COA modeling with probabilistic ontologies
Introduction
Secure area Alfa until D+3 in order to force all Redland troops to retreat to Redland borders and allow Yellowland to regain control over the area.
Secure

- May have different meanings depending on the coalition partner’s doctrine and the operational domain (maritime, airspace or land) = ambiguity
- As an effect, may be obtained through different actions
- Must be coordinated in space and time (joint planning)
Introduction

- Battle Management Language (BML) - effort to reduce the ambiguity of the command intent description

**Label 15** - force all Redland troops to retreat to Redland borders and allow Yellowland to regain control over the area

nlt – no later than

Secure, Alfa, nlt D+3 in order to accomplish Label15

WHAT WHERE WHEN WHY

**RESTRICTED SEMANTICS** – There is no description on the relation between the effects and the actions that can contribute to reach the desired intent
## Introduction

### SECURE ALFA

<table>
<thead>
<tr>
<th>Maritime</th>
<th>Land</th>
<th>Airspace</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Patrol Yellowland’s north coast</td>
<td>• Attack Redland’s 2nd Brigade on ALFA</td>
<td>• Support the other component’s activities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Establish a NO-FLY zone over ALFA</td>
</tr>
</tbody>
</table>

Table 1 - Possible tasks to reach the Secure effect

Which capabilities, tasks and resources?

• **Master Air Attack Plan - MAAP**
MASTER AIR ATTACK PLAN INPUTS

- CJTF Guidance
- JFACC Strategy
- JAOP
- ROE
- Air Defense Plan
- Air Support Plan
- Weather
- Target/ETF
- EOB
- Threats/ACF
- BDA
- ALLOREQ: Allocation request
- JGAT: Joint guidance, apportionment, and targeting
- JGAT Worksheets
- Operational Context
- MAAP: Master air attack plan
- Operational Environment
- Logistics
- Communications Plan
- Bases
- Fuel/POL
- FROB
- Munitions/SCL
- UTE

DoD - Joint Publication 3-30 Command and Control for Joint Air Operations/2003

MASTER AIR ATTACK PLAN DEPICTION

- 24-Hour DCA CAP
- 10-Hour CAS Window
- Two Packages
  - Package 1 (HD/LD)
  - Belgrade/N. Serbia
  - Overlapping threats
  - Urban targets
  - Northern flow
  - Package 2 (COMAO)
  - Nis/S. Serbia
  - Isolated threats
  - Diverse targets
  - Southern flow

Tactical Level

JFACC

CAP: Combat air patrol
CAS: Close air support
COMAO: Composite air operations

DCA: Defensive counterair
HD/LD: High density/low density
Introduction
Proposed C2 Interoperability Planning Framework

Actual M&S Interoperability framework
Semantic Planning Layer
Task Probabilistic Ontology

Partial Semantic Structure of the mid-level Task Probabilistic Ontology
The main goal of this work is to generate Course of Action (COA) representation to improve planning automation

- The key elements of the approach are:
  - To model the relationship between activities (high level tasks) and effects
  - To represent the decomposition from activities to tasks (atomic)
  - To infer about the uncertainty on the production of the desired effects, based on a set of tasks, in order to reach the end state
Agenda

- Joint Operation Planning Process
- COA Modeling
- COA Development
- Conclusion and Future Work
Joint Operation Planning Process – JOPP

DoD - Joint Publication 3-30 Command and Control for Joint Air Operations/ 2010

Joint Operation Planning Process divided into six steps [Marques 2011]
Phase 1
- Acquire 60% of Air-Superiority over ALFA
- Secure Yellowland Coast
- Deploy 3rd Brigade

Phase 2
- Establish a No-Fly Zone
- Destroy at least 60% of Redland armored vehicles

Phase 3
- Deny Movement of Redland’s Forces
- Establish control over ALFA

Goal
- Secure ALFA
COA Modeling

- Phase Decomposition
COA Modeling

- Cumulative Effects Model

- Operational Level
  - Activity
  - hasTask
  - Causes
  - Effect

- Tactical Level
  - Task 1
  - Task 2
  - Task 3
  - Causes
  - Effects
    - Ef1
    - Ef2
    - Ef3

- Accumulated Effect
- Produced Effect
COA Modeling

Activity Fragment

Effect Fragment

Phase Fragment
COA Modeling

- The model also has the local probability distribution tables (LPD) for the resident nodes of interest;

<table>
<thead>
<tr>
<th>producedEffect</th>
<th>Recon</th>
<th>Attack</th>
<th>SEAD</th>
<th>Recon</th>
<th>Attack</th>
<th>SEAD</th>
<th>Recon</th>
<th>Attack</th>
<th>SEAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>.70</td>
<td>.60</td>
<td>.80</td>
<td>.60</td>
<td>.50</td>
<td>.55</td>
<td>.55</td>
<td>.20</td>
<td>.40</td>
</tr>
<tr>
<td>Medium</td>
<td>.20</td>
<td>.20</td>
<td>.10</td>
<td>.25</td>
<td>.30</td>
<td>.20</td>
<td>.30</td>
<td>.30</td>
<td>.35</td>
</tr>
<tr>
<td>Low</td>
<td>.05</td>
<td>.15</td>
<td>.05</td>
<td>.10</td>
<td>.15</td>
<td>.15</td>
<td>.10</td>
<td>.35</td>
<td>.20</td>
</tr>
<tr>
<td>None</td>
<td>.05</td>
<td>.05</td>
<td>.05</td>
<td>.05</td>
<td>.05</td>
<td>.10</td>
<td>.05</td>
<td>.15</td>
<td>.05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ObjType</th>
<th>Recon</th>
<th>Attack</th>
<th>SEAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft</td>
<td>.05</td>
<td>.05</td>
<td>.05</td>
</tr>
<tr>
<td>Medium</td>
<td>.05</td>
<td>.05</td>
<td>.05</td>
</tr>
<tr>
<td>Hard</td>
<td>.05</td>
<td>.15</td>
<td>.05</td>
</tr>
</tbody>
</table>

The producedEffect’s LPD
Phase 1 – Activity 1

- Acquire at least 60% of Air Superiority

Table 1 – Tasks definition

<table>
<thead>
<tr>
<th>Phase - Air Superiority</th>
<th>Outcome - Acquire at least 60% of Air Superiority</th>
<th>Effect</th>
<th>Activity</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Destroy AAA</td>
<td>SEAD</td>
<td>SEAD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Destroy Radar</td>
<td>Attack Radar</td>
<td>Attack DMPI01 and DMPI02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Destroy C2 Comm</td>
<td>Attack C2 Comm</td>
<td>Attack DMPI03 and DMPI04</td>
</tr>
</tbody>
</table>
COA Ontology

[Diagram of COA Ontology with nodes and edges representing tasks, outcomes, phases, and effects.]
After all instances and LPDs are included in the probabilistic ontology, a query can be posted to the model to assess a specific outcome;

A Specific Situation Bayesian Network—SSBN is the result of a query on the planned outcome of the AirSuperiority phase \([\text{hasAccomplishedPhaseGoal} (\text{Phase1\_AirSuperiority\_COA\_02A})]\);

In the resulting SSBN, there are planned effects accumulated from Time \(T_0\) and \(T_1\) for the activity \(\text{SEAD\_AAA\_01Alfa}\) to object \(\text{Target\_AAA\_01Alfa}\) and the activity \(\text{Attack\_C2Comm\_03Bravo}\) over object \(\text{Target\_C2Comm\_03Bravo}\).
Phase Instance

Activity Instance1

Activity Instance2

Activity Instance3

Activity Instance4

Activity Instance5

Effect Instance1

Effect Instance2

Effect Instance3

Query hasAccomplishedPhaseGoal

Phase Instance
1st Query to support Phase Outcome inference
**Task Inference**

<table>
<thead>
<tr>
<th>GenerateTaskList</th>
</tr>
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<tbody>
<tr>
<td><strong>Input:</strong> A knowledge base (kb), a Phase and it’s defined threshold</td>
</tr>
<tr>
<td><strong>Output:</strong> A list of tasks that contribute with the desired effect or NIL</td>
</tr>
</tbody>
</table>

1. Create an empty list of tasks called R;
2. $Q_1 = \text{Query(Phase)}$;
3. If Phase’s threshold was already reached, Return NIL;
4. Else get the activities TaskList from Phase; ## previous planned activities for the phase
5. While not (EMPTY TaskList){
   6. $A = \text{TOP(TaskList)}$;
   7. **Generate a NewActivity based on A;** ## external function
   8. $Q_2 = \text{Query(Phase)}$;
   9. If ($Q_2 > Q_1$) R receives A;
   10. If ($Q_2 \geq$ threshold) Return R;
11. }EndWhile
12. Return R;
2nd Query to support Phase Outcome inference after generating a new task
Conclusion

- The present research is a work in progress
- At this moment we have achieved:
  - An Activity-Effect relationship description with uncertainty
  - A reasoning model to support task analysis
- Our goal is to improve planning automation through
Future Work

- Improve the effects model showing also the secondary effects
- To model behavioral effects
- Improve reasoning with Decision Nodes and Utility Functions in the resulted SSBN
- Planning system integration
- Verification through simulations
COA modeling with probabilistic ontologies

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Planning Process - Interoperability

- COA Determination
  - Decision Support Systems – $C^2$ Systems
  - Planning system as a module
- Different Players may have different planning systems with different problem-solving methods
- How to describe COA to improve planning interoperability?
M&S Interoperability Framework
Probabilities described through PR-OWL, a probabilistic OWL language [Costa 2005, Carvalho 2011]

PR-OWL implements Multi-Entity Bayesian Networks (MEBN) inference [Laskey 2008]

Describes the relations and properties as a deterministic ontology, but has the ability to also describe a Situation Specific Bayesian Network (SSBN) to support reasoning under uncertainty
COA Probabilistic Ontology
Activity Probabilistic Description

- Cumulative Effects Model in PR-OWL

![Diagram showing a model of cumulative effects in PR-OWL with nodes and edges representing relationships such as `isA`, `isActivityToObject`, `isReportedEffect`, `Subject`, `Task`, `ObjType`, `producedEffect`, and `ActivityReport`. The diagram also includes a legend for context and resident nodes.]
Activities Reasoning

- Pull BML/MSDL high level tasks
- Through the support of the probabilistic task ontology, identify activities to be pruned by analyst criteria (defined threshold for each phase and activity)
- Generate SSBN to support the activities inference
- Export a list of the activities to be described within the Planning Context Definition module
process to establish the problem context to be submitted to the domain-independent planning system

- Planning Domain definition – identification of the methods that decomposes the activities and also the operators
- Planning Problem definition – description of the tasks to be decomposed and the initial state declared on the MSDL message
- PDDL files generation