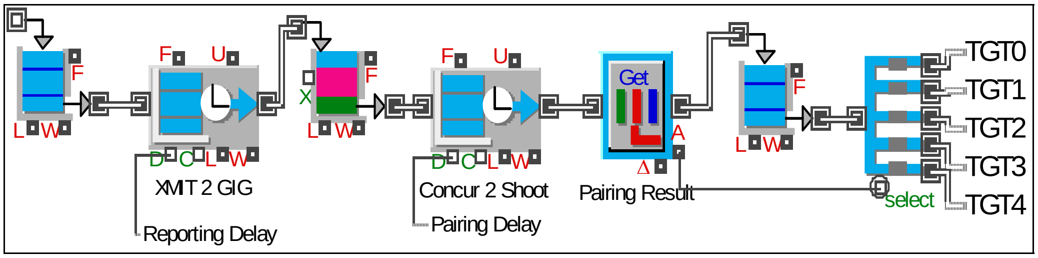

Figure 66: EXTEND6™ DJFSN Processing

SUMMARY OF PROCESS DELAYS

Table 27 summarizes the average delays for each process. The listed distributions were used and the specifics are discussed in the Process Delay Distributions section.

	Status Quo +	**CJFSN**	**DJFSN**	**Distribution**
Initial Call for fire request	0.5	0.5	0.5	weibull
Engagement Times				
Company Asset	3	3	3	lognormal
Battalion Asset	3	3	3	lognormal
Brigade Asset	3	3	3	lognormal
Close Air Support	10	10	10	lognormal
Naval Fires	10	10	10	lognormal
Process and Tasking Times				
Company Asset	3	5	3	weibull
Battalion Asset	5	5	3	weibull
Brigade Asset	5	5	3	weibull
Close Air Support	3	5	3	weibull
Naval Fires	3	5	3	weibull
ASOC/DASC/JOC	5			weibull
Joint Fires Cell decision		5		weibull
GIG collaborative decision			3	weibull

Table 27: Summary of Simulation Delays (Minutes)

ORGANIZATIONAL ALTERNATIVES SIMULATION ANALYSIS

Thirteen runs with a limit of 200 targets per run were conducted in each EXTEND6^{TM} model. The results were exported to Minitab for initial analysis. The models show statistically significant differences in expected systems performance.

Analysis of variance (ANOVA, general linear model) evaluation of these results was conducted with a null hypothesis that all systems and providers were equal. Summary results show that provider (F statistic=154, p=0.0000) and system (F statistic=391, p=0.0000) have statistically significant differences in response time, therefore at least one system and provider was different from the others. The main effects plot, Figure 67, graphically represents these differences. Additionally Figure 68 shows the organizational time performances.

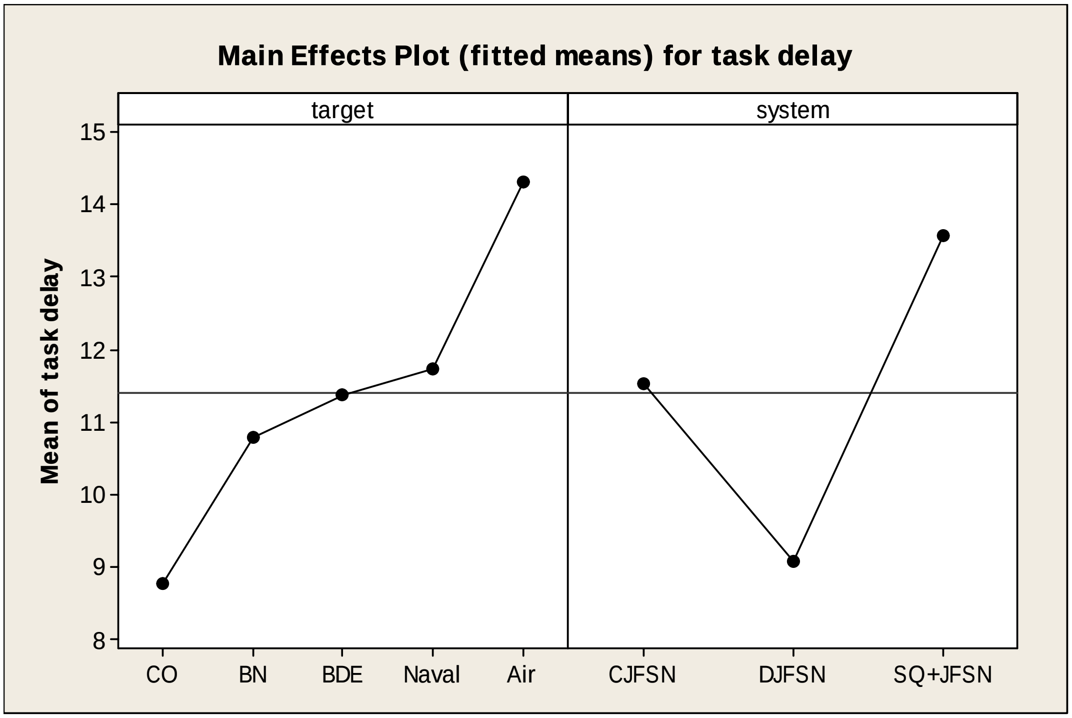

Figure 67: Main Effects Plot for Task Delay

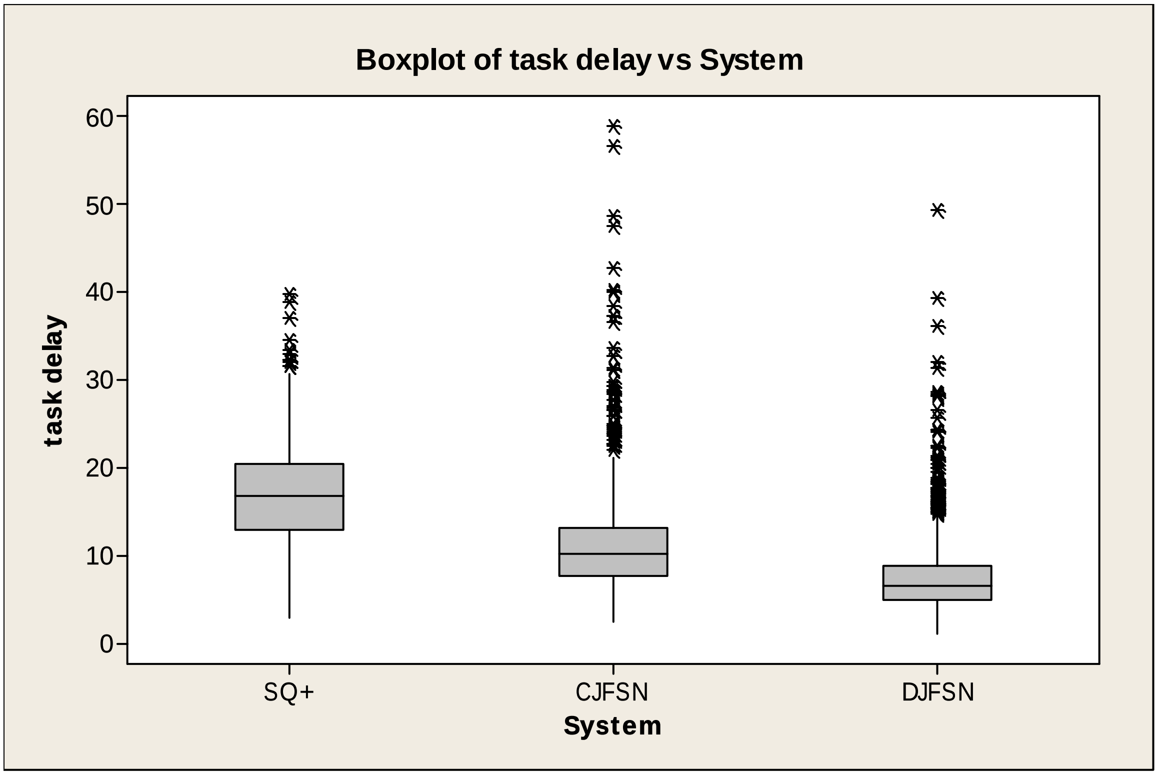

Figure 68: Boxplot of Organizational Time Performance

ANOVA comparison of the data assumes normal distributions which is not the case for the simulation results. In order to better compare the systems, a non-parametric analysis was conducted. The Kruskal-Wallis results are show in Table 28.

Kruskal-Wallis Test on Delay

System	**N**	**Median**	**Ave Rank**	**Z**
CJFSN	1753	8.873	3045.1	16.43
DJFSN	1701	5.696	1673.0	-30.53
SQ+	1689	8.822	2986.5	14.00
Overall	5143		2572.0	

H = 933.16 DF = 2 P = 0.000

Table 28: Test on Delay

DJFSN was the quickest overall system as evident from both ANOVA and Kruskal-Wallis tests. There was no significant difference between CJFSN and Status Quo Plus results based on the Kruskal-Wallis test because this is a one-way (single variable) test. The delay effect attributed to provider (target type) may mask the potentially significant three minute improvement shown in the main effects plot. The preponderance of company level targets may unfairly advantage the Status Quo Plus system. The assumption that a permissive fire environment with the company having the capability to self-deconflict fires on roughly half the targets applies to a permissive ROE environment and not a cross section of potential future conflicts. Figure 69 shows the distribution of times by system and target type.

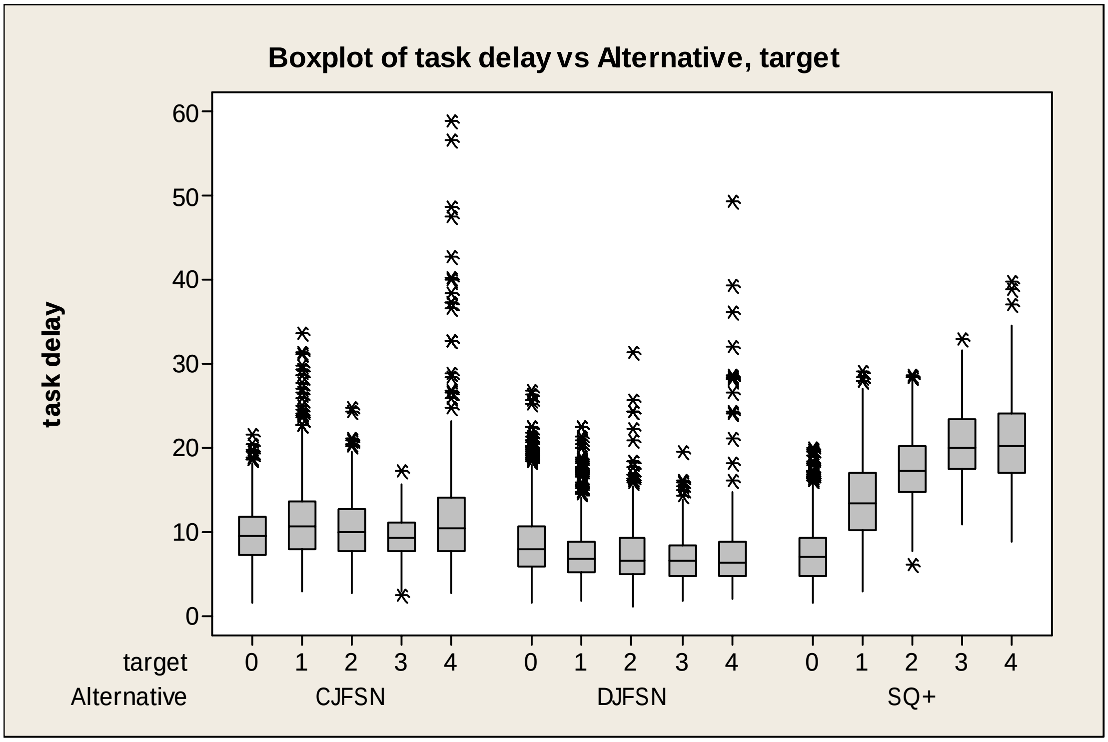

Figure 69: Tasking Order Processing Delays

Target type 4, which required an air asset to prosecute, shows numerous outliers that are due to the limited number of providers. With no consideration for servicing the target with a different asset within the simulation, these requests waited in the queue until the next aircraft showed up, on a 2 per 40 minute cycle.

The box plot also displays a fairly consistent median response time for both the CJFSN and DJFSN systems. The increasing response times for status quo plus was expected due to the hierarchy built into this alternative. Comparing the CJFSN and Status Quo Plus alternatives shows the CJFSN appears quicker at the battalion level and higher. The target set (50% company level targets) assumption is masking a potentially statistically significant improvement of the CJFSN alternative over Status Quo Plus.

Removal of all company level targets and evaluating the simulation data for all higher echelon commands with the non-parametric Kruskal-Wallis test yields the results in Table 29.

```
Kruskal-Wallis Test on Delay

System          N     Median      Ave Rank    Z
CJFSN           975   8.786       1358.7      -2.12
DJFSN           921   5.656       694.9       -32.38
SQ+             909   15.745      2168.0       34.64
Overall         2805              1403.0

H = 1517.91  DF = 2  P = 0.000
H = 1517.91  DF = 2  P = 0.000  (adjusted for ties)
```

Table 29: Higher Echelon Non-Parametric Results

The results for higher echelon providers show statistically significant differences in all three alternatives. The centralized system is slightly better than average, while the decentralized had the fastest and status quo plus the slowest time to process a request and task a provider. This implies that both alternatives present an improvement over the status quo plus system when an individual company does not have assets or authority to employ offensive fires without involvement of higher headquarters.

SENSITIVITY ANALYSIS

In order to examine the effects of the various distribution means on the performance of each system, sensitivity analysis was conducted. Each parameter was systematically varied (individually) and overall average tasking times were calculated for 30 runs. The results are tabulated in Table 30.

Task Time (min)	**Status Quo +**	**CJFSN**	**DJFSN**
Baseline	11.02	9.83	6.20
Unlimited Assets	10.52	9.33	5.79
Unlimited Engagements	10.87	9.39	6.04
Double CO Decision	12.62	11.63	7.27
Double BN Decision	12.34	10.41	6.80
Double BD Decision	11.78	10.03	6.38
Double JF/Concur/ASOC	11.20	14.07	8.53
Double Report Time	11.82	10.07	6.62
Target Set 2	12.28	9.36	5.90

Table 30: Sensitivity Analysis of Tasking Times

Decision times were individually doubled to examine the impact of lower echelon decision times. The Joint Operations Cell, GIG process, and

JOCC/ASOC/DASC times were then doubled to compare impact of the time required for higher level decision processes. Asset quantities were set to 10 times their original value and engagement limitations removed to assess impact of these initial assumptions. Finally, a second target type distribution was input into each model to compare performance of each alternative against fewer company level targets.

Removing limitations on assets and engagements improved all systems, while increasing decision times degraded all systems. The only parameter that demonstrated a system interaction was the target set, Table 31. As more targets requiring response above the company level are generated, the SQ Plus system performance degraded while the other two alternatives remained about the same.

	Target Set	
Provider	**I**	**II**
Company	50%	30%
Battalion	20%	30%
Brigade	15%	25%
Naval	7%	7%
Air	8%	8%

Table 31: Target Distributions

Process Delay Distributions

Random number generators and statistical distribution functions were used to model time delays for each of the alternatives. Consistency with time delays and distributions were made to allow a comparison of the alternative architectures.

The lognormal distribution was used to model engagements. All of the results are positive and the central tendency of the function limits the number of very rapid (near zero) engagements.

Human-in-the-loop decision delays were modeled by Weibull distributions. The shaping and location values for all were kept the same, the center value changed based on Project Team consensus as to what the average delay should be. There is a greater probability of a very quick decision being made using this distribution vice a lognormal. During routine operations, it was agreed that the decision makers would more rapidly assess, assign, or concur with a tactical aid recommendation thus these low values were probable.

Response Time Data

Open source response time data was collected from several sources to baseline inputs for the various models.

Dr. De et al. reported average response times for close air support depending on target type and threat density about from 5 to 10 minutes. Artillery response times were recorded with an average response of about 3.5 minutes, and naval gunfire at 2 to 4 minutes. "Digital artillery, mortar and naval surface fires missions executed twice as fast as air missions. This is because all necessary information for resource management is readily available in the fully digital artillery, mortar and naval surface fires missions. In the air missions, two different systems: AFATDS and TBMCS are necessary to assign an aircraft to a mission."[67]

RAND Corporation[68] references 15 minutes as a typical response time for aircraft engagements, with significant variability based on CAS employment (stack vs. deck launched) and flight times based on geography. Additionally, prosecuting a second target could be very quick for an attack helicopter "(b)ut a bomber employing JDAM usually required about ten minutes between drops to enter new coordinates and to reposition itself, a considerable time when friendly troops were under fire".[69] Their modeling used 15 minute time estimate for the prosecution of 2 mobile targets with a section of aircraft.[70]

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[67] U. S. Marine Corps, Marine Corps Combat Development, "Marine Corps Fire Mission Profiling Through Experimentation with Real and Simulated Systems," Raytheon, 2006, pp. 15.

[68] Pirnie, Vick, Grissom, Mueller, Orletsky, "Beyond Close Air Support," RAND, Santa Monica CA, 2005, p. 78.

[69] Ibid, p. 88.

[70] Ibid, p. 151.

Process Delay Times

Generate and Send Request (All Alternatives)

Figure 70 depicts the default reporting delay (30 sec) added to all targets. The team assumed a process where data is entered (preferably automatically) and digitally transmitted to the next higher authority. Occasionally requests may take more than a minute to send due to transmission delays or need to use voice calls.

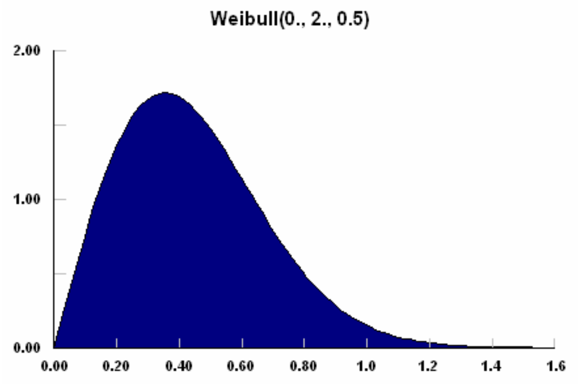

Figure 70: Default Reporting Delay

Army Surface Fires Engagements (All Alternatives)

Figure 71 depicts the engagement process that was modeled for company, battalion and brigade assets as a lognormal distribution (3 +- 0.6 min). The time does not count against the tasking message, but along with finite simultaneous engagements may cause the target queues to fill up.

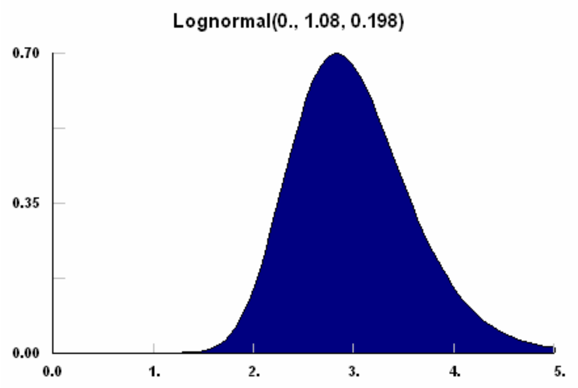

Figure 71: Army Engagement Process Delay

CAS and NSFS Engagements (All Alternatives)

Figure 72 depicts the Close air support and naval fires (both gun fire and TLAM) which were estimated with the below distribution. The distribution (10 +- 2 min) may be optimistic depending on asset position relative to target and actual unit readiness. Engagement time is used to limit simultaneous engagements and does not directly add to the tasking time of the fires request. Aircraft were not returned to a ready for tasking state following the engagement, but naval fires were.

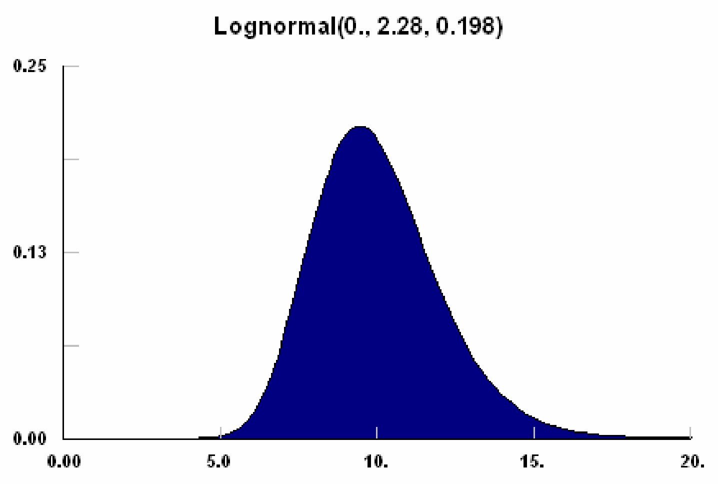

Figure 72: CAS/NFCS Engagement Process Delay

GIG-Enabled Distributed Processing

Decision Processes (GIG and All Lower Echelon Engage Orders)

After much discussion, “near-perfect connectivity” of brigade and higher echelon commands (basically O-5/O-6 and senior commands) was evaluated as a reasonable level of distributed control. Figure 73 depicts that with the quantity of HQ units it was proposed to use a 3 minute delay for all commands to concur on a provider-target pair. Addition of lower echelon commands connected to the GIG and participating in a distributed pairing process would drastically increase the amount of message traffic and yield a significantly higher expected processing delay. Tasking of lower echelon commands was assumed to be via a local digital network and considered as part of the 3 minute delay.

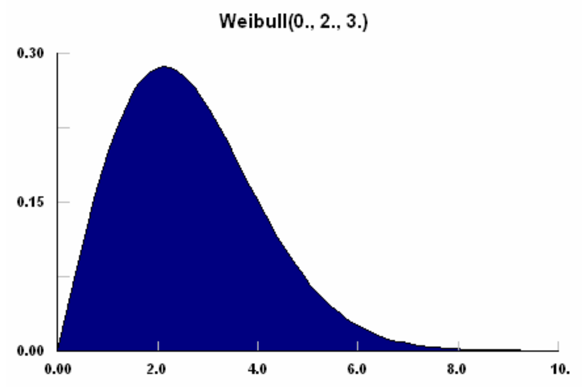

Figure 73: GIG Lower Echelon Decision Process Delay

CJFSN Decision Processing

Centralized Decision Process and Lower-Echelon Tasking

Figure 74 depicts that the centralized Joint Fires Coordination Cell using pairing algorithms and tactical aides was determined to be able to deconflict, pair, authorize, and transmit provider tasking in about 5 minutes. Lower echelon commands use similar processes to prioritize and translate the tasks to their organic providers with the same time-delay distribution.

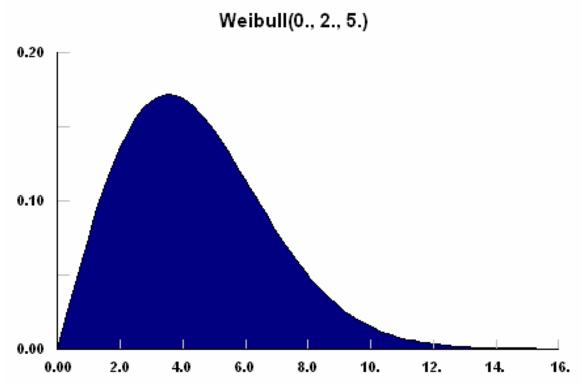

Figure 74: CJFSN Lower Echelon Decision Process Delay

Status Quo Plus Processing

Separate delays were used for company and all higher echelon commands in the status quo plus alternative.

Status Quo Plus CO Engagement Decision

Figure 75 illustrates that under the status quo plus, requests arrive at the company for processing. With limited assets, it was assumed that the company would decide to prosecute or forward the request in about 3 minutes. Actual engagement by company assets follows the lognormal distribution described above.

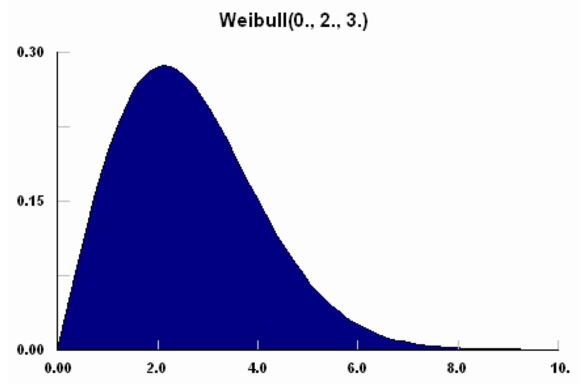

Figure 75: CJFSN Lower Echelon Decision Process Delay

Engagement Decision for BN/BDE and JOCC

The battalion, brigade and Joint Operations Centers were assumed to take longer than the company to decide whether assets were capable or available to provide support. The team modeled this decision process at about 5 minutes per step. Adding the engagement delay time of 10 minutes with the above lognormal distribution matches historical data on close air support call-to-engage times of about 15 minutes referenced in Response Time Data Section illustrated in Figure 76. Naval fires, both guns and Tomahawk were pooled and given the same average delay of CAS to not show a preference for response time in the models.

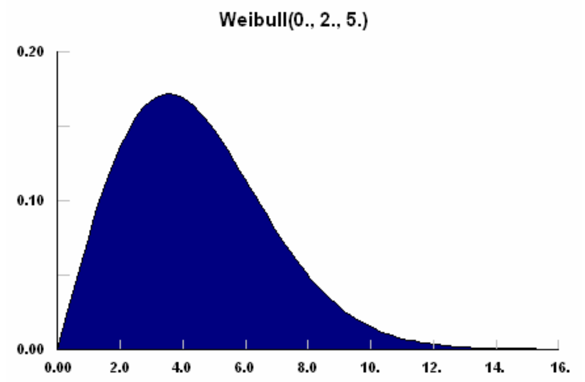

Figure 76: BN/BDE Engagement Decision Process Delay

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APPENDIX K. EXTEND MODELING OF PAIRING PROCESSES

Common Assumptions

Calls for fire were modeled as discrete events with three attributes. Target type was uniformly distributed from 0-9; target location uniformly distributed in the battlespace; and desired effects were determined (10% harass; 15% disrupt; 50% neutralize; 25% destroy). The target set was randomly generated then fixed for inject into the three models.

Weapon effectiveness was based on target type and desired effects. It was assumed that a single provider was tasked and the effectiveness applied to the target was tagged as another attribute on the request. Effectiveness was fixed and involved a table lookup.

Providers were represented by Army Artillery, USMC Artillery, AF CAS, Navy-USMC CAS, and Naval Fires. Effectiveness of similar weapons was identical.

Model Description

Figure 77 represents the target generation and pairing algorithm. Targets are generated from the program block on the left. Target type, desired effects, and target location are read and exported to an excel spreadsheet. This spreadsheet determines the notional best provider from all that can strike the target based on location. The DE equations then determine which provider to task based on a resource representing the provider being available to task. The request is then sent to the applicable engagement section.

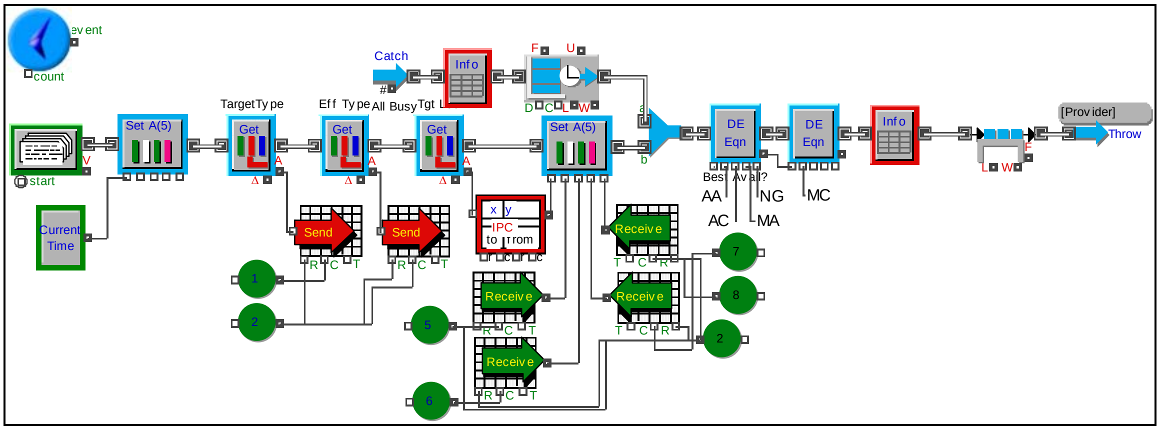


Figure 77: Target Generation and Provider Selection

Figure 78 represents an engagement block, USMC artillery in this case. The request enters the engagement queue, target type and desired effects are then determined. The effectiveness of the given weapon is then tagged onto the request, representing how well the target was engaged. The resource (artillery battery for example) is then released for further tasking.

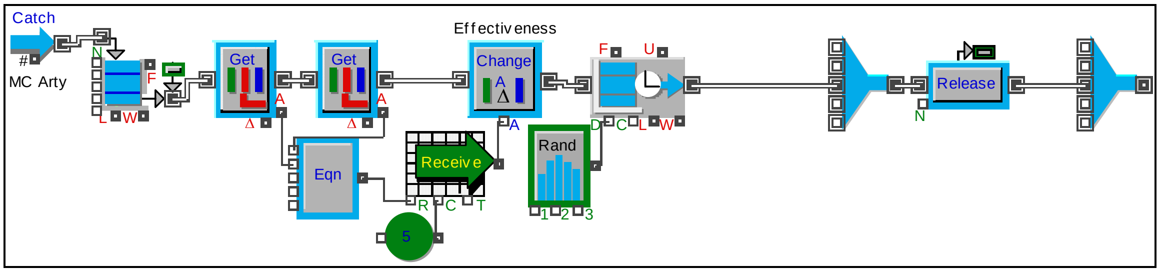


Figure 78: Engagement and Applied Effects Section

Following the engagement section, the targets are combined and sent through a process that outputs the target type, provider, desired effects and effectiveness applied to an excel file for data analysis, as shown in Figure 79

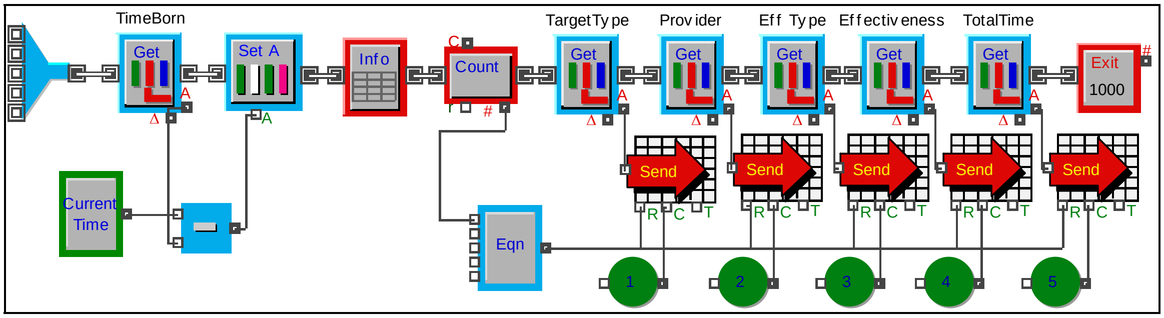


Figure 79: Data Output Section

Status Quo Plus

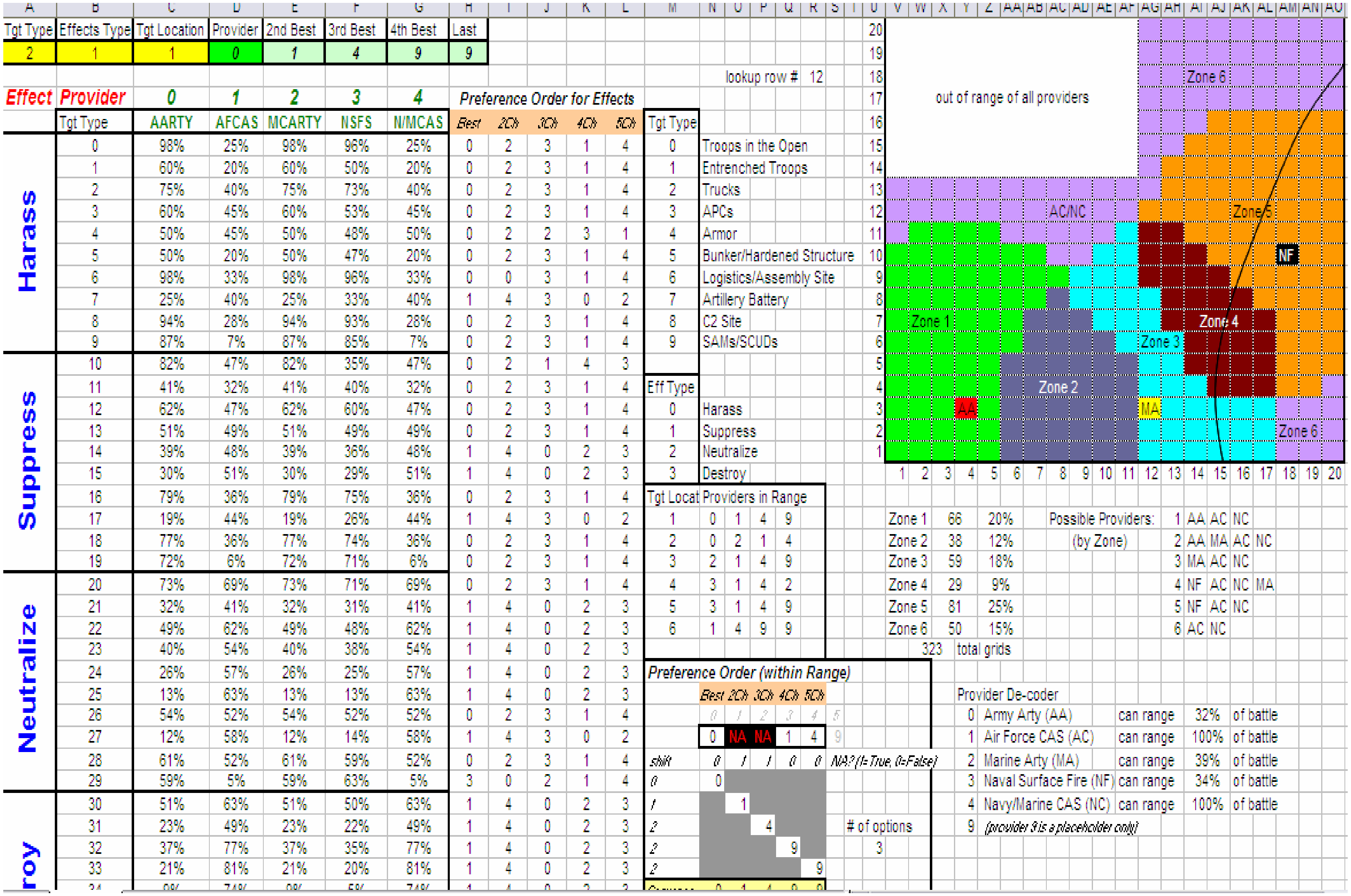
The status quo plus system prioritization scheme was based on preference for Army artillery fires, followed by USAF CAS then Navy and Marine Corps assets on a effectiveness basis. This bias towards own-service and existing stove-pipes resulted in a lower average effectiveness applied to the target set.

CJFSN and DJFSN Joint Asset Pairing

Both Centralized and Distributed Joint Fire Support Networks used a pooling of all available assets to make a pairing decision. The time delays generated from the communications model are the fundamental difference in the models. These delays, with the given asset availability for this target set, resulted in nearly identical results for the two systems.

Optimal Pairing Solution

To determine the maximum effectiveness that the providers could apply to the given target set, an ‘optimal pairing solution’ was designed. This system used an unlimited quantity of providers so that only target location limited the ability to task the best asset to any given target. Removing the location limitation would have resulted in a perfect effectiveness ratio, with every target being assigned the best asset. Figure 80 depicts a portion of the Excel spreadsheet used to process and prioritize the provider-pairings.



Tgt Type	Effects Type	Tgt Location	Provider	2nd Best	3rd Best	4th Best	Last
2	1	1	0	1	4	9	9

lookup row # 12

Effect	Provider	0	1	2	3	4	Preference Order for Effects				
	Tgt Type	AARTY	AFCAS	MCARTY	NSFS	N/MCAS	Best	2Ch	3Ch	4Ch	5Ch
Harass	0	98%	25%	98%	96%	25%	0	2	3	1	4
	1	60%	20%	60%	50%	20%	0	2	3	1	4
	2	75%	40%	75%	73%	40%	0	2	3	1	4
	3	60%	45%	60%	53%	45%	0	2	3	1	4
	4	50%	45%	50%	48%	50%	0	2	2	3	1
	5	50%	20%	50%	47%	20%	0	2	3	1	4
	6	98%	33%	98%	96%	33%	0	0	3	1	4
	7	25%	40%	25%	33%	40%	1	4	3	0	2
	8	94%	28%	94%	93%	28%	0	2	3	1	4
	9	87%	7%	87%	85%	7%	0	2	3	1	4
Suppress	10	82%	47%	82%	35%	47%	0	2	1	4	3
	11	41%	32%	41%	40%	32%	0	2	3	1	4
	12	62%	47%	62%	60%	47%	0	2	3	1	4
	13	51%	49%	51%	49%	49%	0	2	3	1	4
	14	39%	48%	39%	36%	48%	1	4	0	2	3
	15	30%	51%	30%	29%	51%	1	4	0	2	3
	16	79%	36%	79%	75%	36%	0	2	3	1	4
	17	19%	44%	19%	26%	44%	1	4	3	0	2
	18	77%	36%	77%	74%	36%	0	2	3	1	4
	19	72%	6%	72%	71%	6%	0	2	3	1	4
Neutralize	20	73%	69%	73%	71%	69%	0	2	3	1	4
	21	32%	41%	32%	31%	41%	1	4	0	2	3
	22	49%	62%	49%	48%	62%	1	4	0	2	3
	23	40%	54%	40%	38%	54%	1	4	0	2	3
	24	26%	57%	26%	25%	57%	1	4	0	2	3
	25	13%	63%	13%	13%	63%	1	4	0	2	3
	26	54%	52%	54%	52%	52%	0	2	3	1	4
	27	12%	58%	12%	14%	58%	1	4	3	0	2
	28	61%	52%	61%	59%	52%	0	2	3	1	4
	29	59%	5%	59%	63%	5%	3	0	2	1	4
roy	30	51%	63%	51%	50%	63%	1	4	0	2	3
	31	23%	49%	23%	22%	49%	1	4	0	2	3
	32	37%	77%	37%	35%	77%	1	4	0	2	3
	33	21%	81%	21%	20%	81%	1	4	0	2	3

Tgt Type	
0	Troops in the Open
1	Entrenched Troops
2	Trucks
3	APCs
4	Armor
5	Bunker/Hardened Structure
6	Logistics/Assembly Site
7	Artillery Battery
8	C2 Site
9	SAMs/SCUDs

Eff Type	
0	Harass
1	Suppress
2	Neutralize
3	Destroy

Tgt Locat	Providers in Range			
1	0	1	4	9
2	0	2	1	4
3	2	1	4	9
4	3	1	4	2
5	3	1	4	9
6	1	4	9	9

Preference Order (within Range)

	Best	2Ch	3Ch	4Ch	5Ch		
	0	1	2	3	4	5	
	0	NA	NA	1	4	9	
shift	0	1	1	0	0	NA? (1=True, 0=False)	
0	0						
1		1					
2			4			# of options	
2				9		3	
2					9		

Zone 1	66	20%
Zone 2	38	12%
Zone 3	59	18%
Zone 4	29	9%
Zone 5	81	25%
Zone 6	50	15%
323	total grids	

Possible Providers: (by Zone)

1	AA	AC	NC	
2	AA	MA	AC	NC
3	MA	AC	NC	
4	NF	AC	NC	MA
5	NF	AC	NC	
6	AC	NC		

Provider De-coder

0	Army Arty (AA)	can range	32%	of battle
1	Air Force CAS (AC)	can range	100%	of battle
2	Marine Arty (MA)	can range	39%	of battle
3	Naval Surface Fire (NF)	can range	34%	of battle
4	Navy/Marine CAS (NC)	can range	100%	of battle
9	(provider 9 is a placeholder only)			

Figure 80: Provider-Pairing Process and Prioritization Spreadsheet

MINITAB14^{TM} Data Analysis Results

The resultant data was imported into MINITAB14^{TM} for analysis. Analysis of variance (ANOVA) and non-parametric ranking (Kruskal-Wallis) methods were used for data reduction.

Effectiveness ratio was used as a surrogate for weapons effects. It was calculated as (effects applied) divided by (max weapon effects available). If 50% effects was the maximum available (from the weapon effects table) then 50% applied = 1.0 effectiveness and 25% applied = 0.5 effectiveness.

Assumption of normality is suspect as shown in Figure 81, the normal probability plot. ANOVA analysis was conducted regardless and compared to non-parametric analysis. The null hypothesis for all analysis is that there is no difference between alternative systems, providers, or targets.

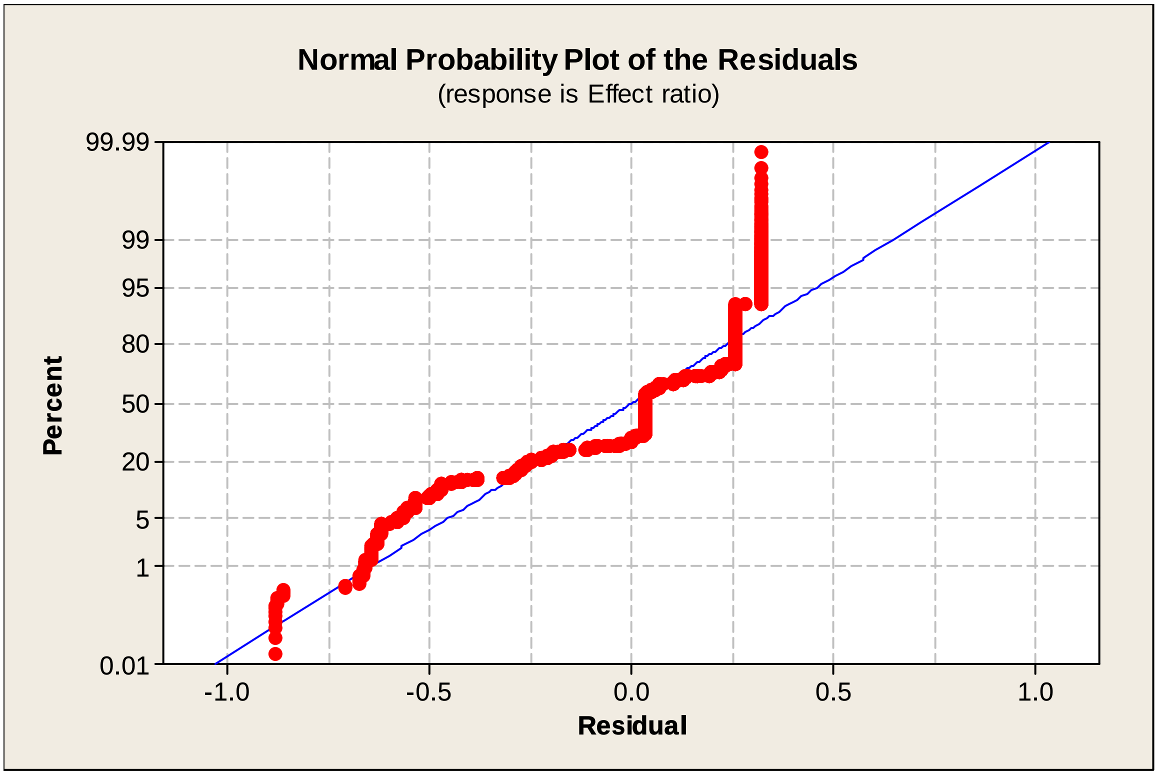


Figure 81: Normal Probability Plot

Figures 82 and 83 represent ANOVA results which show that at least one alternative is different and at least one asset (provider) is different.

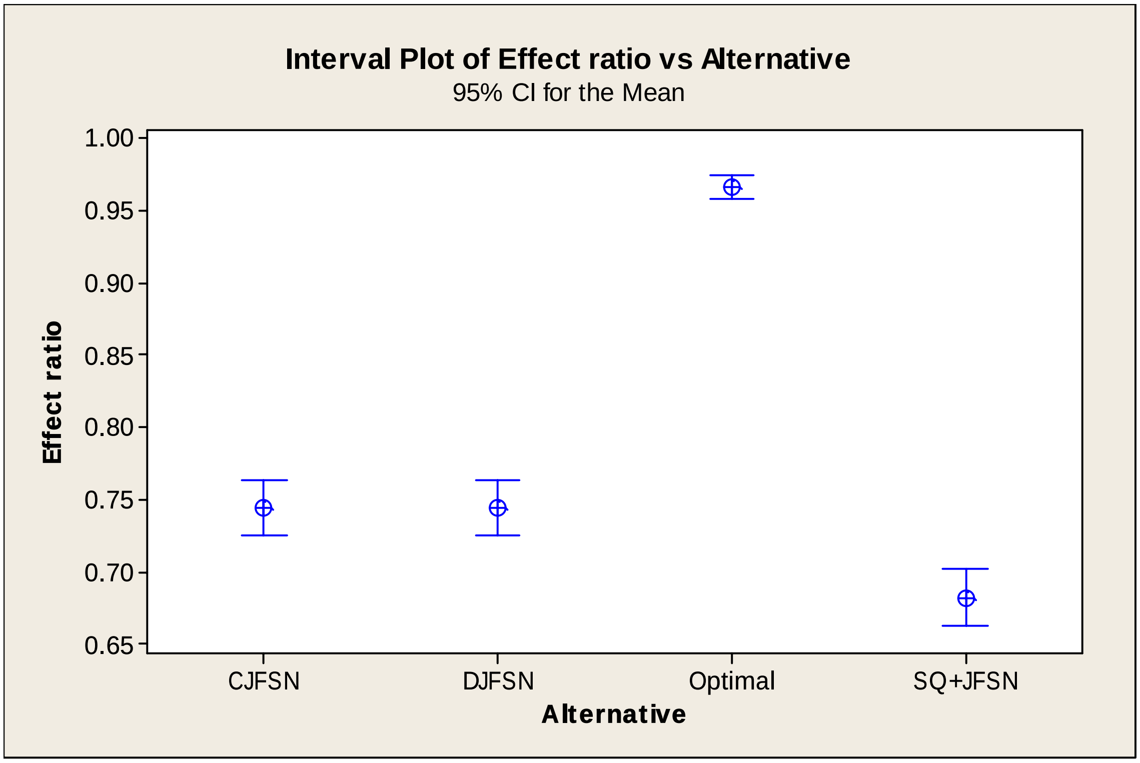


Figure 82: Mean Effectiveness Applied by Alternative

```
Analysis of Variance for Effect ratio, using Adjusted SS for Tests


Source        DF   Seq SS    Adj SS     Adj MS     F      P
Alternative    3   47.0023   18.5371    6.1790     82.39  0.000
Asset          4   9.3043     9.3043     2.3261     31.02  0.000
Error       3992   299.3896  299.3896  0.0750
Total       3999   355.6962
```

Figure 83: Effect Ratio ANOVA

Figure 84 represents the overall effectiveness versus the Alternative and Asset represented as a boxplot which shows significant overlap of results.

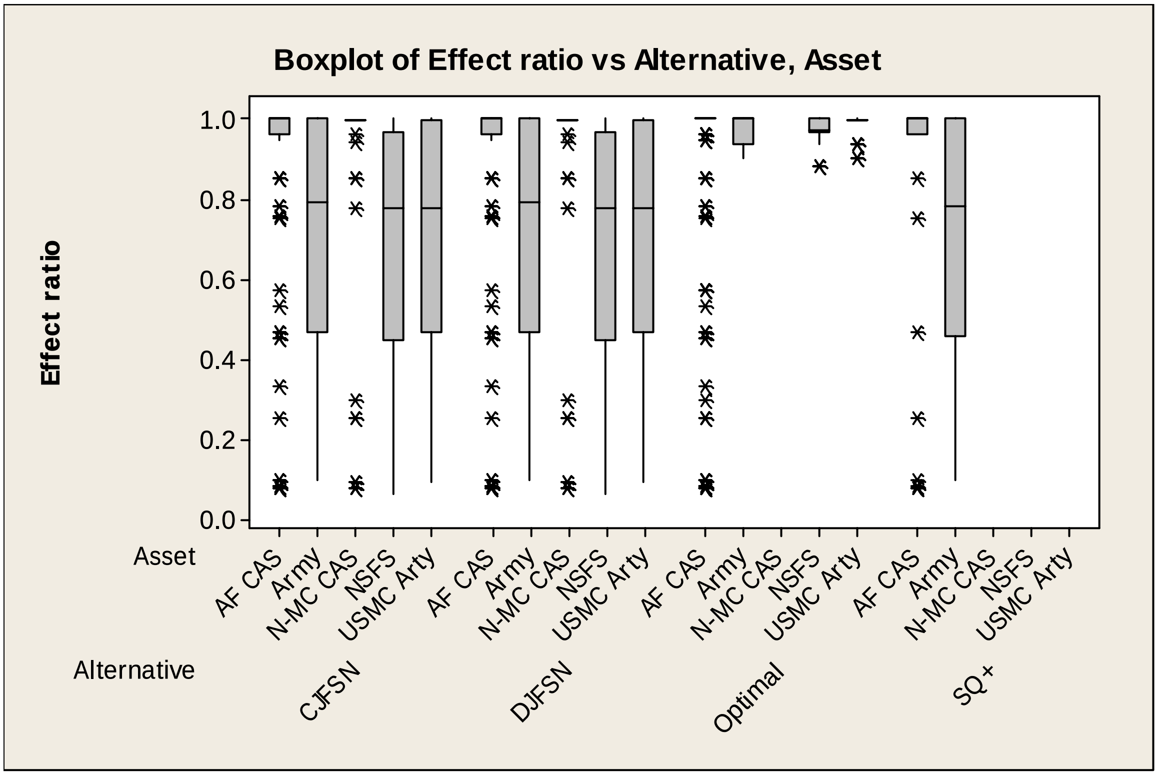


Figure 84: Effect Ration vs. Alternative Boxplot

Non parametric analysis in Figure 85 shows the optimal solution is significantly better than the proposed alternatives. The optimal solution represents the absolute best solution possible. The difference between Status Quo Plus and CJFSN and DJFSN effectiveness ratio is within two standard deviations and not statistically significant.

```
Kruskal-Wallis Test: Effect ratio versus Alternative


Kruskal-Wallis Test on Effect ratio


Alternative      N      Median   Ave Rank     Z
CJFSN          1000     0.9039   1735.9     -8.37
DJFSN          1000     0.9039   1734.2     -8.42
Optimal        1000     1.0000   2862.9      27.27
SQ+            1000     0.7810   1669.0     -10.48
Overall        4000     2000.5


H = 745.75  DF = 3  P = 0.000
H = 790.06  DF = 3  P = 0.000  (adjusted for ties)
```

Figure 85: Effect Ratio vs. Alternative

Conclusions

Consideration of all joint fires providers available to prosecute a target improves effects applied to the targets. Using actual weapons data in the effectiveness table could yield results that indicate militarily significant differences in the proposed systems. Target sets for a variety of scenarios could then be generated to examine resource requirements to achieve desired effects.

An algorithm to pair available assets to requests for fire can be built and meet the assumed processing time (3 to 5 minutes) used in the communications model. The Extend-Excel simulation processed 1000 targets in under 3 minutes. Software designed for this processing should be able to meet or exceed this constraint.

APPENDIX L. MANA MODELING

Building the Model

The Project Team built a model using MANA (Map Aware Non-uniform Automata), an agent based model to define agent behaviors and states, dictate topography, routes, and weapons.

The Battlefield

The first step in building the Urban scenario was battlefield layout. Google Earth provided the graphic for an urban area (in this case, downtown Baghdad). It is important to note the vertical and lateral limits of the graphic in terms of units of distance. For this simulation we chose a 10 mile by 6.6 mile area of Baghdad. This directly corresponded to battlefield dimensions of 1000 by 660 pixels (units), yielding a pixel distance of 52.8 feet. This graphic was then converted to an 8-bit bitmap. This format is required by MANA to distinguish terrain features, each of which is defined by a RGB (Red-Green-Blue) value. Each color thus represents a specific terrain feature, and each terrain feature has three associated attributes; Going (ease of transit), Cover (terrain which will block incoming rounds) and Conceal (terrain which acts as camouflage, but doesn't prevent agents from getting shot). After the picture (.jpg) is converted to bitmap (.bmp), it is then touched up using Microsoft Paint. Users must ensure that there are only the desired colors, and that they are continuous. If there is a break in color, agents exhibit unintended manner.

MANA automatically inserts six terrain features (Billiard Table, Wall, Hilltop, Road, Light Brush and Heavy Brush), each with their own color. The user is then able to add 5 additional terrain features and define their 3 attributes (or delete the default settings and define 11 user-specific terrain features). For simplicity and expediency, 3 terrain features were used; Roads (Going 1, Cover 0, Concealment 0), Heavy Urban (.3, .5, .5) and Light Urban (.6, .3, .3). The graphics for the battlefield layout and terrain map are shown in Figures 86 and 87.

Figure 86: Terrain Map (From[70])

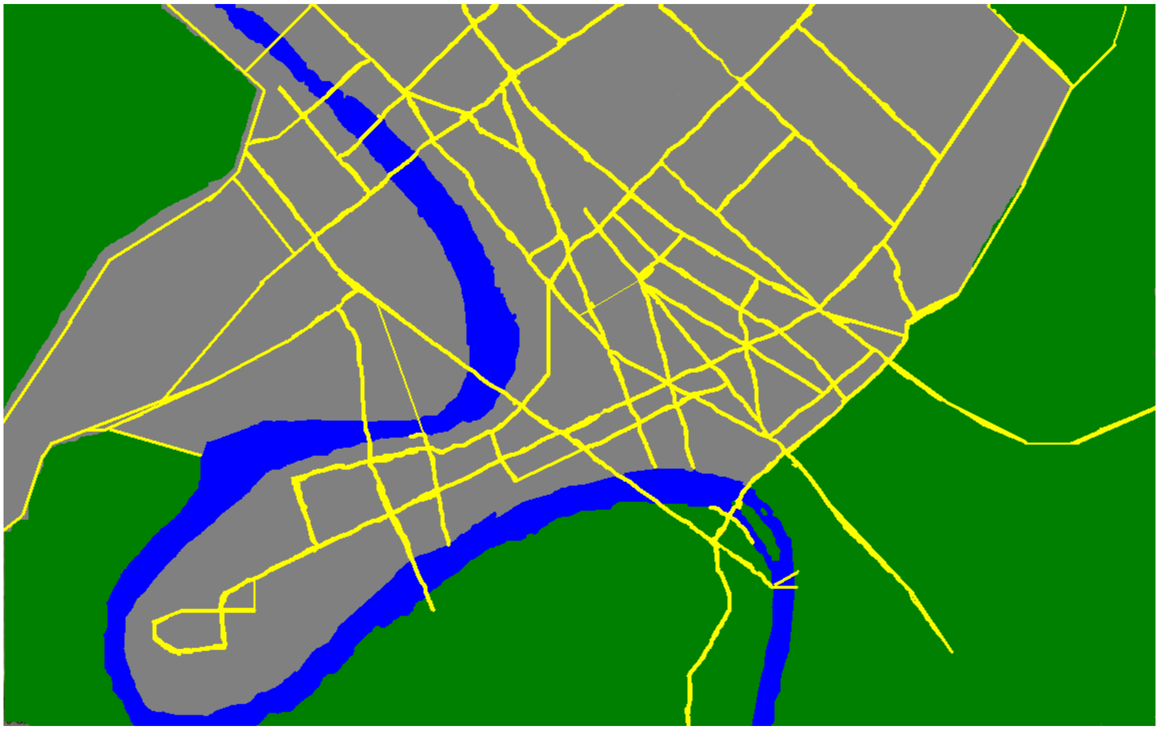


Figure 87: Terrain Layout

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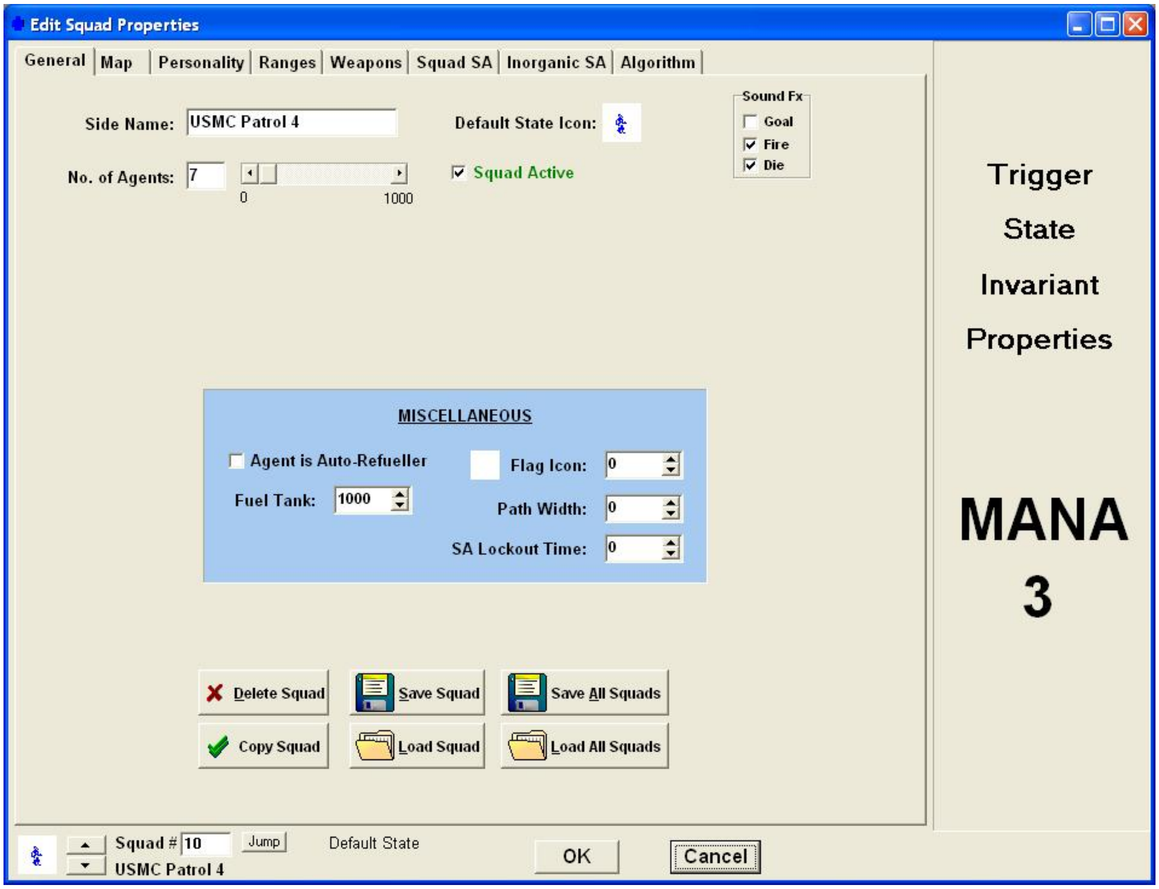
[70] Google, Google Earth © .jpg image, [www.google.earth], Oct 06,

Entities (Agents)

After the Battlefield was built, the principal players were inserted into the simulation. This began with one red squad of a single agent and 1 blue squad of a single agent. Each squad has properties which can be manipulated to determine agent behavior. The Squad Properties menu is depicted below in Figure 88.



Side Name: USMC Patrol 4

No. of Agents: 7 (0–1000)

Default State Icon:

☑ Squad Active

Sound Fx
☐ Goal
☑ Fire
☑ Die

MISCELLANEOUS

☐ Agent is Auto-Refueller

Fuel Tank: 1000

Flag Icon: 0

Path Width: 0

SA Lockout Time: 0

Squad # 10

USMC Patrol 4

Default State

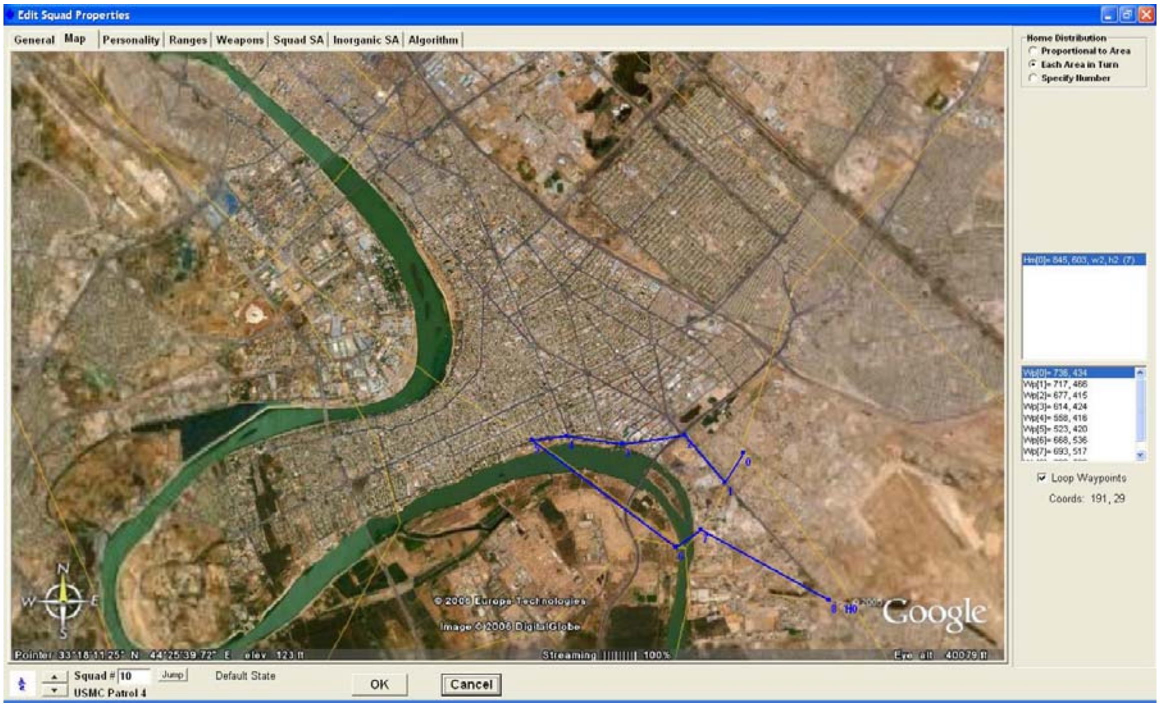
Figure 88: Squad Properties Menu Window

General Control Window

The General window allows you to name each squad, enter the number of agents, and allocate fuel (not used for this simulation). The copy squad button is the most useful feature of the simulation, because all squad properties (communications, weapons, ranges, etc.) are transferred.

Map

The map window allows the user to determine the squad's starting point (with a user-defined region of uncertainty so that each time the simulation is reset, the squad starts at a different location). As shown in Figure 89 the waypoints for the squad to transit are also available. Inserting waypoints is as easy as a left mouse click. The only difficulty in selecting waypoints is the agents traverse the waypoints in reverse order.



Home Distribution
○ Proportional to Area
● Each Area in Turn
○ Specify Number

Hm[0]= 845, 603, w2, h2 (7)

Wp[0]= 736, 434
Wp[1]= 717, 466
Wp[2]= 677, 415
Wp[3]= 614, 424
Wp[4]= 558, 416
Wp[5]= 523, 420
Wp[6]= 668, 536
Wp[7]= 693, 517

☑ Loop Waypoints

Coords: 191, 29

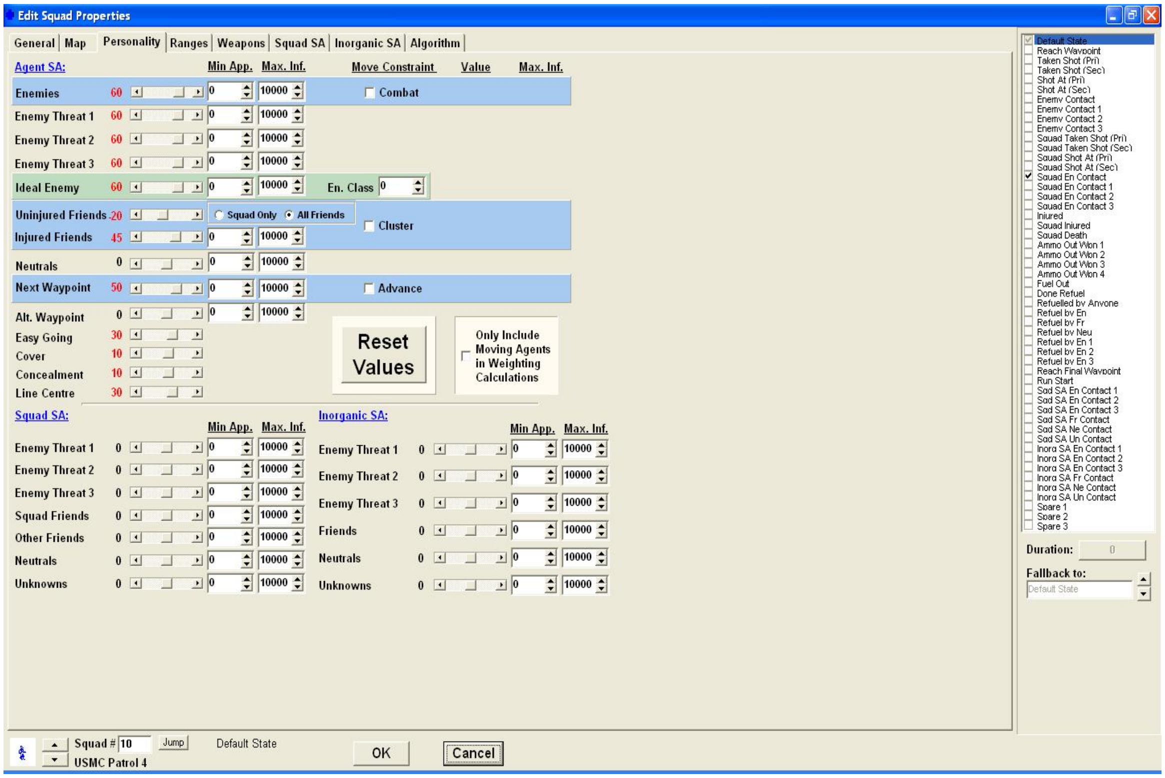
Squad # 10
USMC Patrol 4
Default State

Figure 89: MANA Map Window

Personality

The personality window is what gives the simulation its agent-based behavior. As shown in Figure 90, this screen allows the user to give each agent relative behaviors for Enemy contact, including three separate enemy threats and an "Ideal Enemy" (i.e., a tank for a Javelin gunner). Tendency towards the enemy and blue forces (either injured or uninjured), the next waypoint in series and Cover and Concealment are included. Variation from direct routing is adjusted through the "Line Center" slide bar.

Tendency toward enemy engagement can be adjusted from -100 to +100, with the two extremes representing complete retreat and charging the enemy respectively. Each squad has a threat attribute in the Range window which is realized upon detection (once the entity is detected by the enemy, the enemy recognizes what threat class the entity represents). This allows a separate response for each of the three enemy threats. Also included are adjustments for tendencies based on proximity to another agent (i.e., do not apply this attribute to agents within XX units (Min App), or apply this weighting to agents within YY units (Max Inf)). The cluster option prevents agents from congregating within a small area by applying the opposite tendency towards aggregation when XX agents are present. This attribute was used only during Enemy Contact states (discussed later). Situational awareness tendencies were not used in this simulation.



Agent SA:

		Min App.	Max. Inf.	Move Constraint	Value	Max. Inf.
Enemies	60	0	10000	☐ Combat		
Enemy Threat 1	60	0	10000			
Enemy Threat 2	60	0	10000			
Enemy Threat 3	60	0	10000			
Ideal Enemy	60	0	10000	En. Class 0		
Uninjured Friends	-20	○ Squad Only ● All Friends		☐ Cluster		
Injured Friends	45	0	10000			
Neutrals	0	0	10000			
Next Waypoint	50	0	10000	☐ Advance		
Alt. Waypoint	0	0	10000			
Easy Going	30					
Cover	10					
Concealment	10					
Line Centre	30					

☐ Only Include Moving Agents in Weighting Calculations

Squad SA:

		Min App.	Max. Inf.
Enemy Threat 1	0	0	10000
Enemy Threat 2	0	0	10000
Enemy Threat 3	0	0	10000
Squad Friends	0	0	10000
Other Friends	0	0	10000
Neutrals	0	0	10000
Unknowns	0	0	10000

Inorganic SA:

		Min App.	Max. Inf.
Enemy Threat 1	0	0	10000
Enemy Threat 2	0	0	10000
Enemy Threat 3	0	0	10000
Friends	0	0	10000
Neutrals	0	0	10000
Unknowns	0	0	10000

- ☑ Default State
- ☐ Reach Waypoint
- ☐ Taken Shot (Pri)
- ☐ Taken Shot (Sec)
- ☐ Shot At (Pri)
- ☐ Shot At (Sec)
- ☐ Enemy Contact
- ☐ Enemy Contact 1
- ☐ Enemy Contact 2
- ☐ Enemy Contact 3
- ☐ Squad Taken Shot (Pri)
- ☐ Squad Taken Shot (Sec)
- ☐ Squad Shot At (Pri)
- ☐ Squad Shot At (Sec)
- ☑ Squad En Contact
- ☐ Squad En Contact 1
- ☐ Squad En Contact 2
- ☐ Squad En Contact 3
- ☐ Injured
- ☐ Squad Injured
- ☐ Squad Death
- ☐ Ammo Out Wpn 1
- ☐ Ammo Out Wpn 2
- ☐ Ammo Out Wpn 3
- ☐ Ammo Out Wpn 4
- ☐ Fuel Out
- ☐ Done Refuel
- ☐ Refuelled by Anyone
- ☐ Refuel by En
- ☐ Refuel by Fr
- ☐ Refuel by Neu
- ☐ Refuel by En 1
- ☐ Refuel by En 2
- ☐ Refuel by En 3
- ☐ Reach Final Waypoint
- ☐ Run Start
- ☐ Sqd SA En Contact 1
- ☐ Sqd SA En Contact 2
- ☐ Sqd SA En Contact 3
- ☐ Sqd SA Fr Contact
- ☐ Sqd SA Ne Contact
- ☐ Sqd SA Un Contact
- ☐ Inorg SA En Contact 1
- ☐ Inorg SA En Contact 2
- ☐ Inorg SA En Contact 3
- ☐ Inorg SA Fr Contact
- ☐ Inorg SA Ne Contact
- ☐ Inorg SA Un Contact
- ☐ Spare 1
- ☐ Spare 2
- ☐ Spare 3

Duration: 0

Fallback to: Default State

Squad # 10

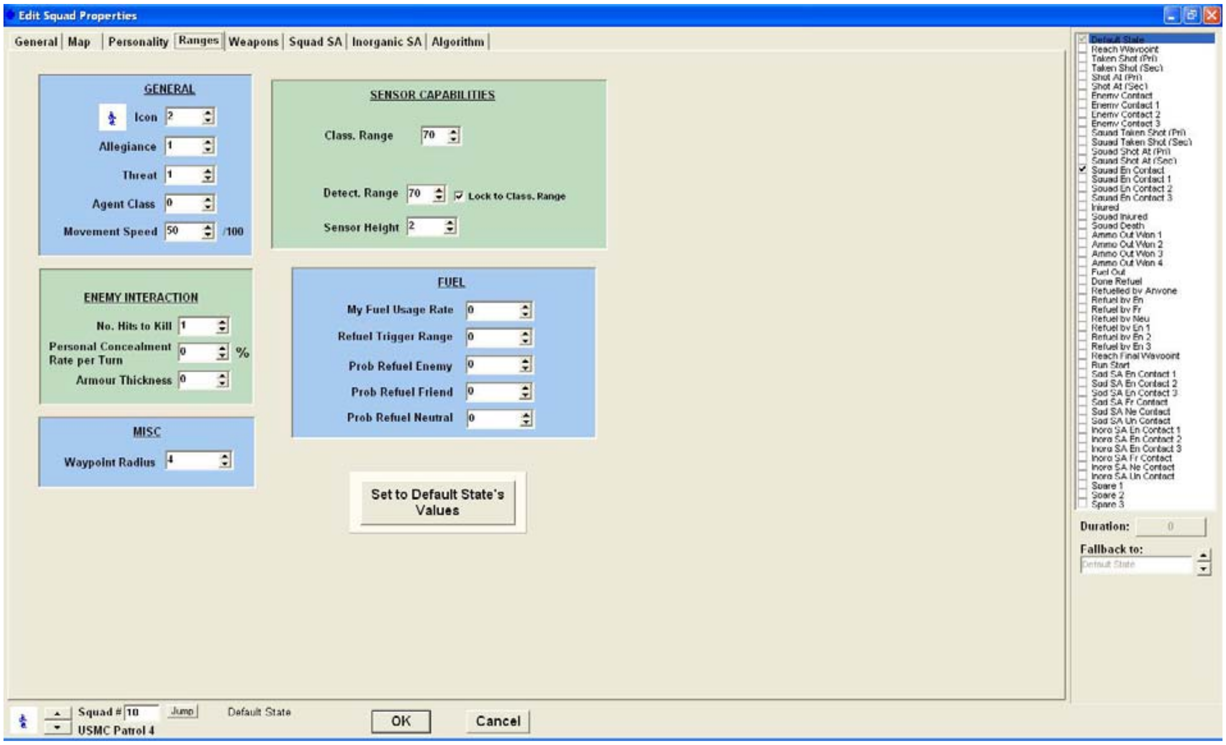
USMC Patrol 4

Default State

Figure 90: MANA Squad Properties Menu Window

States

Inherent in MANA is the use of trigger states. Trigger states are transitory states of a user-specified duration that elicit a specific behavior. As shown in Figure 91, there are dozens of trigger states, and separate controls for each of the Personality, Range and Weapons windows. Because of the exponential increase in complexity with additional trigger states, the simulation uses two states: the default state for patrolling, and the Enemy Contact state for actual engagements with enemy agents (for both the red and blue forces). Each state allows separate settings, which may lead to confusion when transiting states. Care must be taken to document and understand state changes and how they affect agent behavior.



GENERAL
Icon 2
Allegiance 1
Threat 1
Agent Class 0
Movement Speed 50 /100

SENSOR CAPABILITIES
Class. Range 70
Detect. Range 70 ☑ Lock to Class. Range
Sensor Height 2

ENEMY INTERACTION
No. Hits to Kill 1
Personal Concealment Rate per Turn 0 %
Armour Thickness 0

FUEL
My Fuel Usage Rate 0
Refuel Trigger Range 0
Prob Refuel Enemy 0
Prob Refuel Friend 0
Prob Refuel Neutral 0

MISC
Waypoint Radius 4

- ☑ Default State
- ☐ Reach Waypoint
- ☐ Taken Shot (Pri)
- ☐ Taken Shot (Sec)
- ☐ Shot At (Pri)
- ☐ Shot At (Sec)
- ☐ Enemy Contact
- ☐ Enemy Contact 1
- ☐ Enemy Contact 2
- ☐ Enemy Contact 3
- ☐ Squad Taken Shot (Pri)
- ☐ Squad Taken Shot (Sec)
- ☐ Squad Shot At (Pri)
- ☐ Squad Shot At (Sec)
- ☑ Squad En Contact
- ☐ Squad En Contact 1
- ☐ Squad En Contact 2
- ☐ Squad En Contact 3
- ☐ Injured
- ☐ Squad Injured
- ☐ Squad Death
- ☐ Ammo Out Wpn 1
- ☐ Ammo Out Wpn 2
- ☐ Ammo Out Wpn 3
- ☐ Ammo Out Wpn 4
- ☐ Fuel Out
- ☐ Done Refuel
- ☐ Refuelled by Anyone
- ☐ Refuel by En
- ☐ Refuel by Fr
- ☐ Refuel by Neu
- ☐ Refuel by En 1
- ☐ Refuel by En 2
- ☐ Refuel by En 3
- ☐ Reach Final Waypoint
- ☐ Run Start
- ☐ Sqd SA En Contact 1
- ☐ Sqd SA En Contact 2
- ☐ Sqd SA En Contact 3
- ☐ Sqd SA Fr Contact
- ☐ Sqd SA Ne Contact
- ☐ Sqd SA Un Contact
- ☐ Inorg SA En Contact 1
- ☐ Inorg SA En Contact 2
- ☐ Inorg SA En Contact 3
- ☐ Inorg SA Fr Contact
- ☐ Inorg SA Ne Contact
- ☐ Inorg SA Un Contact
- ☐ Spare 1
- ☐ Spare 2
- ☐ Spare 3

Duration: 0
Fallback to: Default State

Squad # 10
USMC Patrol 4
Default State

Figure 91: MANA Trigger States Menu Window

Ranges

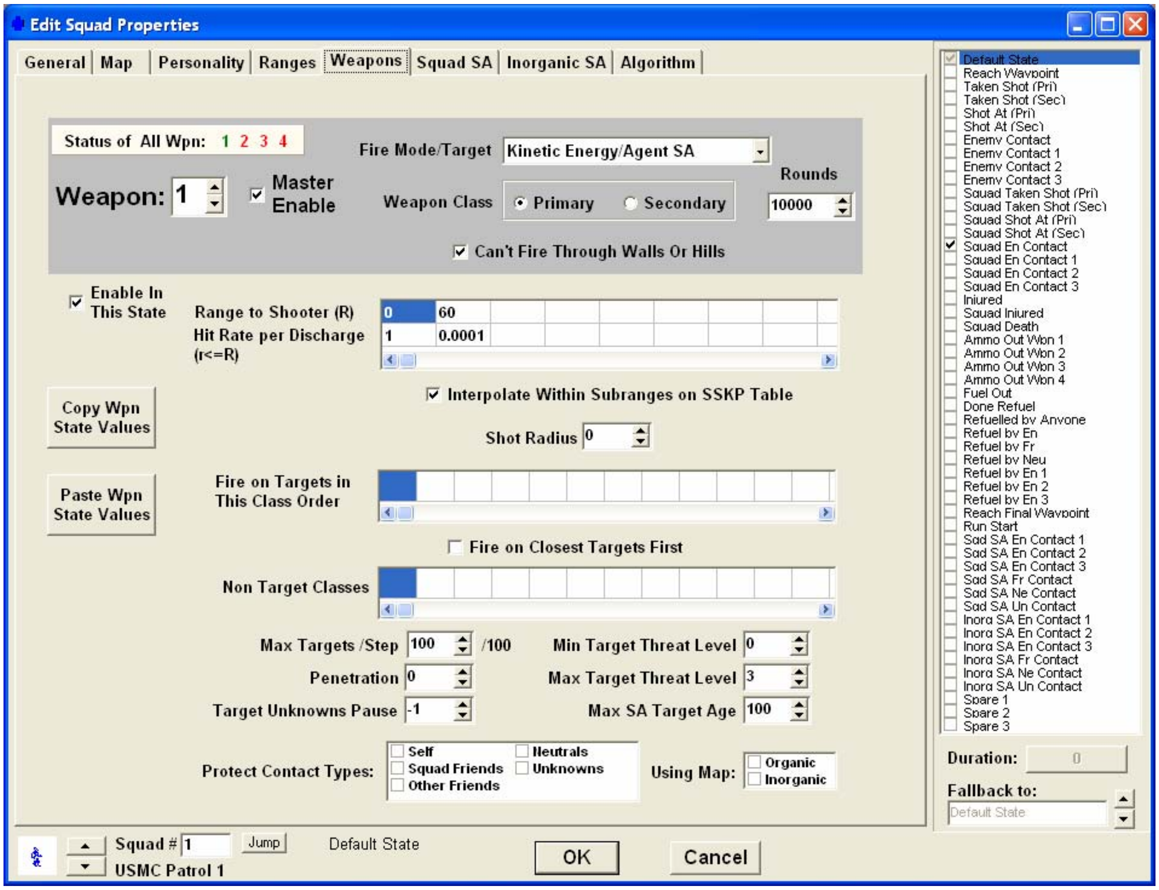
The ranges window allows the user to select the agent icon for each trigger state. This is useful for differentiating which state the agent is in during a simulation. The team's urban scenario used a patrolling (Default) and engagement (Enemy Contact) icon. Allegiance is either White (neutral), Red

(Enemy) or Blue (Friendly). Only red and blue are represented in our simulation. Threat classes range from 0 to 9999, although only threat classes 1 through 3 are available for specific trigger state response. Agent class is used to determine order of engagement for enemy forces (i.e., target priority). Movement speed is based on a per time unit basis (i.e., 100/100 is 1 step per time unit). The danger of using any number greater than 100/100 is agents may then be able to step through walls which are 1 unit thick within a single time step. Typical foot patrol speeds of up to six miles per hour yield a speed of between one half (50/100) and one (100/100) for each time step. Each time step is equivalent to one minute.

Enemy interaction in the form of hits-to-kill, % concealment per turn and Armor are included as well. Percent concealment per turn represents a cumulative concealment for the agent on a time-step basis. In other words, 50% concealment after 2 time steps is the equivalent of 25% concealment ((1-.5)^2). Armor thickness is measured in millimeters. Agents were given either a single or two shot hit-to-kill based upon body armor and support (medical, etc.). Neither percent concealment nor armor attributes were used in the simulation.

Weapons

Available weapons for each agent include kinetic energy and indirect fire weapons. Also included are options for agent, squad or inorganic situational awareness cueing (weapons firing using outside sensors). As shown in Figure 92, up to four weapons may be defined for use in each trigger state. The JFS simulation used only weapon 1 and a single trigger state (default). Each agent was given nearly unlimited ammunition (10,000 rounds). The Range to Shooter (R) table allows for decreasing P_k with increasing range, with the ability to linearly interpolate between two values. Soldier agents in the simulation were guaranteed a hit at zero range, and a near-zero probability of hit at 1,000 yards (3,000 feet or 60 distance units). Priority order and non-target classes may be entered as well. The remaining settings for target engagement capability, penetration and threat levels were not used.



Status of All Wpn: 1 2 3 4

Weapon: 1

☑ Master Enable

Fire Mode/Target: Kinetic Energy/Agent SA

Weapon Class: ● Primary ○ Secondary

Rounds: 10000

☑ Can't Fire Through Walls Or Hills

☑ Enable In This State

Range to Shooter (R)	0	60
Hit Rate per Discharge (r<=R)	1	0.0001

☑ Interpolate Within Subranges on SSKP Table

Shot Radius: 0

Fire on Targets in This Class Order

☐ Fire on Closest Targets First

Non Target Classes

Max Targets /Step: 100 /100

Penetration: 0

Target Unknowns Pause: -1

Min Target Threat Level: 0

Max Target Threat Level: 3

Max SA Target Age: 100

Protect Contact Types: ☐ Self ☐ Neutrals ☐ Squad Friends ☐ Unknowns ☐ Other Friends

Using Map: ☐ Organic ☐ Inorganic

☑ Default State

☑ Squad En Contact

Duration: 0

Fallback to: Default State

Squad # 1

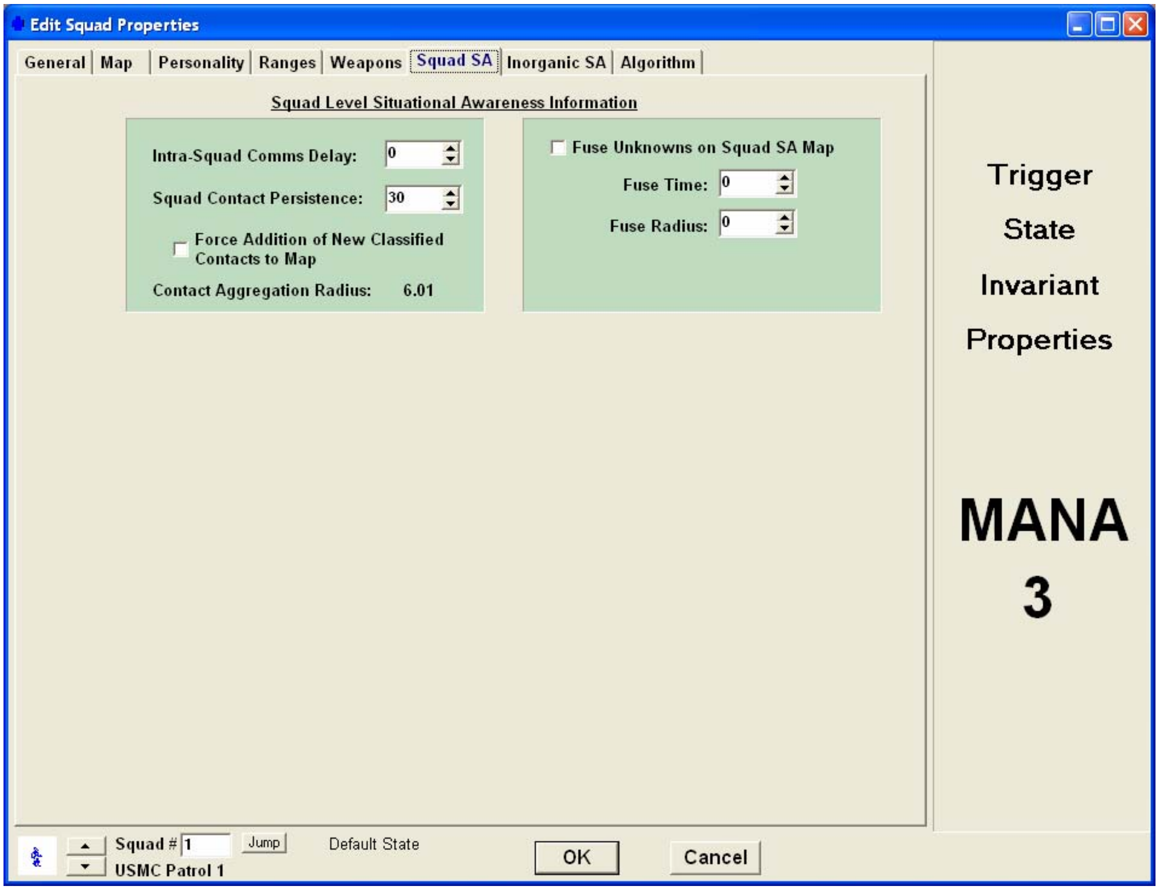
USMC Patrol 1

Default State

Figure 92: MANA Weapons Window

Squad SA

As illustrated in Figure 93, situational awareness for the squad is composed of a communications delay within the squad and contact persistence. All values were left at default (0 and 30, respectively).



Squad Level Situational Awareness Information

Intra-Squad Comms Delay: 0

Squad Contact Persistence: 30

☐ Force Addition of New Classified Contacts to Map

Contact Aggregation Radius: 6.01

☐ Fuse Unknowns on Squad SA Map

Fuse Time: 0

Fuse Radius: 0

Squad # 1

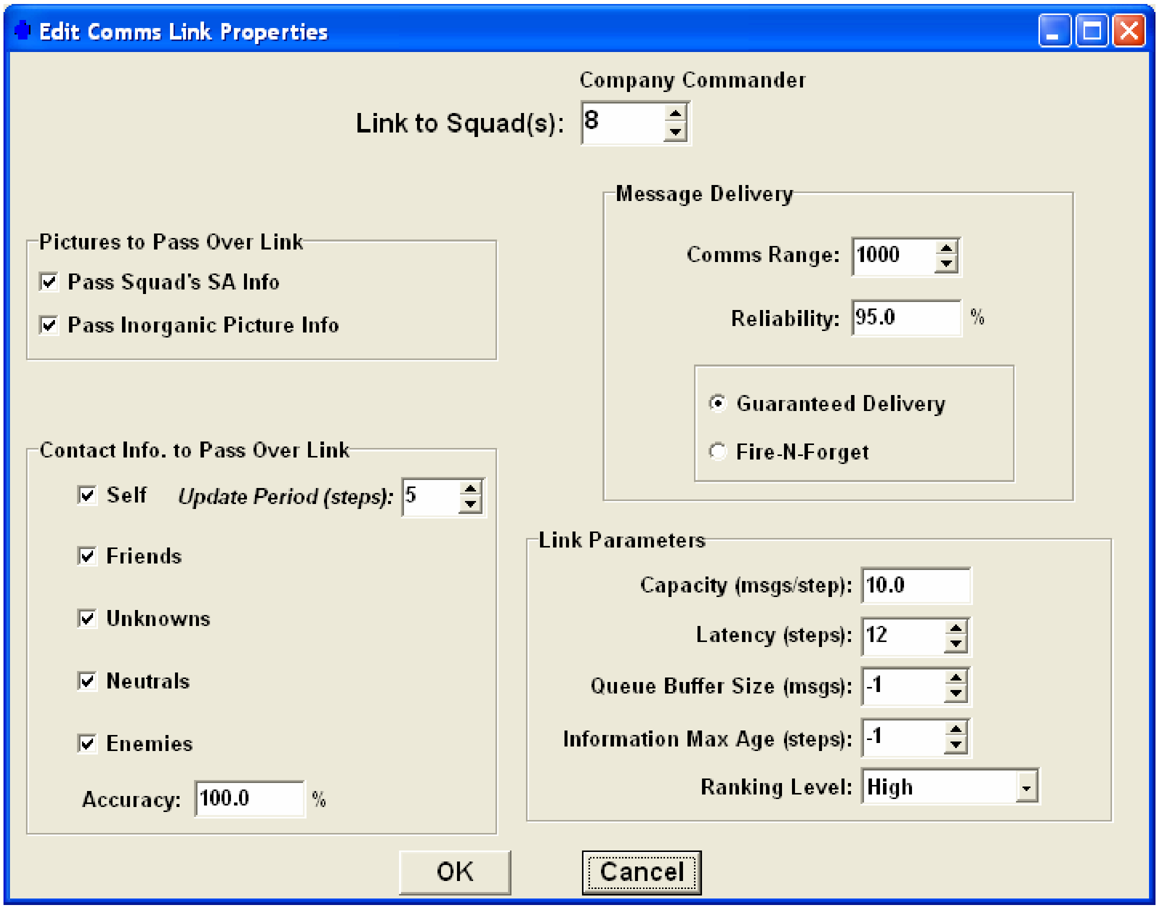
USMC Patrol 1

Default State

Figure 93: MANA Squad Situational Awareness (SA) Window

Inorganic SA

Extensive use was made of the Inorganic SA window. Communication between squads is entirely controlled by the matrix of allowed communications shown in Figure 94. Communication implies situational awareness to the extent that contact information is passed over the communications link as shown above. Message delivery can be made in either a Fire-and-Forget context, or in the case of this simulation, an acknowledged receipt (Guaranteed Delivery). Accuracy and reliability, as well as parameters for latency and message memory can be changed to suit the scenario.



Company Commander

Link to Squad(s): 8

Pictures to Pass Over Link

☑ Pass Squad's SA Info

☑ Pass Inorganic Picture Info

Contact Info. to Pass Over Link

☑ Self *Update Period (steps):* 5

☑ Friends

☑ Unknowns

☑ Neutrals

☑ Enemies

Accuracy: 100.0 %

Message Delivery

Comms Range: 1000

Reliability: 95.0 %

● Guaranteed Delivery

○ Fire-N-Forget

Link Parameters

Capacity (msgs/step): 10.0

Latency (steps): 12

Queue Buffer Size (msgs): -1

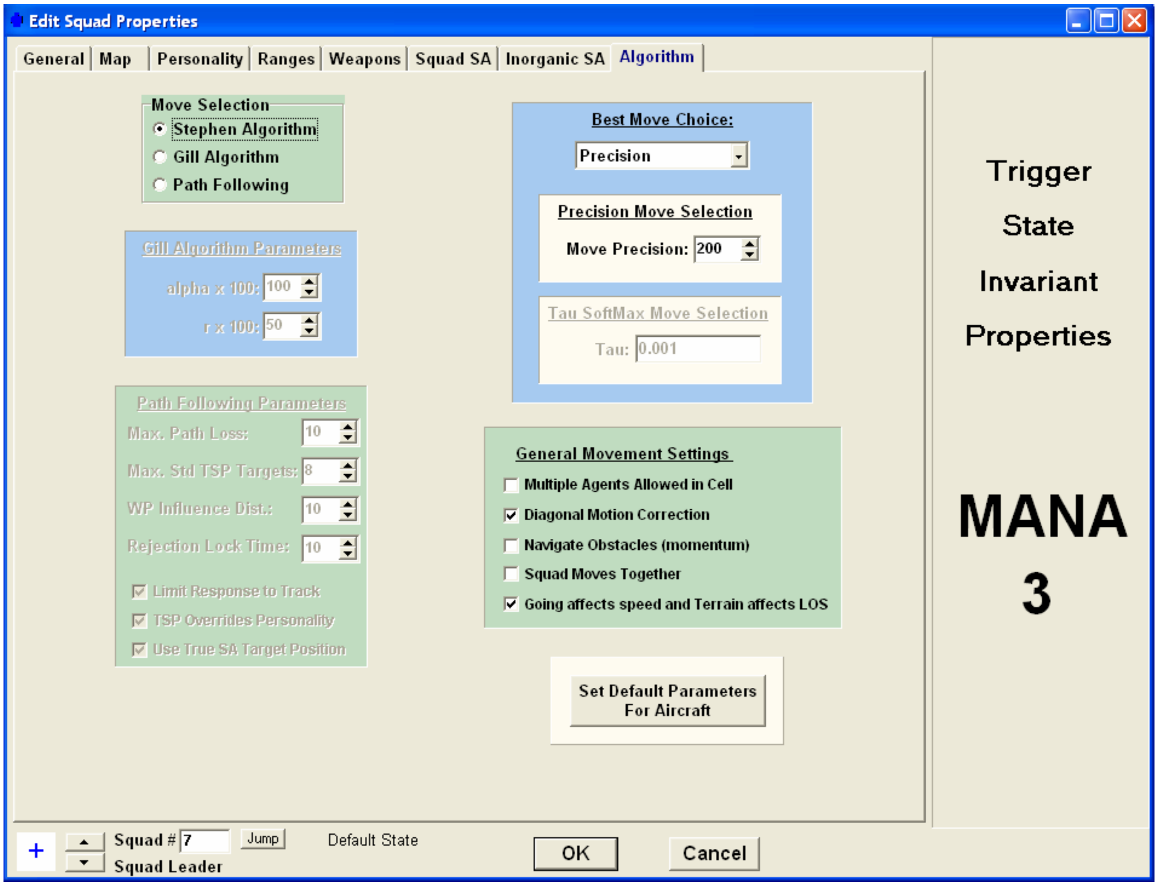
Information Max Age (steps): -1

Ranking Level: High

Figure 94: MANA Squad Communications Window

Algorithm

The algorithm window shown in Figure 95 was left at default settings for the simulation (Stephen Algorithm) as changing the algorithm had little effect on the outcome of multiple simulation runs.



Move Selection
● Stephen Algorithm
○ Gill Algorithm
○ Path Following

Gill Algorithm Parameters
alpha x 100: 100
r x 100: 50

Path Following Parameters
Max. Path Loss: 10
Max. Std TSP Targets: 8
WP Influence Dist.: 10
Rejection Lock Time: 10
☑ Limit Response to Track
☑ TSP Overrides Personality
☑ Use True SA Target Position

Best Move Choice: Precision

Precision Move Selection
Move Precision: 200

Tau SoftMax Move Selection
Tau: 0.001

General Movement Settings
☐ Multiple Agents Allowed in Cell
☑ Diagonal Motion Correction
☐ Navigate Obstacles (momentum)
☐ Squad Moves Together
☑ Going affects speed and Terrain affects LOS

Squad # 7
Squad Leader
Default State

Figure 95: MANA Algorithm Window

Conclusion

In summary, the MANA simulation provided the project with a means to test agent behavior in a specific, controlled environment in order to draw conclusions about the efficacy of each of the alternatives. A summary of simulation settings is shown below in Table 32.

		Wpt 0		Tendencies (Default/Contact)													
ne	# Agents	Map X	Map Y	Enemies	Uninj Friends	Inj Friends	Next Wpt	Easy Going	Cover	Conceal	Threat	Agent Class	Speed	Hits to Kill	Class/Det Range	Weapon Type	Wpn Rng
Sqd 1	7	778	321	60/80	-20/20	45/50	50/0	30/30	10/50	10/50	1	1	50/100	2	70/75	KE/Sqd SA	60
Sqd 2	7	810	148	60/80	-20/20	45/50	50/0	30/30	10/50	10/50	1	1	50/100	2	70/75	KE/Sqd SA	60
Sqd 3	7	390	60	60/80	-20/20	45/50	50/0	30/30	10/50	10/50	1	1	50/100	2	70/75	KE/Sqd SA	60
Sqd 4	7	845	603	60/80	-20/20	45/50	50/0	30/30	10/50	10/50	1	1	50/100	2	70/75	KE/Sqd SA	60
Arty 1	6	912	252	100/100	0/0	0/0	0/0	0/0	10/50	10/50	3	2	0	5	70/75	HE/Inorg SA	700
Arty 2	6	201	550	100/100	0/0	0/0	0/0	0/0	10/50	10/50	3	2	0	5	70/75	HE/Inorg SA	700
Sqd 1	5	642	311	-50/100	0/100	0/0	0/0	0/0	30/30	60/30	1	1	50/100	1	74/80	KE/Agent SA	50
Sqd 2	5	560	355	-50/100	0/100	0/0	0/0	0/0	30/30	60/30	1	1	50/100	1	74/80	KE/Agent SA	50
Sqd 3	5	552	253	-50/100	0/100	0/0	0/0	0/0	30/30	60/30	1	1	50/100	1	74/80	KE/Agent SA	50
Sqd 4	5	142	286	-50/100	0/100	0/0	0/0	0/0	30/30	60/30	1	1	50/100	1	74/80	KE/Agent SA	50
Sqd 5	5	405	340	-50/100	0/100	0/0	0/0	0/0	30/30	60/30	1	1	50/100	1	74/80	KE/Agent SA	50
Sqd 6	5	614	538	-50/100	0/100	0/0	0/0	0/0	30/30	60/30	1	1	50/100	1	74/80	KE/Agent SA	50
Sqd 7	5	899	443	-50/100	0/100	0/0	0/0	0/0	30/30	60/30	1	1	50/100	1	74/80	KE/Agent SA	50
niper 1	1	619	193	-50/100	0/100	0/0	0/0	0/0	30/30	60/30	2	2	0	2	71/80	KE/Squad SA	70
niper 2	1	385	528	-50/100	0/100	0/0	0/0	0/0	30/30	60/30	2	2	0	2	71/80	KE/Squad SA	70
niper 3	1	264	222	-50/100	0/100	0/0	0/0	0/0	30/30	60/30	2	2	0	2	71/80	KE/Squad SA	70
Sqd	1	905	167	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0	0	0	3	10/10	None	N/A
Co.	1	908	166	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0	0	0	3	10/10	None	N/A
Btn	1	905	167	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0	0	0	3	10/10	None	N/A
Bde	1	905	167	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0	0	0	3	10/10	None	N/A
AGTF	1	905	167	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0	0	0	3	10/10	None	N/A
JFC	1	905	167	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0	0	0	3	10/10	None	N/A
BCD	1	905	167	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0	0	0	3	10/10	None	N/A
SCC	1	905	167	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0	0	0	3	10/10	None	N/A

Table 32: MANA summary of simulation settings

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3. TRADOC Analysis Center-Monterey
   Naval Postgraduate School
   Monterey, CA

5. Joint Fires Integration and Interoperability Team (JFIIT)
   Eglin AFB, FL

6. Air Force Institute of Technology (AFIT)
   Graduate School of Systems Engineering (AFIT/ENY)
   Wright-Patterson AFB, OH