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The Coordinated Spiral: Concurrent Modeling and Simulation Development with C4ISR Systems

Major Scott C. Johnston
Air Force Research Laboratory, Warfighter Training Research Division (AFRL/HEA)
6030 South Kent Street
Mesa, AZ, USA 85212-6061
480-988-6561
scott.johnston@williams.af.mil

ABSTRACT: Currently Modeling and Simulation (M&S) requirements in support of Command, Control, Communications, Computer, Intelligence, Surveillance and Reconnaissance (C4ISR) systems tend to be developed following the effected C4ISR system fielding. The resultant, delayed, fielding of the supporting M&S not only causes several problems from the viewpoint of the user (i.e. lack of training) but also is a potential advantage lost to both the C4ISR and M&S system developers. The popularity of the spiral development process with its shortened requirement to fielding timelines compounds this problem.

M&S development conducted for a recent Joint Expeditionary Force Experiment (JEFX) produced an interface between the Air Warfare Simulation (AWSIM) and the Theater Battle Management Core System (TBMCS) which modified the traditional spiral development process as it occurs between C4ISR systems and supporting M&S. This modified process produced a workable interface faster, which not only provided users training prior to C4ISR system but also aided in the requirements/acquisition and test and evaluation processes. This paper discusses the modified spiral development process, its effects on the JEFX process and presents some lessons learned and suggestions for future modifications.

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Modeling & Simulation (M&S) Challenges

There are several challenges facing the modeling and simulation community today. The reduction in cost coupled with the increase in power of readily available processors has made modeling and simulation technologies available to a much wider audience. Along with the wider availability has come a more selective audience, the bar has been raised on what is acceptable and what will gather dust in the corner. Users today require a much higher degree of realism and they want new requirements met faster. This is especially true in exercising battlestaffs in the employment of Command, Control, Communication, Computer, Intelligence, Surveillance and Reconnaissance (C4ISR) systems.

C4ISR systems are being acquired and modified at an ever increasing rate and the golden rule of "training the way you fight" dictates that operators use their go-to-war systems for training. This requires that modeling and simulation systems integrate with each of these C4ISR systems. This paper will present a modification to the current spiral development process which allows M&S systems to not only be fielded with the C4ISR systems they support but benefit additional warfighter areas as well.

Why Integrate

Using your real-world system to train on is certainly a driving reason to integrate C4ISR systems with the M&S that can stimulate it, but is that the only benefit? If one considers that the synthetic battlespace presented by M&S can replace portions, or all of the real-world battlespace, and if done properly, not only the operator, but the C4ISR system itself cannot tell the difference, then a wealth of opportunities opens up.

Very often system deficiencies do not surface until a system is fielded. Lab conditions do not accurately represent the flood of information which can occur in a contingency operation. M&S provides the capability to produce realistic (or excessive if you prefer) traffic amounts to discover problems prior to fielding for purposes of test and evaluation or experimentation. Additionally, these test environments can help organizations define their future requirements and even help acquisition communities select the proper systems to meet those requirements.

Software Development Models

As presented in the previous section, there are many compelling reasons for the integration of M&S with C4ISR systems. However, if the reasons for integration are so good, then why are the associated development challenges the stuff of so many program managers' nightmares? A primary factor is the manner in which most M&S interfaces are developed – separately from the C4ISR systems that they will eventually support.

Separate development tracks may have occurred due to the fact that the requirement for the M&S interface was not recognized at the time the original C4ISR system requirements were defined. A lack of program funding can also cause interfaces between systems to be pushed back to follow-on development efforts. Regardless of the reason, the fact that highly related software projects were proceeding separately warranted a fresh look at the development methodologies being used to look for pitfalls to avoid and opportunities to capitalize on.

Early software development models

Developed in the late 1960's and early 1970's and still popular in the early 1990's, the waterfall development model (see figure 1) was the guiding design principle for many of the software systems that are fielded today [1]. Growing out of refinements to the stagewise model, which stipulated that software be developed in successive stages, the waterfall model recognized the presence of feedback loops between stages (feedback was limited to the previous stage

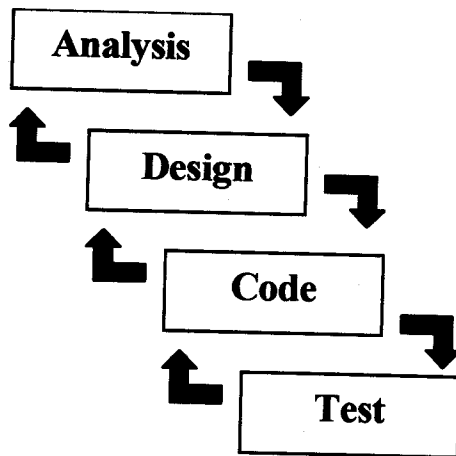only) and included initial incorporation of prototyping [2].

Figure 1: The Waterfall Model

Although it made improvements to the stagewise model, the waterfall model had several limitations itself. First, it required a complete set of requirements at the beginning of the project [3], something that is very difficult to do if the user is not really sure what it is he wants (but he will know it when he sees it). Additionally, the waterfall model delayed the detection of errors to the end of the development process [1] where they were the most expensive and time consuming to fix and where there was the greatest pressure to field something. Finally, nothing is done on the project until it's all done [4]. As development schedules get tight, the customer typically wants to see some type of product. With the waterfall model, there was nothing to show but a stack of documents and some code until the end of the project. These weaknesses led to the development of another model known as the spiral model.

Spiral development model

The spiral development model (see figure 2) has as its underlying concept a series of spirals, each cycle of the spiral consisting of the same series of steps as the previous cycle, each in itself similar to a miniature waterfall model. An important feature of this model is that each spiral of this iterative

process concludes with a review to ensure that all participants are committed to the current approach before proceeding on [2]. This model of development combats many of the problems of the waterfall model by allowing the developer to simultaneously seek to understand the problem while searching for the best process [5]. Rather than only doing each of the development phases once (i.e. analysis, design, coding, testing) the cycle is repeated several times, each time getting a little closer to the desired finished product.
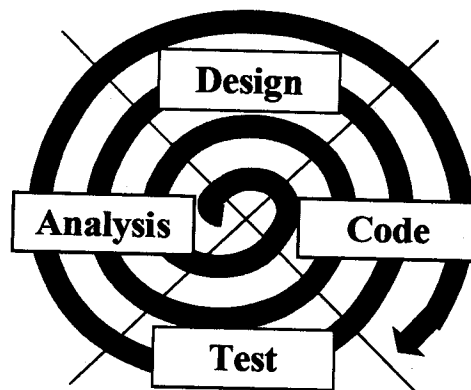

Figure 2: Spiral Development Model

The spiral model, with its use of iterative development and prototypes, is seen as well suited to risky development projects and as such, is a popular model among aerospace, defense, and engineering specialists [3].

Coordinated Spiral Development Process

Although the spiral development process has aided in developing new C4ISR systems by allowing operators the opportunity to try the system early in the development process and offer feedback, in some respects is has further hampered the development of M&S interfaces. With the current implementation of the spiral development model for C4ISR systems, products are being fielded at an ever-increasing rate.

With the increased rate of fielding of C4ISR systems the M&S community received a commensurate amount of new requirements for interfaces. Unfortunately, due to the

reduced development lead times, the M&S community would often only find out about changes to C4ISR systems after they were fielded. The M&S development community had also embraced spiral development for faster production times; however with the late identification of requirements, the supporting M&S was always playing catch-up, as illustrated in figure 3.
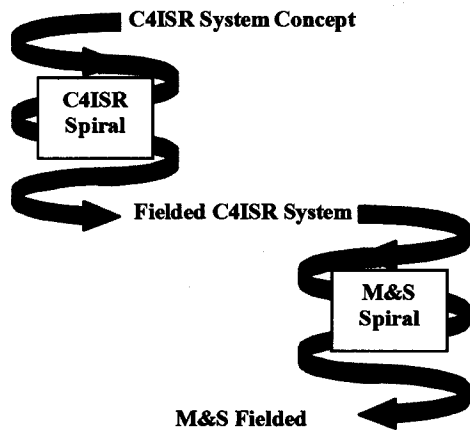
Figure 3: Current Offset Spiral Development

The offset spiral development cycles between C4ISR and M&S caused several problems. First, training was late to the field. One of the primary roles M&S interfaces play is in stimulating real-world

systems for the benefit of training system operators. Since M&S, which was compatible with the new C4ISR systems didn't exist, work-arounds had to be developed. Additionally, the added benefits of having compatible M&S available to the C4ISR developers for debugging, as well as test and evaluation purposes, was lost.

Boehm suggested [2] that the spiral development effort for a product could be split amongst multiple organizations, with each organization developing a portion of the whole. This split development environment was very similar to what was happening to the development of C4ISR and M&S systems. Both the C4ISR and M&S developers could be looked at as jointly developing a larger system – unfortunately via disjointed spirals, the goal then, was to synchronize, or coordinate the development process.

If one imagines backing up the M&S spiral so that both the C4ISR and M&S system were starting at the same or nearly the same time (see figure 4), the spirals could be linked. Each organization maintains a separate development effort, but comes together at key reviews for course corrections. This method has the added benefit of providing the C4ISR developers a stimulator to test out their system under real-world loads. It additionally provides the M&S developers some level of confidence that their system will properly interface to the real-world C4ISR system once fielded.
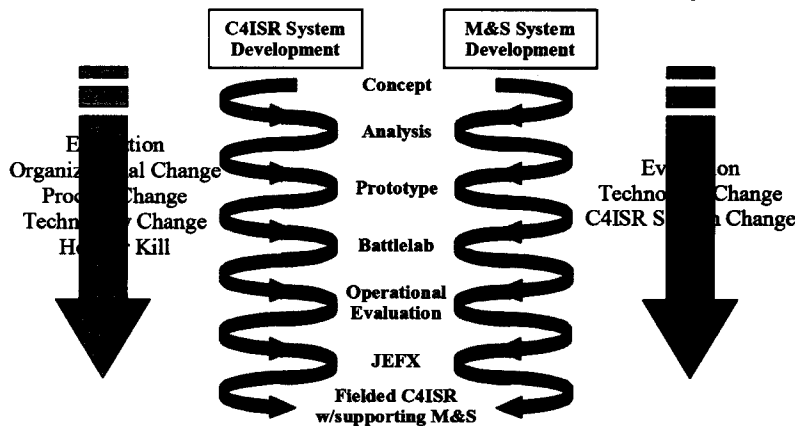
Figure 4: Coordinated Spiral Development

Coordinated spiral development promises to offer many benefits to the combined C4ISR and M&S system development effort. Factors, which influence system development (seen on the extreme right and left sides of figure 4), often, result in modifications to the product under development. Under spiral development, these changes can occur quite often. Under the coordinated method, these changes are now communicated much earlier to the interfaced system resulting in fewer fielding problems.

The Air Force's newly implemented experiment series, the Joint Expeditionary Force Experiment (JEFX), provided us the perfect opportunity to implement the coordinated spiral development process. The Air Warfare Simulation (AWISM) had a new requirement to interface to the Theater Battle Management Core System (TBMCS) which was one of the primary systems participating in JEFX. Linking the development of these two systems would provide us valuable insight into the coordinated spiral development process.

To understand the challenges faced by the developers of the AWSIM/TBMCS Interface (ATI), it is helpful to have a basic background of the interconnected M&S (AWSIM) and C4ISR (TBMCS) systems. The next section will provide that background followed by an explanation of the JEFX program. Finally, this paper will present some of the lessons learned from JEFX.

System Descriptions

The following sections provide a short description of each of the M&S and C4ISR systems used as successful examples within this paper of the coordinated spiral process.

Air Warfare Simulation

AWSIM is the United States Air Force's official air combat simulation model [6]. AWSIM is used to train senior commanders and their battle staffs in the execution of joint and combined operations. AWSIM's computer simulation supports air component commander-level battle staff training for Air Force conducted exercises and the air portion of joint exercises.

AWSIM is a real-time interactive simulation that supports a two-sided scenario. Friendly and opposing sides define, structure, and control their forces. Neutral air forces can also be portrayed. Mission packages can be developed consisting of single aircraft or multiple-aircraft missions. Tail number tracks the aircraft. This level of fidelity supports training requirements of the Joint Forces Air Component Commander (JFACC), his staff, and the Air Operations Center (AOC) that develop Air Tasking Orders (ATOs), Rules of Engagements (ROEs), and target nomination lists.

AWSIM is a latitude and longitude based theater-level model. It simulates day and night operations. Modeled features include: aircraft, air bases, surface-to-air missiles (SAMs), Short Range Air Defense Systems (SHORAD) radar sites, surface-to-surface missile (SSM) sites, and cruise missiles. AWSIM also contains All Range Air Defense Systems (ALLRAD) or those systems whose fire control can be transferred between AWSIM and the Army's Core Battle Simulation (CBS) model.

AWSIM's scope is limited to conventional warfare, but can conduct nearly all Air Force defined missions and includes virtually all-conventional air-to-air, air-to-surface, and surface-to-air weapons. AWSIM missions consume munitions and fuel on an "as used" basis. AWSIM uses Monte Carlo for probability of kill attrition. AWSIM supported missions and functionality's are listed in Table 1.

Air-to-Air	Reconnaissance
Airborne Early Warn	Aerial Refueling
Air Interdiction	Helicopters
Battlefield Air Ind	Cruise Missile
Close Air Support	Surface-to-Surface
Electronic Combat/ Electronic Warfare	Surface-to-Air
Airlift	Weather

Table 1: AWSIM Mission/Functionality

AWSIM graphics display or Graphic Interface Aggregate Control (GIAC) contains menu options for controlling aircraft, air defenses as well as filters for information viewed, map scales, and the ability to add text and lines (such as the Forward Line of Own Troops (FLOT) or transit routes).

AWSIM has Air Status Boards (ASTABs) to portray information. These boards contain data on air base status, logistics, history of missions, history of destroyed aircraft, radar, and active flights. ASTABs also have filtering ability.

AWSIM database requirements for an exercise are the unique force structure and targets. This includes items such as air bases, assigned squadron names, squadron aircraft type and number, early warning radars, and air defense sites.

Theater Battle Management Core System

TBMCS consolidates force-level and wing-level command and control systems that utilize the Air Force Theater Battle Management (TBM) Command, Control, Communications, Computers, and Intelligence (C4I) standards [7]. The acquisition of this system allows the execution of TBM planning, intelligence, and operational functions in support of the JFACC. The system provides connectivity horizontally to other Services and allies and vertically among standard or composite wings, other elements of the theater control system, and deployed units and higher headquarters. It is modular to build up or scale down capabilities by adding or deleting information sources, operating units, weapons available, participating Services and allies, and dispersal requirements. Data and functions are distributed for survivability. Department of Defense (DoD) and TBM General Officer Steering Group (GOSG) open system standards applies to the system. TBMCS provides automated decision support tools to improve the planning, preparation, and execution of joint air combat capabilities. It also provides support for peacetime operations, e.g., humanitarian, United Nations peacekeeping, etc. Advanced technology is transitioned to

the field using evolutionary acquisition and rapid prototyping. To meet operational performance criteria, TBMCS receives, displays, and integrates into related applications of current space, air, ground, and maritime situations as provided by US and allied sensors and specified ground processing elements. AF Space Command (AFSPC) provides the theater with space support (i.e., satellite imagery, satellite weather data, Global Positioning System (GPS) data, launch information, etc.) for battle management.

Two core components of TBMCS that directly interact with AWSIM are the combat planning and combat operations modules.

The combat planning module provides automated decision support to combat planners for preparing the ATO. It keeps track of resource status and can provide proposed mission packages, routing, tanker, and Electronic Counter- Countermeasures (ECCM) support, etc. for planners' approval. It is required to reduce ATO cycle time. Additional automation will support planning for electronic warfare, airspace control, communications/frequency management, reconnaissance tasking, and ancillary support as required.

The combat operations module provides additional automation to the combat operation division for the command and control systems architecture for the Combat AF (CAF) to assist in the near real-time monitoring and execution and replanning of the ATO based on rapidly changing battlefield conditions. It also provides for automated assistance to the JFACC and staff to monitor force structure status and composite displays of the battlefield in near real-time.

AWSIM – TBMCS Interface

The AWSIM-TBMCS Interface (ATI) is a program designed to interface the real-world TBMCS system with the AWSIM wargaming system. ATI allows the database that the Combat Panning module of TBMCS utilizes to be mapped to an existing AWSIM database. ATI provides automated support for loading a TBMCS-generated ATO into AWSIM, producing AWSIM mission order

stacks, and a mission editing capability. Personnel in an air component response cell use the ATI to create files that define a specific mission such as close air support including aircraft type and number, weapons load, take-off time, transit routes, refueling, target, and the way home. The missions are launched at the appropriate times and flight followed by the response cell which can adjust the flight profile, if required. Results of the mission including kills, losses, and success are displayed. ATI also supports the communications of mission takeoff and landing times from AWSIM to TBMCS.

Joint Expeditionary Force Experiment Program

JEFX provides the Air Force with a semiannual vehicle for experimentation with operational concepts and attendant technologies for enhancing capabilities of the 21st century Aerospace force [8]. The experimentation will lead to new ways of accomplishing Air Force missions, while motivating leading-edge thought and encouraging operational activities that will significantly advance Air Force Core Competencies as the Air Force prepares to fight the nation's conflicts. The JEFX program provides mechanisms for transitioning proven initiatives, to serve as operational leave-behinds or as candidates for incorporation into the formal acquisition cycle.

JEFX concept

The overall JEFX concept calls for the deployment and employment of an Air Expeditionary Force (AEF) into a large asymmetric force-on-force simulated combat scenario [9]. The Experiment Director will incorporate live-fly activities of a Rapid Response Air Expeditionary Force (RAEF), along with virtual and constructive simulations as an operational laboratory. The design supports experimentation with concepts and systems intended to improve Air Force capabilities in three C2 focus areas: Global Awareness (GA), Global Grid (GG); and dynamic Analysis, Planning, and Execution (dAPE). These three C2 focus areas are outcomes of the Air Force C2 Summit in June 1997 [10]. It is envisioned

that enhancements in these C2 capabilities will improve Air Force operational capabilities and Core Competencies.

JEFX will experiment with advanced C2 technologies to enable use of fixed and deployable C2 centers along with distributed and collaborative planning tools. It will integrate information technologies with robust communications and exploit new C2 concepts, processes, and procedures. JEFX will establish and leverage the capabilities of GG, GA, and dAPE. In a limited warning (48 hours) scenario, JEFX will demonstrate the unique qualities of Aerospace power (speed, range, flexibility, lethality) and apply adequate lethal force within the early halt phase (first 15 days) to forge a decisive edge [11].

JEFX mission

The JEFX mission is to conduct a semiannual CSAF-sponsored, MAJCOM-executed experiment that combines live-fly forces, constructive and virtual simulations, and technology insertion into a seamless warfighting environment. The purpose of this experimentation is to demonstrate dramatically enhanced C2 capabilities and weapons in the application of integrated Aerospace power to advance Air Force Core Competencies.

JEFX goals

Numerous benefits are expected from semiannual JEFX experimentation. JEFX initiatives and technologies should reduce overall manpower requirements, particularly the footprint of forward deployed forces. It will be able to leverage/emphasize Aerospace power's speed, global range, flexibility, and lethality. JEFX will allow us to "train the way we fight," within the context of a standing Joint AOC (JAOC). Using lessons learned, the Air Force can guide the planning and execution of the annual warfighting experiments focusing on accelerated development/fielding by implementing initiatives through the spiral development process. This innovative process co-evolves concept, process, and people and ultimately improves acquisition responsiveness.

JEFX objectives

JEFX objectives guide the general arrangement of experiment activities, the establishment of criteria for acceptance of conceptual and technology initiatives for experimentation and the definition of planning limits for experimentation. JEFX will institute and continuously employ a spiral technology development process to expeditiously introduce new technologies and operational concepts spanning development, experimentation, and integration of enhanced capabilities into the active inventory. JEFX will explore AEF capabilities, baseline C2 capabilities and provide insights for C2 Roadmap plans, and evaluate and recommend changes to current doctrinal procedures for contingency response operations and Core Competencies. Finally, it will establish the JEFX process as the mechanism to introduce and evaluate technologies and operational concepts for enhanced applications of Aerospace power.

JEFX Utilization of the Spiral Development Process

The nature of spiral development and how it supports innovation critical to the Air Force's developmental community define the JEFX process. The spiral development process takes emerging and maturing technologies and transforms them into fielded systems or concepts through a chain of analysis, prototyping, battlelab development, experimentation, and operational evaluations. JEFX is a key aspect of the experimentation process, as each JEFX will incorporate selected battlelab development efforts, with conceptual and systems initiatives offered up by government sponsors and industry, to advance Air Force Core Competencies.

Lessons Learned

JEFX provided an excellent opportunity to explore the capabilities of the coordinated spiral development model. The opportunity to have the M&S interface available for initial spiral events allowed ATI and TBMCS to mature jointly, aided in test & evaluation and helped to provide for training initial cadre.

The Air Force Agency for Modeling and Simulation after action report [12] on JEFX highlighted this fact. "The simulation environment allowed Air Force personnel to examine and refine their functional processes on how they would use TBMCS to execute air warfare. Flexibility of the simulation systems to rapidly configure and stimulate different C4ISR configurations with different interfaces provided a cost effective testbed environment." The C2 Earlybird: JEFX lessons learned edition [13], also noted "The linking of C4ISR and M&S spiral development was very successful. The development of the AWSIM/TBMCS Interface concurrently with TBMCS provided the TBMCS developers a tool to use for system tests and gave the M&S world the capability to interface with this new C4ISR system as soon as it was released to the players. We must continue to link C4ISR and M&S development."

One of the keys to the success of the implementation of the coordinated spiral at JEFX, was the excellent working relationship that existed between the developers. Although this developed at the grass roots level out of necessity, in the future this relationship must be formalized. Development work beyond the JEFX environment was hampered by the lack of a formalized Interface Control Document, which would have helped JEFX as well.

Even with the shortened development times and the benefits associated with having an M&S interface available immediately upon C4ISR system fielding, there are still questions as to if this manner of development lowers costs. The concern here is that even with the M&S and C4ISR systems being developed separately there are still costs associated in the C4ISR system development that did not exist prior to working with the M&S systems. If one considers operational readiness of the C4ISR system to be the desired endstate then the cost of operational readiness would be the cost of all the preceding events leading up to that endstate. This includes not only the funds spent for acquisition but for the test & evaluation and training to reach that goal. At the time of JEFX, I was unable to gather cost information for previous interface developments to compare

against the coordinated spiral effort. The belief is that the development time saved due to a higher quality test & evaluation phase and increased training quality (i.e. fewer training days) outweighs interface development costs as compared to those systems developed in the non-coordinated manner using waterfall or follow – on spiral efforts.

Summary

The coordinated spiral development process as applied during JEFX matured the ATI project along with AWSIM and TBMCS systems, providing a working C4ISR and M&S interface much earlier than had been seen during previous interface developments. Additionally, the availability of a M&S interface for testing TBMCS aided developers greatly as witnessed by their requests to leave the simulation environment active after training was done for the day for test purposes. Future efforts which compare the fielding costs of systems built under the coordinated spiral development environment with the costs of those systems developed under the waterfall or follow – on spiral efforts should show a cost savings and quality improvement for systems built in the coordinated environment.

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Disclaimer

The views expressed in this paper are those of the authors and while every attempt was made to report the events factually the results are not to be construed to represent official positions.

Author Biographies

MAJOR SCOTT C. JOHNSTON is assigned as Chief, Warfighter Training Simulation Branch at the Air Force Research Laboratory, Warfighter Training Research Division in Mesa, Arizona, USA. Major Johnston holds both a B.S. in Computer Sciences and a M.S. in Artificial Intelligence from the University of Florida. He has held numerous positions during a period of more than 14 years; researching, developing, implementing, and using M&S tools in support of major Air Force and Joint theater-level battlestaff training exercises. His former position at the Air Force Agency for Modeling and Simulation (AFAMS) in Orlando, Florida, USA, was as Chief of the Joint Simulation System (JSIMS)/ National Air and Space Model (NASM) Branch, managing the development of the next generation Air Force battlestaff training M&S tool.