"Raytheon Reference Architecture (RA): Enabling Timely & Affordable Customer Solutions" Paper #040

Topic 1: C2 Concepts, Theory, and Policy

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Raytheon Reference Architecture (RA): Enabling Timely & Affordable Customer Solutions

Abstract

The complexity of Command and Control in today's information-driven world demands robust, well designed systems to orchestrate the timely exchange of information, employment of resources, and collaboration between units. Customers are demanding architecture-based solutions for their mission needs. Raytheon has made significant investments in a corporate level, enterprise-wide initiative called RayMAP (Raytheon Mission Architecture Program) to respond to these demands. RayMAP coordinates Reference Architecture (RA) efforts across multiple business units and programs. These RAs are being used to promote commonality, reuse, interoperability, increased responsiveness and affordability in systems and enterprises. Using the Raytheon Enterprise Architecture Process (REAP), standardized architectures can be defined, described, evolved, and assessed throughout Raytheon and was used to develop several RAs. A key Raytheon RA is the Command and Control Reference Architecture (C2 RA) developed using REAP and an activity based methodology. C2 RA artifacts have been captured in the Unified Modeling Language using Rhapsody as a modeling tool. The C2 RA is easily tailored, is extensible, and can be applied to Department of Defense (DoD) and non-DoD situations and solutions. This paper describes the process Raytheon used to tailor and evolve the C2 RA to build more timely and affordable customer solutions, including lessons learned.

Keywords: Command and Control, RayMAP, Architecture, Reference Architecture, Unified Modeling Language

1.0 Background: Architecting and Reference Architectures

1.1 More than ever, today's rapidly changing, and increasingly complex systems demand quality architecture development time prior to detailed design and implementation. Experience shows the benefits of multiple models (views) of the system along with a consistent, structured approach for describing and developing these systems. Architecture development benefits customers by helping to define the problem space, validating needs and requirements, and providing a platform for sharing ideas, aids in system development by concisely and comprehensively describing the system's architecture to the developers and maintenance engineers, and facilitates technology transfer by fostering reuse of domain architectural styles and patterns.

The complexity of Command and Control in today's information-driven world demands robust, well designed systems to orchestrate the timely exchange of information, employment of resources, and collaboration between units. Command and Control systems cry out for architected solutions. The purpose of this paper is to share with the Command and Control community at large Raytheon's approach of using a Reference Architecture (RA) for Command and Control systems, how this RA was applied for a specific application, the challenges of modeling a C2 system using an RA, along with lessons learned in using RAs.

1.2 What is the *architecture* of a system? Some industry definitions include:

- **U.S. Department of Defense Architecture Framework:** An architecture description is a representation of a defined domain, as of a current or future point in time, in terms of its component parts, what those parts do, how the parts relate to each other, and the rules and constraints under which the parts function. [DoDAF-04a]
- **ANSI-IEEE 1471-2000:** The fundamental organization of a system embodied in its components, their relationships to each other and to the environment, and the principles guiding its design and evolution. [IEEE1471-00]
- **Object Management Group's Model Driven Architecture (MDA) Guide, Version 1.0.1:** The *architecture* of a system is a specification of the parts and connectors of the system and the rules for the interactions of the parts using the connectors. [MDA-03]
- **Enterprise Architecture:** The interrelation and integration of a business architecture and technical architecture, including as-is and to-be states with migration plan(s). [Raytheon REAP]

1.3 Common themes across architecture definitions are:

- A complex entity is scoped and partitioned into pieces with specified roles/activities/functions
- Interfaces and rules are established between the parts internal to the complex entity
- Interfaces and rules are established between the internal parts and parts external to the complex entity
- Parts, activities, rules, and interfaces must evolve over time

1.4 What is a Reference A*rchitecture?* A Reference Architecture is a template, as well as a high-level system design free of implementation details. It provides reusable solutions, promotes interoperable designs, serves as a straw man architecture for a particular domain, reduces potential duplication of effort, facilitates compliance with policies, incorporates lessons learned from previous use, and reduces development time and risk.

2.0 Raytheon Investments — RayMAP – Raytheon Mission Architecture Program

2.1 The Raytheon Mission Architecture Program (RayMAP) is Raytheon's response to customer demands for architected solutions. RayMAP is made up of several elements that collectively provide the foundation for solid, disciplined architecture capabilities (see Figure 1). A family of RAs is being used to promote commonality, reuse, interoperability, increased responsiveness and affordability in systems and enterprises. The initial Reference Architecture focus of RayMAP was for a command and control systems, and has expanded to include hard real time sensors and effectors (e.g. missiles, sensors, fires control, etc.). The C2 Reference Architecture (C2 RA) was developed using the Raytheon Enterprise Architecture Process (REAP) and the Activity Based Methodology (ABM). Architecture artifacts have been captured in the Unified Modeling Language (UML) using Rhapsody and System Architect modeling tools. Other RayMAP initiatives include the establishment of a corporate-level Architecture Review Board, a company-wide architecture repository, a method for giving architects across Raytheon access to high powered COTS architecture tools, as well as leadership for the Raytheon Certified Architecture Program (RCAP).

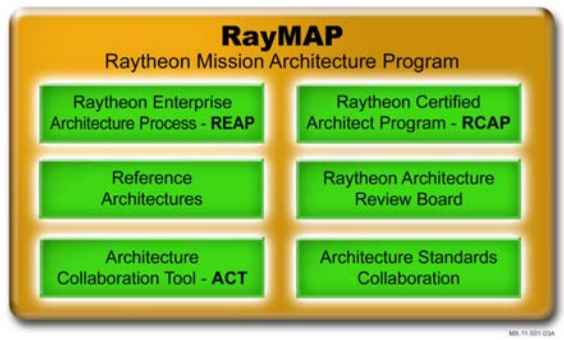

Figure 1 Elements of Raytheon's Mission Architecture Program

2.2 RayMAP Elements

<u>Raytheon Enterprise Architecture Process (REAP):</u> REAP is the company-wide, standards-based architecting process which includes both technical and non-technical aspects of addressing a customer's problem. The first stages of REAP are focused on context, need, mission, operations, etc. The entire REAP capability is available internally to Raytheon via the Integrated Product Development System since 2002. The most current revision (G) was published in November 2007 and includes 60 subprocesses to guide our architects from "enterprise understanding" through "architecture validation".

<u>Raytheon Certified Architect Program (RCAP):</u> RCAP is the company-wide certification program for systems and enterprise architects. Sponsored by Raytheon's Corporate Vice President of Engineering, Technology, and Mission Assurance, Taylor Lawrence, approximately 240 senior engineers are currently enrolled in this rigorous program which began in January 2004. As of February 2008, sixty two engineers are fully certified. This program is monitored by Raytheon's CEO Bill Swanson and Raytheon's Board of Directors.

Reference Architectures (RAs): These partially populated architecture 'templates' have been developed across Raytheon over the past several years. Several of these RAs exist at both the business unit level and at the corporate level, which include C2 and Hard Real Time.

Architecture Review Board (ARB): The Corporate ARB was established in 2003 and is Raytheon's cross-Business governing body responsible for Raytheon’s architecture initiatives. This group of senior architects from across the company conducts independent architecture reviews for critical pursuits.

Architecture Collaboration Tool: In 2008, an internal Raytheon collaboration environment that includes a repository of RAs and implementation architectures, a national architecture tool server, and an architecture “social networking” capability will be rolled out. This “portal” will provide architects, systems engineers, and other users access to a common framework of information for developing architectures, new capabilities, and systems.

Architecture Standards Collaboration: Raytheon is actively engaged with government and industry architecture standards bodies. As a contributing participant and in some cases, as a leadership role within these various groups, Raytheon provides state of the art architectural guidance and direction. We fold any improvements from these groups back into our REAP architecting process. These groups include:

- Department of Defense Architecture Framework (DoDAF) 2.0 Working Group
- The Open Group Architecture Forum
- Zachman International
- Object Management Group
- System Architecture Forum
- International Council on Systems Engineering System Architecture Working Group

2.3 Recognizing a critical need for architecture solutions in several key areas, Raytheon has invested millions of dollars in recent years on the development of a family of reference architectures. These reference architectures are a (partially populated) set of architecture artifacts for specific domains, incorporating best practices and patterns from Raytheon-developed systems. They provide a starting point for architecting activities within their respective domain areas. Reference architecture initiatives have been funded at both the corporate level and at the business unit levels of Raytheon.

Reference Architectures bridge the gap between Customer-Focused Marketing (CFM) processes and the implementation of domain-specific architectures that build on legacy systems and emerging technologies. Figure 2 illustrates the relationship between customer needs, RAs, simulations, testbeds, and ultimately the objective mission architecture. Modeling and simulation are essential tools to evaluate the effectiveness of reference architectures and the resulting domain-specific architectures. The results of the modeling and simulation effort provide metrics that can be used to eliminate, aggregate or validate the key components, technologies, and relationships. Simulations and testbeds built upon a pedigree of an architecturally sound framework provide more credibility to the customer community reducing costs and risks in the objective architecture (and warfighter systems).

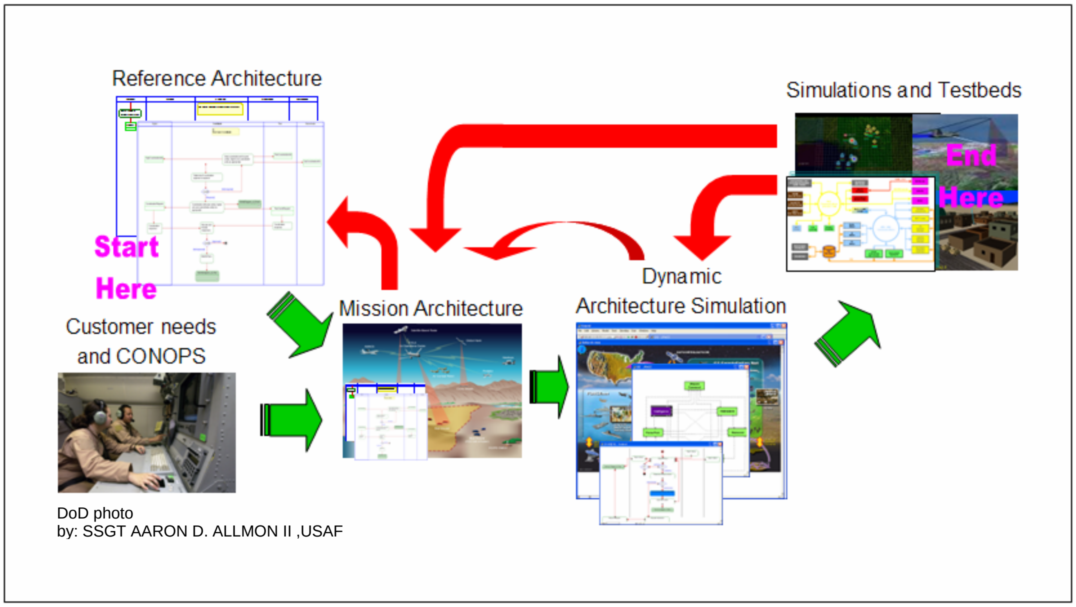

Figure 2 Reference Architectures serve as the foundation for developing new capabilities

3.0 Family of Raytheon Reference Architectures

3.1 Raytheon's Enterprise-wide Reference Architectures were developed and are organized primarily from a temporal standpoint (see Figure 3). The three primary types of Reference Architectures within RayMAP are:

1) Hard Real Time,
2) Decision Real Time, and
3) Non Real Time.

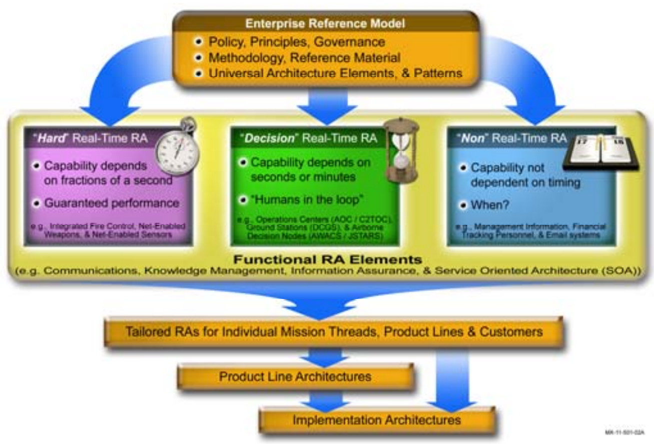

Figure 3 Raytheon family of Reference Architectures

Hard Real Time involves capabilities and systems that must complete key operations within deterministic time periods (typically fractions of a second). Examples of these types of systems include flight control systems used to hit fast moving targets. Decision Real Time typically involves command and control centers with automated systems and humans making key decisions within seconds or minutes. A Combined Air Operations Center (CAOC) includes key staff members and information systems to prosecute an integrated air combat or air support tasking. Non Real Time systems include traditional information management systems, such as logistics management, payroll systems, and the like. An initial version of a Hard Real Time RA has been developed, and work has begun in the area of Non Real Time RAs. The focus of Raytheon's enterprise-wide RAs has been initially on the Decision Real Time arena, due to the ubiquitous nature of Command and Control systems being involved in almost any type of complex system.

4.0 Command and Control Reference Architecture

4.1 According to the Defense Technical Information Center's Joint Electronic Library, Command and Control is defined as:

> **(DOD) 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. Also called C2.**

One could argue that DTIC's definition of Command and Control not only applies to the Department of Defense, but to all organizations, regardless of the nature of their mission. Other organizations have a need for Command and Control capabilities for their planning and critical decision making include, but are not limited to: the banking industry, the oil industry, shipping and transportation, etc.

4.2 The United States Department of Defense (DoD) is challenged with deploying increasingly capable technologies in a world where information is king. As the DoD is further challenged with the potential for increased risk of schedule and cost growth, good Systems Engineering to organize the information, technology, and the people who use them is paramount. The DoD now mandates that contractors express system architectures using the DoDAF (DoD Architectural Framework) to capture capability-driven requirements that are traceable to systems and functions and promote interoperability. Just as traditional architecture uses sectional, elevation, and floor-plan views, DoDAF features a wide spectrum of specification levels to address the Operational, System, and Technical aspects of architecture. Architects use this framework to develop a cost-effective, reusable, and scalable design that meets the needs of their end users.

Figure 4 The Cabinet Room, Cabinet War Rooms. Churchill Museum and Cabinet War Rooms Copyright © 2006 Kaihsu Tai

Looking back fifty years ago, Britain developed, stood up, and orchestrated a complex operation for Command and Control at the Cabinet War Room (see Figure 4). The basic principles of Command and Control are the same as today's high-tech version (see Figure 5): Operations Management, Situational Awareness Management, Intelligence Management, Logistics Management, Sensor Management, Platform Management, Infrastructure Management, Communications Management, and Resource Management. These highly integrated functions must be coordinated without missing a beat to maximize the effectiveness of the overall mission. Of course, the primary difference between the Cabinet War Room and say the National Operations Center at the U.S. Department of Homeland Security (Figure 5) boils down to the speed at which information is transferred from point to point and the amount of information that is transferred. The functions remain the same, but the complexity and the size are what create the need for a disciplined approach at developing these kinds of systems.

4.3 The Raytheon C2 Reference Architecture (C2 RA) facilitates rapid mission systems integration of C2 solutions for DoD, Non-DoD, international Government organizations, and non-governmental organizations. The C2 RA products and the tools used to develop this RA are identified in Appendices A and B. This particular reference architecture has been reviewed by subject matter experts and has been approved by the Raytheon Corporate Architecture Review Board (ARB) for use across Raytheon for new concept generation and proposal development.

Figure 5 Homeland Security National Operations Center. DHS photo

While the C2 RA has been developed with the purpose of making it applicable across domains, we make it a practice to include subject matter experts from a wide variety of domains to validate concepts developed for a new domain.

4.4 One of the goals of developing the C2 RA was to create an architecture that can be applied across different C2 domains from homeland security to disaster response to general war, etc. As a result, the business use cases for the C2 environment start with the common C2 functions applicable to all C2 environments. The definitions of the C2 functions are found in Table 1 and the Node definitions are listed in Table 2.

C2 Function	Description
Planning	Receives op and support plans from commanders; assesses, develops, refines, updates plans
Operations Management	Receives plans from OP; supports decision makers in assessing and storing plans; provides decision aids, alerts, queries, notifications; issues tasking;
Situational Awareness Management	Collects, processes, fuses sensor data; develops, maintains, disseminates track data; generates alerts
Intel Management	Defines ISR collection requirements, requests intelligence information from ISR node; develops, maintains, disseminates threat and target data; nominate targets;
Logistics Management	Maintains assets inventory; monitors consumption rate; determines asset request feasibility; predicts asset re-supply requirements.
Sensor Management	Tasks, monitors, provides status on sensors (collectors)
Effector Management	Manage approved target and engagement lists; maintain and report force unit status; execute lethal and non-lethal force applications
Platform Management	Tasks, monitors, provides status on platforms
Infrastructure Management	Manages infrastructure including core enterprise services and computing infrastructure
Communications Management	Manages communications node including interfaces and communications devices
Resource Management	Manage resources and achieve dynamic C2 decision making by managing the sub-functions provided by sensor manager, effector manager, and platform manager

Table 1 C2 RA C2 Functions

C2 Node	Description
Maneuver	The Maneuver node employs forces to achieve a position of advantage with respect to the enemy (threat) to accomplish the mission.
Logistics	Acquires, supplies, and maintains personnel, equipment, medical, and consumable assets.
ISR	Manages, develops, processes, and publishes intelligence information. In addition, it tasks and controls Sensor Nodes.
Sensor	Collection assets that collect data on the operational environment
Effector	Assets that deliver effects on designated targets
Platform	Assets that are used as vehicles in which sensor node, effector node or both are resided on.
Infrastructure	Net-Centric enterprise services that are common to all nodes.
Communication	Resources that provide communications services to all the nodes.

Table 2 C2 RA C2 Nodes

4.5 There are four general use cases for C2 that serve as foundational templates applicable to any C2 process from homeland security to disaster response to general war: Plan, Direct, Coordinate, and Understand the Environment.

Plan - The Plan use case describes the activities involved in transforming mission requirements from higher authority into actionable plans that will be used direct subordinates in accomplishing the mission. Plans are also used to facilitate coordination of activities with peer organizations.

Direct - The Direct use case identifies activities involved in issuing orders and directions that clearly communicate actions and functions needed to be accomplished, why they need to be accomplished, who will accomplish them, how they will be accomplished, and how results will be reported.

Coordinate - The Coordinate use case identifies activities involved in harmonizing operations and creating synergies among units. Passive coordination is accomplished to inform higher, peer, and subordinate units of activities around them that could impact their situation but require no coordination response from them. Active coordination is accomplished when two or more units must operate directly in concert with each other to achieve designated task(s) or when the action of one unit must cleared by another unit lest the other unit's operations be disrupted or negatively impacted.

Control - The Control use case describes the activities involved in regulating forces and functions to best meet higher authority guidance. Control is necessary to determine the status of organizational effectiveness, identify variance from set standards, and correct deviations from these standards. Ultimately, it provides commanders a means to measure, report, and correct performance.

Inherent in all the general use cases listed above is the requirement for the commander to understand his or her environment as it applies to mission accomplishment. This is an area of special interest sometimes referred to a battle space awareness or situational awareness that is invoked by all the general use cases. Consequently, another general use case is included to highlight a significant area impacting C2 system development and to address architectural completeness and clarification:

Understand Environment - The Understand Environment Use Case describes the activities involved in developing, updating, and publishing the data from which various staffs and organizations visualize the current operational situation. All relevant data is compiled and analyzed to produce the most complete, accurate and relevant operational picture possible. This includes activities associated with planning, tasking and executing sensor tasks; monitoring and controlling sensor resources, including direct control of allocated resources and service requests to non-allocated resources; collecting, processing and fusing sensor reports and data; developing, maintaining, and disseminating track, threat, target, and environment information; generating alerts and cross-cues; compiling and disseminating an operational picture; and supporting collaboration.

4.6 The C2 RA provides an organizational and echelon independent architecture. As explained in the previous section, planning, directing, coordinating, and controlling are common functions to any C2 process. Consequently, in any C2 process, there must be Planner, Director, Coordinator, and Controller roles that address the general C2 functions common to all environments. A particular role player may have one or more roles. In any organization and at any echelon these roles/duties will apply although duty titles will vary.

Raytheon has designed the C2 RA with an open architecture in mind, so that implementing systems can readily apply the full set of Net-Centric Enterprise Solutions for Interoperability

(NESI) design tenets, and specify that the implementing system must follow the NESI design tenets. Through the use of other Reference Architectures in developing the C2 RA and the continued adoption of the C2 RA as a framework for new designs, the open nature of the C2 RA has grown as a necessary product of the collaborative efforts of a company-wide community of use, where consumers apply the same architectural foundation to problems ranging from defeating IED networks to Air Traffic Control and Missile Defense.

4.7 Raytheon also modeled the C2 RA in accordance with the NESI guidance for Services Oriented Architecture (SOA) to promote flexibility and reuse, to enable complex software systems to be composed from stable interfaces, and to promote discoverable interfaces. An SOA is a design style for building flexible, adaptable, distributed-computing environments. Service-oriented design is fundamentally about sharing and reusing functionality across diverse applications. In concert with the C2 RA, Raytheon developed a Service Identification and Definition process to determine how the functions of a system can be aligned as reusable services that can be exposed in an SOA.

The C2 RA has been developed to ensure trusted access to data and services as specified by the DoD Information Strategy. The DoD Information Assurance (IA) Strategy provides the basis for establishing assured information capabilities in the Net Centric Environment (NCE), and Raytheon has built an Information Assurance Reference Architecture specifically to provide design templates for compliance with the DoD IA strategy. This Reference Architecture was consulted in developing the C2 RA to ensure compatibility with the DoD's standards.

A summary of the architectural quality attributes of Raytheon's C2 Reference Architecture are highlighted in Table 3, below:

Quality Attribute	How Achieved	Tatics Used
Interoperability	(1) All C2 functions will utilize common net-centric enterprise services (NCES) e.g., Discovery service, Messaging service, Information service, etc.(2) A common data model based on JC3IEDM will be used by services to exchange data.	Common infrastructure services and common data model used.
Security	Authorization, auditing, and authentication services will be invoked on each transaction to ensure trusted access to the node data and services.	Authentication; Authorization; Auditing
Maintainability	Use layered Service Oriented Architecture to support modularity which facilitates ease of maintenance. In addition, SOA enables new capabilities to be added with minimal impacted to the architecture.	SOA
Scalability	C2 services and their supported services are designed to be networked enabled and distributed services. This allows the services to be load balanced across the network	SOA and distributed architecture

Table 3 C2 RA Architecture Quality Attributes

The C2 RA conceptual data model is based on the Joint Consultation Command & Control Information Exchange Data Model (JC3IEDM), which is the most widely accepted C2 data model. The JC3IEDM is a collaborative effort between the Multilateral Interoperability Program (MIP) and the NATO Data Administration Group (NDAG) that provides a set of information elements, entities, and relations to describe the information exchange requirements within tactical military operations (previously known as the Command & Control Information Exchange Data Model, C2IEDM).

5.0 Applying Raytheon's Command and Control Reference Architecture

5.1 While Raytheon developed a C2 RA in 2006, in 2007 Raytheon teams applied this Reference Architecture to several key Company-Wide and Business Unit specific initiatives and proposals. One specific application is Raytheon's IED Defeat Command and Control architecture. Improvised Explosive Devices (IEDs) are causing fatalities daily to our Coalition Forces, as well as to civilians. We need to put capabilities into the hands of US and Coalition forces in-country to counter and defeat IEDs (Figure 6). Raytheon's CEO Bill Swanson has taken up this cause citing that

Figure 6 Talon robot is ready to detonate an IED in Rawah, US Army photo

Raytheon has the technologies and capabilities across the company to provide effective Warfighter solutions to this situation. Accordingly, Raytheon has established and funded an IED-Defeat (IEDD) Task Force and an IED-Defeat Enterprise Campaign (EC). The IED Defeat C2 architecture Raytheon is developing describes the current situation and offers solutions for overcoming C2-related limitations for defeating IEDs.

5.2 Defeating IEDs is a broad problem space with many facets, which affects all echelons up and down the chain of command from the Executive branch downward. Although some of the results will have applicability across agencies, theaters, and echelons above Corps (EAC), most IED Defeat C2 limitations are manifested at the Brigade and Regiment echelons and below. Most of the expected benefit will be realized at units up through the Battalion. Accordingly, the focus of the IED Defeat C2 Architecture team has been on, but not strictly limited to, those echelons. The IED Defeat C2 Architecture team developed several products in 2007, which are spelled out in Table 4, below.

Products	Description
"As Is" IEDD C2 Architecture	Description of the current situation for C2 pertaining to IEDD
IEDD C2 Capability Gaps	Identification and analysis of shortfalls and opportunities for improvement in IEDD C2
IEDD C2 Solutions	Identification and description of potential solutions to IEDD C2 shortfalls and improvement opportunities that are most relevant to Raytheon capabilities and offer greatest benefit for IEDD. The description of each potential solution represents a "To Be" IEDD C2 Architecture.
Improvements to Raytheon RAs	Suggestions for improvements to the C2 RA and other RAs

Table 4 Raytheon's IED Defeat C2 Architecture focus

6.0 Process of Tailoring the Raytheon Command and Control Reference Architecture

6.1 One of the challenges is to develop an operationally relevant architecture while leveraging the Reference Architectures. A number of steps were taken to leverage the C2 RA, applying and tailoring it to the IED Defeat domain. Within this IED Defeat problem space, a doctrinally correct approach was used, along with well defined military decision making processes.

The purpose of the IEDD C2 Architecture is to define an Enterprise level Command and Control Architecture that applies to the IED-Defeat domain and supports the DoD Net-Centric Environment (NCE) vision. The resulting architecture views and artifacts will be used to engage in critical discussions with key customers with the goal to improve understanding customer needs. Given the severe nature of this problem space with casualties occurring daily, this architecture development includes identifying key capability gaps in order to discover promising solutions that can be deployed rapidly to our warfighters.

6.2 The team began with an instantiation of the C2 RA. Other appropriate RAs, such as Info Assurance and Communications to include the "best of the best" frameworks were selected. After including what was needed and deleting what was not relevant, the architecture was validated for usefulness and extensibility. Using the C2 RA as a starting point, an "As-Is" C2 Architecture was developed to understand how warfighters are currently trying to defeat IEDs (Figure 7). Taking this initial and important step helped the team to restrict the problem space within a manageable boundary. The team subject matter experts (SMEs) who were recently deployed in Iraq or had served our country in the armed forces, previously. These domain subject matter experts helped to apply a doctrinally correct approach using standard military decision making processes ("Find, Fix, Track, Target, Engage, Assess" or F2T2EA, "Observe, Orient, Decide, Act" or OODA, etc). Next, a common taxonomy was established that was unambiguous for our team members. Time spent on this particular task paid big dividends by having a consolidated method of communicating within and outside the team.

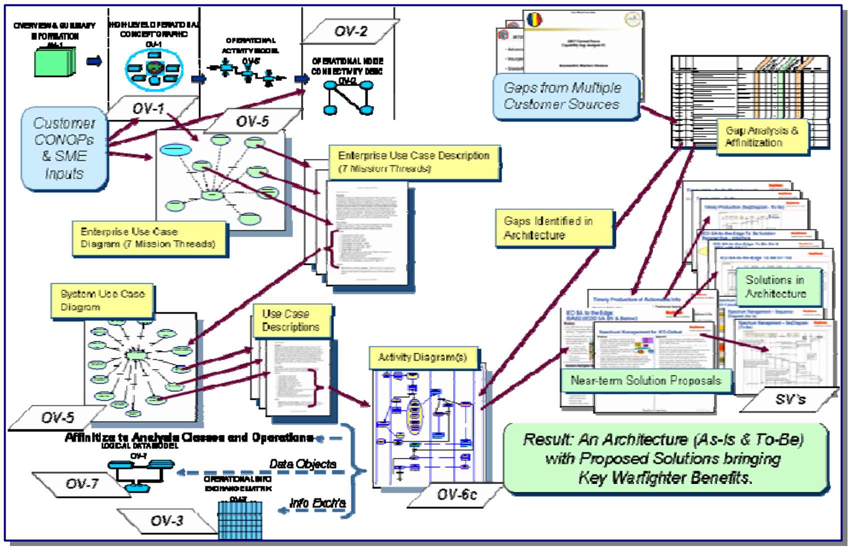

Figure 7 IED Defeat C2 Architecture development process

As one of the first efforts to significantly leverage the Raytheon Reference Architectures (particularly the C2RA), this effort also provided important lessons learned and feedback on how to refine the content and use of the reference architectures in the future.

7.0 Other Applications of C2 RA

7.1 Another area where Raytheon utilized the C2 RA was for a Company-wide initiative to develop an air-to-ground targeting architecture to realize a 5th Generation operational capability using 4th generation platforms by engaging static and moving targets at standoff ranges. Work for this initiative was conducted to ensure the demonstration architecture would be representative of the objective operational capability. Work was also conducted to ensure the models and simulation products were representative of the objective operational capability. This team also assisted in determining key Measure of Effectiveness (MOEs) and Measures of Performance (MOPs) for the mission areas slated for this architecture. Several other initiatives, proposals, and programs that used the C2 RA in 2007 are too numerous to mention in this paper.

8.0 Challenges of Modeling C2

8.1 The architecture discipline seeks to achieve elegant forms, in essence reducing complex problems into addressable parts, but the degree to which these forms address the issue at hand is often not known until systems are built. Hence, DoDAF encourages simulation to verify and validate architectures, but does not mandate or provide constructive guidance for a particular simulation methodology. While it is tempting to think of “simulating architecture,” it is important to define that what we mean by architecture simulations are in fact simulations of the system described by the architecture modeled at an abstract level closely associated with the forms of the architecture itself. In analysis of C2 architectures, there are often behavior details that must be added to the model which exceed the depth of what is described in architectural artifacts, so while tools can be brought to bear on the architecture to simulate the processes, node relationships, and decisions described within, building a useful simulation of a C2 architecture presents its own challenges.

Simulating Command and Control allows analysts to study more efficient patterns of information exchange, optimize the delegation of decision-making authority, and characterize the time allocated to decision-makers. These time characterizations can be used as guidance for real human operators who are conducting time-critical tasks, as well as for planning a distributed workload by allocating the right number of operators to tasks. C2 simulations face unique challenges in the complexity of decisions made, the dynamic nature of human involvement, along with the possibility of human error in judgment.

8.2 Commanders in the field use intuition and experience, Rules of Engagement, and policies to make decisions. Simulating these complex behaviors could quickly turn an architectural assessment study into a major artificial intelligence project, so to control this; we limit the scope or specificity of the simulation. While an image analyst in an Air Defense Center will use his familiarity with missile plumes to make discriminate threats from benign traffic, a simulation must reduce the decision to a random probability. In some cases, these simplifying assumptions are natural, but often it is important to balance the assumptions made in the model with the information that will be collected at the end. If a C2 model is based on a highly deterministic sequence of events, in order to provide useful analysis it would be worthwhile to explicitly model benign and threat targets, with a probability of false-positive detection, and weight the likelihood of correct assessment with pre-intelligence about the launch site. In simulating a very dynamic system of communications for throughput and efficiency, however, a detailed model of threat behavior and identification may not be necessary.

While information system architectures contain clear activity flows and decision points, C2 systems may be less linear. Human operators can instinctively react to situations, and contingency plans can evolve quickly as personnel adapt to changing situations, so that the steps taken on one task might be very different from the next. For example, an image analyst might have a set of tools to zoom, sharpen, crop, rotate, and annotate an image, but he will apply them in a very different sequence depending on the particular task. Modeling people’s behavior inherently introduces variability, making simulation a tough task; often only the nominal cases are described in architecture or CONOPS, or a few illustrative vignettes are laid out. While this is sufficient to convey the essential organizational structure of a C2 system, simulation demands more rigorous detail for each of the test cases. The builder of the simulation must have very complete information, be familiar with the decisions that he is simulating, or cooperate with experts to determine how to correctly model the variability of an operator’s job.

8.3 C2 in many applications is the most time-consuming part of the total system, so a clear understanding of the temporal performance of a C2 organization is critical to overall mission success. Again, the real factors influencing time consumption are many, and for simulation, this must be simplified and modeled statistically. For example, the reaction time of a Dynamic Targeting Cell might depend heavily on how much activity there has been recently in the area of interest, or whether the cell's attention has been focused on a particular location, but rather than explicitly model every event that contributes to the overall decision and compute the reaction time accordingly, we can simply make the overall state of alert and model reaction times variable according to a simple function, and then consider the aggregate effects on total system performance.

No task can perform itself; time in Command and Control is closely related to the actor that performs an action. Often we model resources as a bank of operators who can each conduct tasks interchangeably, but sometimes these operators must juggle several tasks at once, or must shepherd a single job through several tasks. Carefully modeling the overhead involved when human operators multitask can provide useful insights into the operational limitations of a system. Communications can also be a highly strained resource, where the true performance of the system depends on overhead that is best modeled based on empirical observation. While resource contention modeling can be arduous, this can uncover real issues in system scalability or areas where simplified calculations lead to an impractical design.

C2 systems are designed to orchestrate and coordinate resources that are geographically or functionally separated, so the feedback loop between control and response is longer than an organic platform or a person's hand-eye coordination. This means that besides having to move information quickly through many decision points, the C2 network must also minimize error, since there is too much latency to frequently correct mistakes. Error can arise from human mistakes, dropped communications, false identification, and many other causes. When modeling error, one can treat error as an overall metric measured by the simulation to be minimized, but in many cases it is necessary to build error handling into the simulation, such as re-sending messages or firing a second salvo. This can require adding another dimension of complexity to the behavior processes, as nodes in the simulation must now "remember" the decisions they have made and revisit their consequences after a period of time.

The goal of any simulation is to mimic to a certain degree of precision a natural or synthetic phenomenon, while enabling faster trials, more phenomenological control, and development cost reduced by orders of magnitude. In order to use a simulation for study, it is necessary to quantify the performance of a system in order compare different configurations. Modeling C2 is unlikely to be accurate enough to predict real-world performance to a high degree, but comparative studies can help select optimum communications topologies, delegation of command authority, Rules of Engagement, and can also serve as an objective means of comparing several C2 architectures.

9.0 Lessons Learned

9.1 Several programs, project teams, and proposal efforts within Raytheon used the Raytheon C2 Reference Architecture in 2007. These architecture teams have provided the RayMAP team with invaluable feedback, such as: 1) what worked in tailoring the C2 RA, 2) what didn't work in using the RA, 3) additional lessons learned, and 4) suggested areas for improvement. Teams felt having the C2 RA helped them to scope their problem space. Startup time was significantly reduced by having a full set of architectural artifacts, ready to use on "day one" of the project. Another key theme from teams using the C2 RA was having a common set of terminology and taxonomy. Teams also felt having an RA to start off with helped the team focus on the operational side of the problem. Some of the less positive feedback revolved around the fact that the C2 RA was still relatively new in 2007. The C2 RA can be improved in the area of tool import interfaces, training architects in the tailoring of RAs, and having a convenient location within Raytheon to discover, understand, and use RAs. Many of these improvement areas are being addressed in 2008 as part of the RayMAP program. Additional lessons learned can be found in Appendix C.

Conclusion

Since Command and Control is a significant portion of most large scale operations, regardless of the domain or mission area, Raytheon has developed a common, consistent framework for all of its new proposals, initiatives, and programs that require a command and control capability. The company has already used the Command and Control Reference Architecture for several proposals and programs and is incorporating lessons learned into the Reference Architectures and the RA tailoring process. Benefits have been realized having a common framework for command and control by reducing startup times and extensive rework, which equates to a faster time to market, which delivers solutions to customers faster, reducing development costs. Consistent, interoperable designs are one of the key outcomes for our solutions. Raytheon looks forward to engaging with industry and the customer community on this approach to standardizing command and control capabilities through our Reference Architectures.

Raytheon Company, with 2007 sales of $21.3 billion, is a technology leader specializing in defense, homeland security and other government markets throughout the world. With a history of innovation spanning more than 85 years, Raytheon provides state-of-the-art electronics, mission systems integration and other capabilities in the areas of sensing; effects; and command, control, communications and intelligence systems, as well as a broad range of mission support services. With headquarters in Waltham, Mass., Raytheon employs 72,000 people worldwide.

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Appendix A: Raytheon C2 RA Products

Raytheon's C2 RA products are arranged in UML notation and can be applied to a variety of C2 systems and more specialized RAs. All of the C2 RA Model and other artifacts are organized by DoDAF views as described in Table A-1, below.

Architecture Product		Description
Architecture Viewpoint: All		
AV-1	Overview and Summary Information	Scope, purpose, intended users, environment depicted, analytical findings, if applicable
AV-2	Integrated Dictionary	Definitions of all terms used in all products
Architecture Viewpoint: Operational		
OV-1	High-level Operational Concept Graphic	High-level graphical description of operational concept (e.g., high-level organizations, missions, geographic configuration, connectivity)
OV-2	Operational Node Connectivity Description	Operational nodes, activities performed at each node, connectivity & information flow between nodes
OV-3	Operational Information Exchange Matrix	Information Exchange Requirements and related information, which show the express relationships over the basic entities of the operational architecture with a focus on the information flow
OV-4	C2 Roles	Roles associated with C2.
OV-5	Activity Model	Description of the applicable activities associated with the architecture
OV-7	Logical Data Model	Data requirements and business process rules of the architecture's operational view
Architecture Viewpoint: Systems		
SV-1	System Interface Description	Identification of systems and system components and their interfaces, within and between nodes
SV-4	Systems Functionality Description	A list of C2 functions and their relationship
SV-5	Operational Activity to System Function Traceability Matrix	Mapping of system functions back to operational activities
Architecture Viewpoint: Technical		
TV-1	Technical Standards Profile	Extraction of standards that apply to the given architecture

Table A-1 C2 RA DoDAF Views

Appendix B: Tools used to develop Raytheon's C2 Reference Architecture

The following tools were used to develop Raytheon's C2 Reference Architecture:

- Ilogix Rhapsody v6.1
- Telelogic System Architect® v10.7
- Microsoft Office (PowerPoint, Word, Excel)
- Department of Defense Architecture Framework (DoDAF)
- Universal Modeling Language (UML 2.0)

Appendix C: Lessons Learned in tailoring a Reference Architecture

Using the Raytheon C2 Reference Architecture for several initiatives in 2007 provides a combined set of feedback from these Raytheon initiatives: 1) what worked, 2) what didn't work, 3) lessons learned, and 4) suggested RA areas of improvement.

What worked – using the C2 RA in developing a C2 Architecture

1. Having architects on the team with working knowledge of the RA's
2. Assessing the architecture periodically during development for alignment to RA's
3. Using RA alignment to surface issues that must be addressed by the program and architecture team
4. Focusing on solution scalability, distribution, commonality, interoperability
5. Having consistent artifact generation methods and tool usage
6. Having RA examples to look at is useful in stimulating ideas

What didn't work – using the C2 RA in developing a C2 Architecture

1. RA's need to generalize to embrace non-military programs
2. RA's need a more user friendly means of importing data files into architecture tools
3. Need to train architects on the use of RAs
4. Most artifacts are not readily reusable – need RA design modules
5. Some inconsistency in terminology
6. For some applications, the Operational View-5 (Operational Activity Model) was too generic and too high level

Lessons Learned

1. Using the C2 RA helped to bound the IED-D C2 domain
2. Using the C2 RA helped guide the team in development of C2 activities
3. Using the C2 RA helped identify the external interfaces between C2 and non-C2 elements
4. Startup time was significantly reduced
5. Use Case driven approach helped bound the problem space
6. Achieved early alignment with other teams by using the C2 RA
7. Used to establish boundaries between functional groups
8. The C2 RA System View-4 (System Functionality Description) was used directly
9. Architecture workshops used the C2 RA as a foundation and a point of departure
10. The C2 RA definitions used extensively
11. Collaboration and team buy-in is vital to successful and on time completion of work
12. Heavy collaboration through workshops, telecons, and peer reviews aided in the effective use of the C2 RA
13. Having a diverse set of skills involved in the architecture development (Subject Matter Experts, Systems Engineers, Software Engineers, Architects, etc.) ensured a more robust architecture was developed
14. The architecture must be driven by the applicable Concept of Operations (CONOPS)
15. The architecture effort helped to shape the solution

16. Use of the C2 RA helped to identify capability gaps, right from the start
17. Having the C2 RA helped define the scope of planned demonstrations
18. Using the C2 RA helped the architecture team identify possible performance bottlenecks
19. The C2 RA served as a guide for the detailed system and software designs
20. The architecture process aided the team's understanding of the Objective and Demonstration systems
21. Ensure the architecture evolves to meet future capabilities
22. Ensure someone has responsibility and authority for architecture integrity, accountability, and ownership
23. RA alignment is a good goal, but is it practical?
24. RA's cannot be specific enough to address all programs
25. Program needs can drive architectures that diverge from RA's
26. For alignment to work, RA's must be modular at the right level to allow programs to pick and choose reusable modules

Suggested RA areas of improvement

1. Provide a user guide to help architecture teams to leverage the C2 RA
2. Make the RA artifacts and models easier to find and access
3. Provide guidelines to the architecture population on how to use reference architectures
4. Include non-military C2 operations in the C2RA
5. Generate a standard lists of terms and definitions that could be applied across all reference and program architectures, whether military or civilian
6. Either standardize on one architecture modeling tool, or invest in transformation capabilities that convert artifacts from one tool to another
7. OV-5 could be structured to look similar to SV-4 hierarchy
8. More definition is required for architecture change management