12th ICCRTS

“Adapting C2 to the 21st Century”

Title of Paper:

Mapping Network Centric Operational Architectures to C2 and Software Architectures

Topics

C2 Technologies and Systems; C2 Metrics and Assessment; C2 Concepts, Theory, and Policy

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Mapping Operational Architectures to C2 and Software Architectures

Agenda

- Introduction
- Definitions
- Evaluation Process
- Context
- Hypothetical Scenario
- Conclusions

Introduction

- **This paper describes the results of a gedanken experiment. Thought experiment methodology is a priori, rather than empirical, in that it does not proceed by observation or physical experiment. Thought experiments are well-structured hypothetical questions that employ "What if?" reasoning. In our case, we wish to evaluate the proposed architectural taxonomies of Dekker as a possible set of operational baseline configurations with respect to their relationships to command and control models (C2) and software architectures. The Dekker architecture types which will be evaluated are hub request, hub swarming, request based (without a hub), emergent swarming (leaderless), hierarchical swarming, orchestrated swarming, and distributed swarming (leaderless). For this gedanken experiment, a swarm is assumed to have the properties of swarm intelligence normally associated with Particle Swarm Optimization (PSO).**

Introduction Continued

- **Our gedanken experiment results show that the configuration of assets and how they were organized (commanded and controlled) actually increased their collective capabilities given an optimized hybrid SOA, MOMS (Message Oriented Middleware), and Agent Based software infrastructure.**
- **This means that any capability portfolio analysis or competency assessments which only focuses upon individual asset contributions, fails to account for the behavior of a team or the possibility of “collective swarm intelligence”.**
- **This almost by definition will lead to procurement decisions detrimental to the basic capability of the DoD.**

Introduction Continued

- The Dekker architectures evaluated were
  - hub request
  - hub swarming
  - request based (without a hub)
  - emergent swarming (leaderless)
  - hierarchical swarming
  - orchestrated swarming
  - distributed swarming (leaderless).

Introduction Continued

- The Command and Control Approaches Evaluated Were:
  - Cyclic – Chinese Army WWII
  - Selective Control – Israeli Army
  - Interventionist – Soviet Army WWII
  - Problem Solving – American Army
  - Problem Bounding – British Army
  - Control Free – German WWII

Introduction Continued

- The software architectures evaluated were:
  - – Service Oriented Architecture – SOA
  - – Event Driven Architecture - EDA
  - – Message Oriented Middleware - MOMS
  - – Legacy Software Architectures
  - – Agent Based Architectures – ABA
    - Note that the agents had learning and communication capabilities

Process Followed

- Define a simple model with few variables
- Define a simple mission with clear and easy to measure metrics
- For each of the Dekker models, vary the command and control and software architecture models and measure

Context – Hypothetical Mission to find a Missing Plane

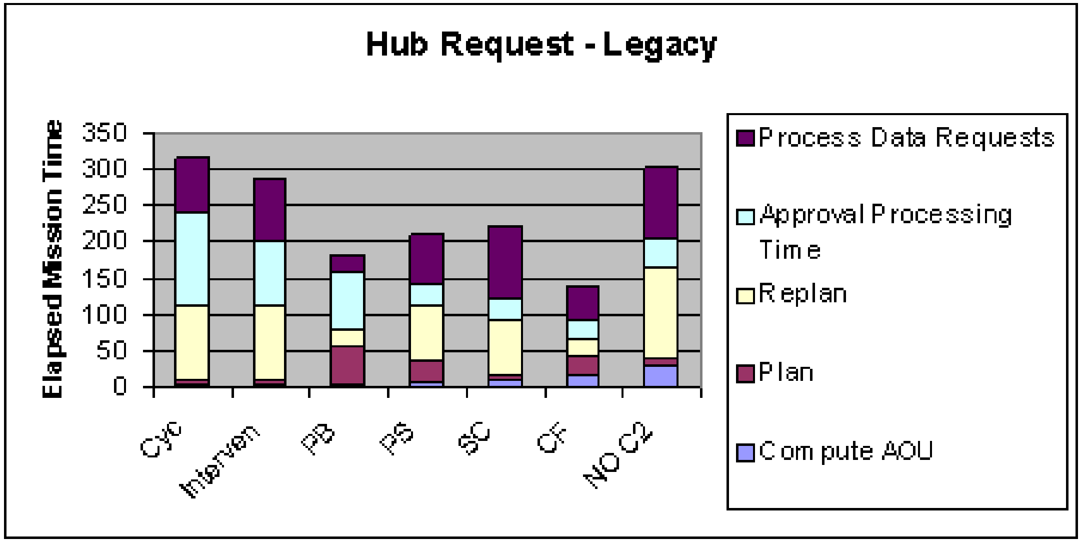
- Assume that we have a set of drones available on a sensor grid
- Each of the drones are fueled and available for tasking
- The drones receive their tasking via GIG Sensor Grid Communications or directly from a "leader drone" in Hub models
- Assume that there are only 3 types of drones available:
  - For this simple example, all drone types have equivalent sensors & range
  - Each drone of the first type contains onboard artificially intelligent software agents capable of planning a search and rescue mission
  - Each drone of the first type can be appointed as a command node and issues search pattern commands to the non command nodes
  - Each drone of the second type cannot plan a mission and can only follow orders
  - Each drone of the third type is used for protection only. Thus it cannot be used in searches in hub type architectures
  - Depending upon the architectural configuration, the onboard agents will be able to communicate with each other or only to a leader.
  - Drones of all types can communicate with the sensor Grid or each other
- The sensor grid contains an adjudication agent which will deconflict concurrent or competing asset requests. This agent was not implemented or its impact on finding the missing plane analyzed for this effort due to staff resource constraints. This is mentioned only to complete the sensor grid description since a given a real set of sensors, some task and sensor request adjudicator will be necessary.

Metrics

- The metrics which will be used to judge each configuration are:
  - Time for the leader drone to process the mission request and “understand it”, for hub or leader based architectures.
  - Time for the “swarm” to process a mission request and “understand it” in non-hub models
  - Time for a leader node to create a search plan.
  - Time for a swarm to create a search plan.
  - Time to compute the area of uncertainty by a leader
  - Time to compute the area of uncertainty by a swarm.
  - Time to determine the search plan for each individual drone by a leader
  - Tine to determine the search plan for individual drones if calculated by the swarm
  - Time for requests to be processed from each drone to the leader
  - Time to re-plan by a leader model if first searches are unsuccessful
  - Time to re-plan by a swarm if first searches are unsuccessful
  - Time from mission start until mission completion (missing plane found)

Observations

- No single command and control model worked (optimized performance) for the mission as a whole
- This means that the individual tasks responded better under different command structures.
- No single software architecture achieved superior results for the mission as a whole


Hub Request - Legacy
Elapsed Mission Time
350
300
250
200
150
100
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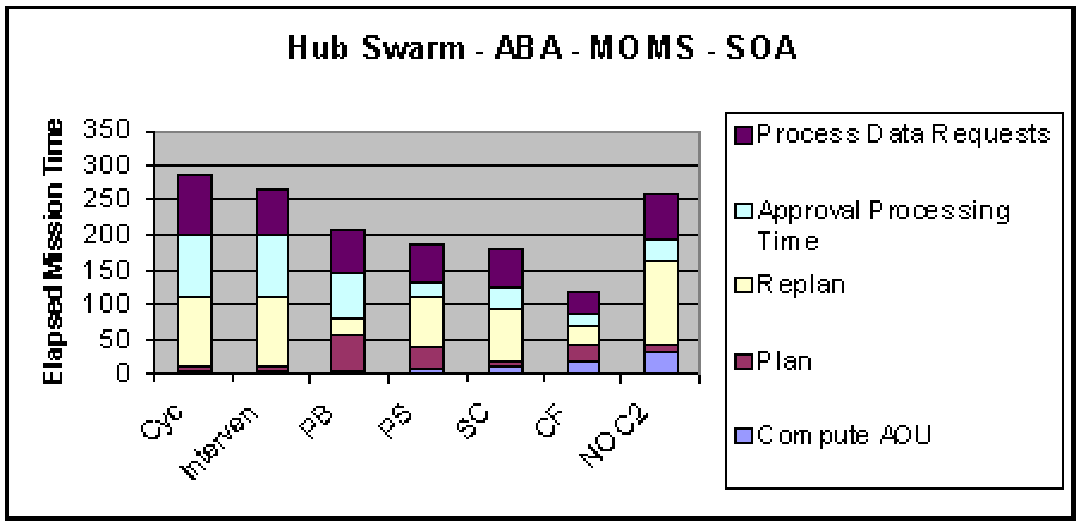
Cyc
Interven
PB
PS
SC
CF
NOC2
Process Data Requests
Approval Processing Time
Replan
Plan
Compute AOU


Hub Swarm - ABA - MOMS - SOA
Elapsed Mission Time
350
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Process Data Requests
Approval Processing Time
Replan
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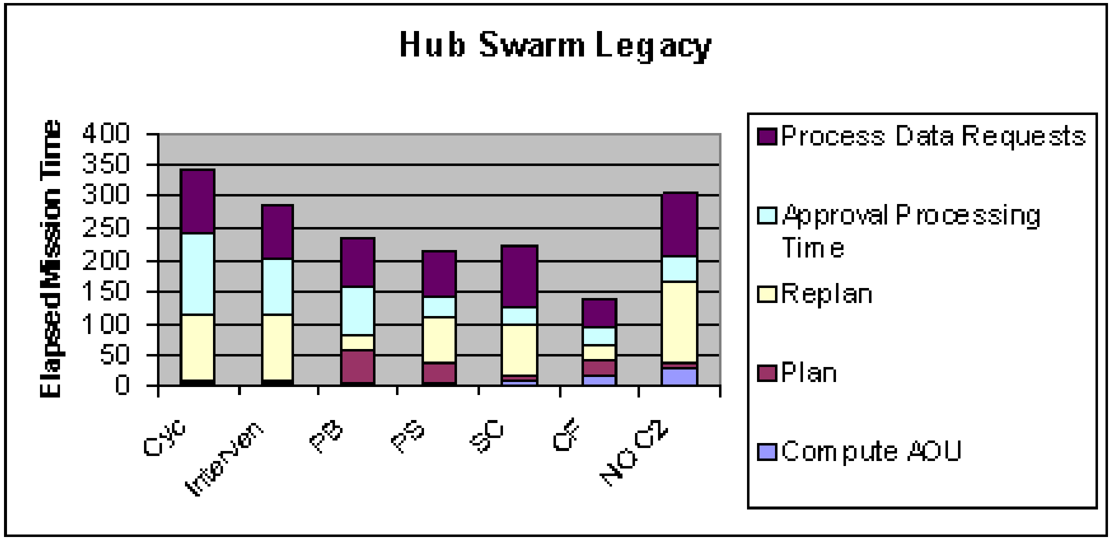
Compute AOU


Hub Swarm Legacy
Elapsed Mission Time
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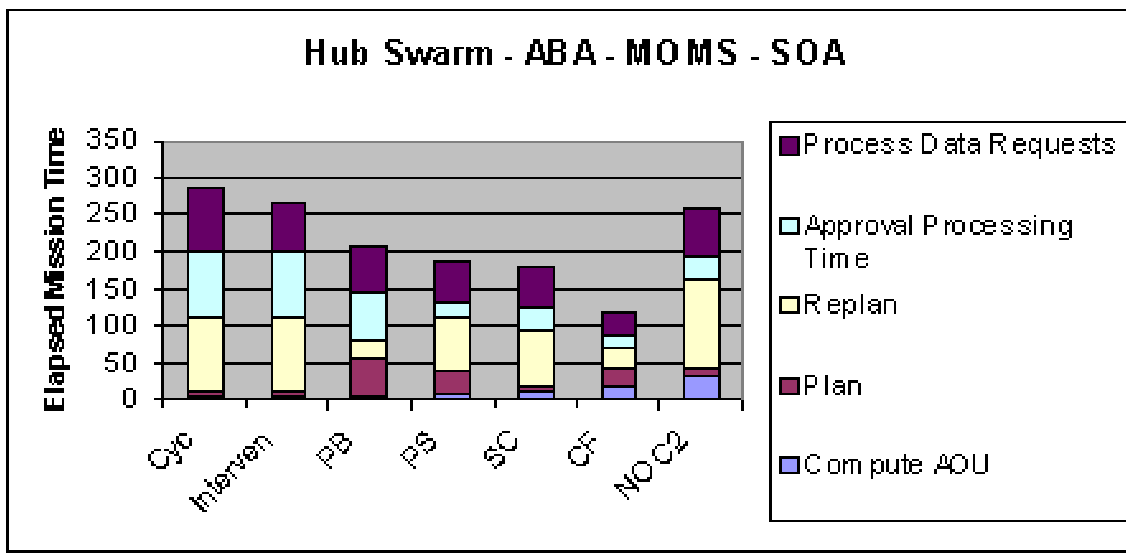
Process Data Requests
Approval Processing Time
Replan
Plan
Compute AOU


Hub Swarm - ABA - MOMS - SOA
Elapsed Mission Time
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Process Data Requests
Approval Processing Time
Replan
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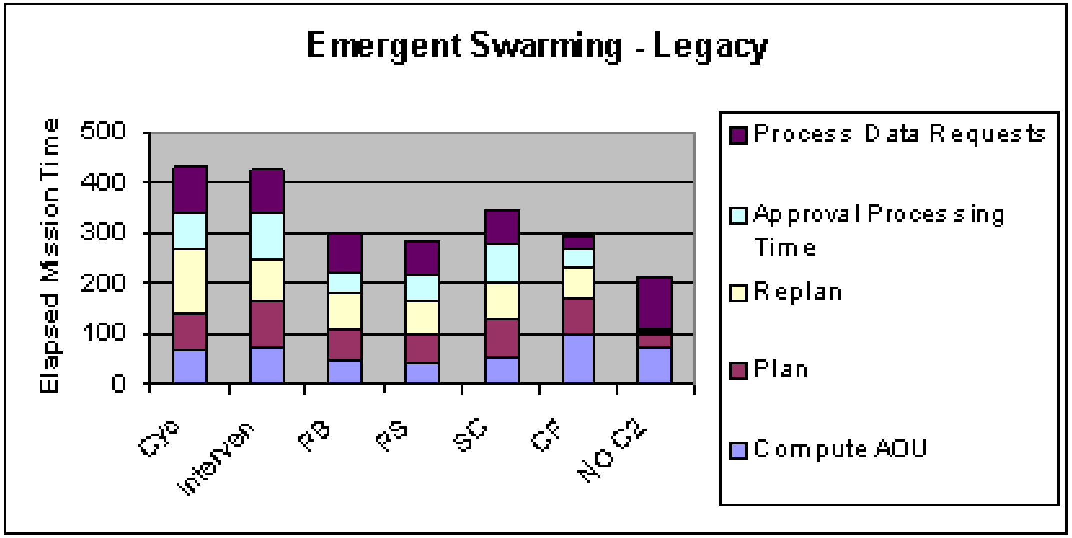
Compute AOU


Emergent Swarming - Legacy
Elapsed Mission Time
500
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Interven
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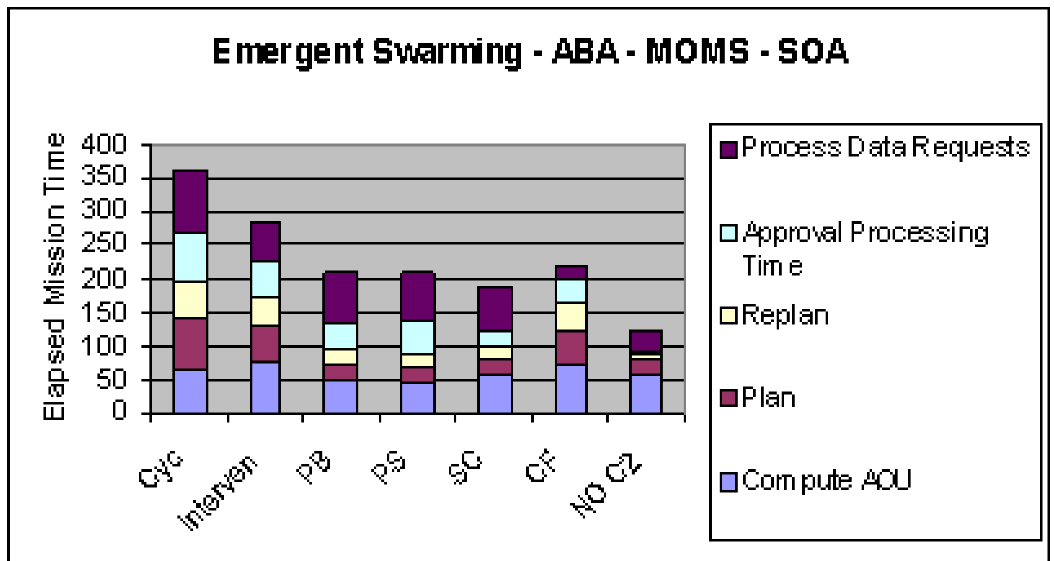
NO CZ
Process Data Requests
Approval Processing Time
Replan
Plan
Compute AOU


Emergent Swarming - ABA - MOMS - SOA
Elapsed Mission Time
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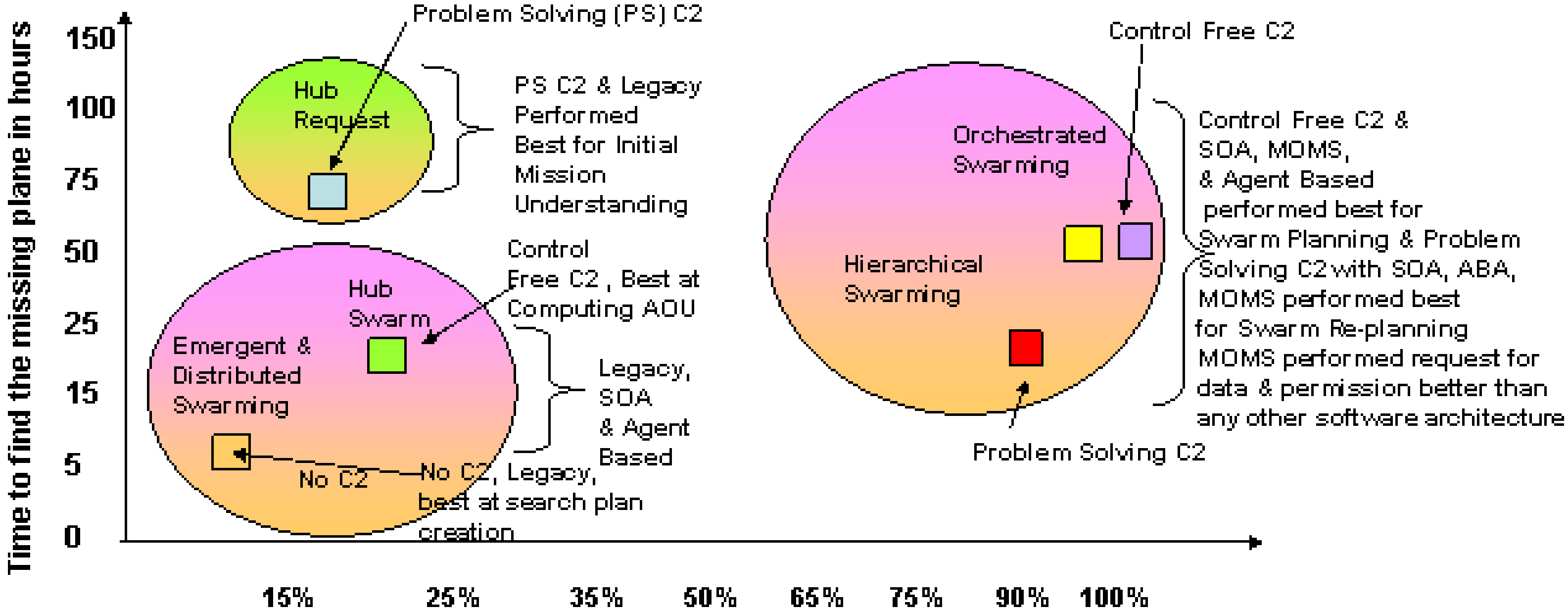
CF
NO CZ
Process Data Requests
Approval Processing Time
Replan
Plan
Compute AOU

Results

- **By definition, operational Hub architectures which required a protector drone had at least one less search asset. Thus, these Hub models were less successful in terms of time to find the missing plane than leaderless models requiring no protector drone.**
- **Orchestrated swarming consistently performed better than any other operational architecture configuration given the simple scenario of finding the missing plane in a fixed time period.**
- **The primary characteristics that we were looking for was consistency of the discovery of the missing plane without a re-planning cycle and the elapsed mission time. In some placements of the missing plane, distributed and emergent swarming (both leaderless) did actually find the missing plane quicker and without re-planning, but not consistently.**
- **In the orchestrated model, the election of the leader did not preclude individual drone initiative and communications between all the other nodes was also enabled. Disabling inter-nodal communications had an adverse impact on all of Dekker’s configurations.**

Solution Space of Most Reliable Configurations of Operational Architectures, Command and Control Models, and Software Architectures. The color coded tasks in each indicate the solution space region where optimal performance for that task was achieved given a particular C2, Dekker, and Software configuration



The x axis represents the probability that the missing plane will be found at the same location repeatedly.

Results:

Emergent & Distributed Swarming found the plane the fastest but least consistently. They also had the fastest time to process requests because there was no C2 in place eliminating approvals from a chain of command.

The hub swarm with control free C2 and Legacy, SOA, ABA, excelled at AOU computation. Hub request excelled at initial mission understanding with PS C2 and a Legacy Software Architecture - Hierarchical and Orchestrated Swarming found the plane most consistently using SOA, MOMS, & ABA software architectures. Orchestrated Swarming excelled at swarm planning and request processing while hierarchical swarming excelled at swarm re-planning using a PS C2 model. The hubs were also inconsistent because they had to assign a protector drone and thus had fewer search assets. Thus, in the end planning & C2 mattered in arriving at consistent repeatable results

Task Legend

Time to Understand Mission (light blue)	Time to Compute Area of Uncertainty (green)
Time to Create a Search Plan (orange)	Time to Process Requests (yellow)
Time to Re-Plan (red)	Swarm Planning Time (purple)

Results Continued

- Dekker's Orchestrated Swarm Architecture using a hybrid software architecture of SOA, ABA, and MOMS, configurations performed best at he mission level
- At the task level
  - Computation intensive tasks (planning and AOU computation) performed best on legacy systems for hub architectures
  - Computation intensive tasks on swarm architectures outperformed legacy through the use of intelligent Agent Based Architectures (GA & ANN based) & Particle Swrm Optimization
  - Message intensive tasks and configurations performed best under the MOMS architecture for both hubs and swarms

Results Continued

- The leaderless C2 models also resulted in less than optimal resource utilization resulting in more frequent re-planning and longer times to successfully complete a search.
- The leaderless swarm models repeatedly duplicated failed search patterns causing excessive amounts of re-planning

Results Continued - A few comments concerning capability portfolio management of assets and organizational competency

- **It is worth noting that the individual drone assets did not change in capability. This is an obvious but often overlooked aspect of NCW research. The configuration of the assets and how they were organized actually increased their collective capabilities. Orchestrated swarming can therefore be said to have exhibited an emergent capability of consistently finding the missing plane in time, this capability was not exhibited by the other configurations to the same degree. Yet all that changed was the organization and how they communicated, not the original capabilities of any single asset. It may be fair to state that indeed individual competency and capability increased by the re-organization of the assets and the methodology of permitting either more or less practical levels of individual freedom of action.**
- **This means that any capability portfolio analysis or competency assessments which do not take collective emergent behavior into account are at best going to cause budgetary overruns and at worst make procurement decisions to the detriment of the basic capability of the United States Military.**