COAST – An Operational Planning Tool for Course of Action Development and Analysis

Australian Government

Department of Defence

Defence Science and Technology Organisation

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Presentation Outline

- Background
- Operational Planning
- Conceptual Modelling of the Planning Domain
- Modelling of COAs
- Analysis of COAs
- Course Of Action Scheduling Tool (COAST)
- Summary and Future Work
Background - Authors

- Lin Zhang, **Brice Mitchell** and Chris Janczura
  - Command and Control Division
  - Defence Science and Technology Organisation
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  - Computer Systems Engineering Centre
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  - Mawson Lakes, South Australia, AUSTRALIA
- Lars M. Kristensen and Peter Mechlenborg
  - Department of Computer Science
  - University of Aarhus
  - Aarhus, DENMARK
Background – Collaborative Research Partners

- Australian National University
  - Canberra, Australia
- University of Adelaide
  - Adelaide, Australia
- TTCP AG3 Dynamic Planning and Execution
  - Australian Representative, Lin Zhang (DSTO)
  - US AFRL, NRL, ARL representatives
  - UK DSTL representative
  - Canada DRDC representative
Background – End Users

- Deployable Joint Force Headquarters, Australia
- Australian Defence Force Warfare Centre, Australia
- HQ Joint Operations Command, Australia
Operational Planning

- Strategic Objectives -> End State = Set of Conditions
- Set of Conditions = Desired Effects
- Desired Effects -> Tasks
- Tasks
  - Assigned Resources
  - Synchronised with other tasks
  - Pre-Conditions
- Tasks ---> Lines Of Operation
- Lines Of Operation = Detailed COA
Operational Planning - Problems

- Time Pressure
- Uncertainty
- Distributed Groups
- 100s of tasks

COAST aims to:
- Resolve potential conflicts in resource requirements
- Ensure causal interdependency (Effects/Pre-Conditions)
- Impose temporal constraints

MS Project:
- Pre-defined schedules of tasks
- No analytical methods
Conceptual Modelling of the Planning Domain

- Mission
- Desired End state
- Initially valid conditions
- Available resources
- Limitations
Conceptual Modelling of the Planning Domain

- Synchronisation
- Preconditions
- Task
  - Duration
  - Success Rate
- Resources
- Effects
Conceptual Modelling of the Planning Domain

Task Duration

- Normal Precondition
- Sustaining Precondition
- Termination Precondition
- Vanishing Precondition

Instant Effect
- Post Effect
- Sustained Effect
- Interruption Effect
- Failure Effect

$t_0$, $t_x$, $t_m$, $t$
Conceptual Modelling of the Planning Domain - Example

- **Mission**: Recover island from the occupation of an opposition force through amphibious operation
- **Desired End State**: Amphibious forces successfully landed
- **Initially Valid Conditions**: Fighter and AAR aircraft deployed to the AO
- **Available Resources**: A number of different Aircraft, Ships, and Troops (detail later)
- **Limitations**: Not to trespass in 3rd party airspace/waters and non favourable weather conditions
Conceptual Modelling of the Planning Domain - Example

**COAST: Conduct amphibious assault**

**Preconditions:**
- Local air control established
- Local sea surface control established
- Local sea sub-surface control established
- En route sea mines cleared
- POE established

**Effects:**
- Amphibious forces successfully landed

**Assigned Forces:**
- 2 x LPA
- 1 x LSH
- 6 x LCH
- 3 x BN

**Task Information**
- Task Duration: 4 Hours
- Probability of Success: 90%
### Conceptual Modelling of the Planning Domain - Example

<table>
<thead>
<tr>
<th>Task name</th>
<th>Preconditions</th>
<th>Effects</th>
<th>Resources</th>
<th>Lost Res.</th>
<th>Duration</th>
<th>Sync. Info.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conduct amphibious assault</td>
<td>• Local air control established (SP)</td>
<td>• Amphibious forces successfully landed (PE)</td>
<td>2 LPA</td>
<td>1 LSH</td>
<td>6 LCH</td>
<td>3 BN</td>
</tr>
<tr>
<td></td>
<td>• Local sea surface control established (SP)</td>
<td></td>
<td></td>
<td></td>
<td>4 Hours</td>
<td>As Soon As Possible</td>
</tr>
<tr>
<td></td>
<td>• Local sea sub-surface control established (SP)</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>• En route sea mines cleared (NP)</td>
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<tr>
<td></td>
<td>• POE established (NP)</td>
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</tr>
<tr>
<td>T2 Conduct combat air patrol</td>
<td>• FOB established (NP)</td>
<td>• Local air control established (SE)</td>
<td>12 FA 18</td>
<td></td>
<td></td>
<td>As required</td>
</tr>
<tr>
<td></td>
<td>• Fighter aircraft deployed to the AO (NP)</td>
<td></td>
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<tr>
<td></td>
<td>• En route refueling provided (SP)</td>
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</tr>
<tr>
<td>T3 Conduct ASW operations in the AO</td>
<td>• FOB established (NP)</td>
<td>• Local sea sub-surface control established (SE)</td>
<td>2 MPA</td>
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<td></td>
<td>As required</td>
</tr>
<tr>
<td></td>
<td>• Local air control established (SP)</td>
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</tr>
<tr>
<td>T4 Conduct airborne operations</td>
<td>• Local air control established (SP)</td>
<td>• POE established (PE)</td>
<td>12 Blackhawk</td>
<td>2 ABN BN</td>
<td>2 Blackhawk</td>
<td>8 Hours</td>
</tr>
<tr>
<td></td>
<td>• FOB established (NP)</td>
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<tr>
<td></td>
<td>• FARP established (NP)</td>
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</tr>
<tr>
<td>T5 Conduct maritime escort operation</td>
<td>• Local air control established (SP)</td>
<td>• Local sea surface control established (SE)</td>
<td>4 FFH</td>
<td></td>
<td></td>
<td>As required</td>
</tr>
<tr>
<td></td>
<td>• Local sea sub-surface control established (SP)</td>
<td></td>
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</tr>
<tr>
<td>T6 Conduct mine clearance operation</td>
<td>• Local air control established (SP)</td>
<td>• En route sea mines cleared (PE)</td>
<td>• 4 Mine Hunters</td>
<td></td>
<td>48 Hours</td>
<td></td>
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<tr>
<td></td>
<td>• Local sea surface control established (SP)</td>
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<tr>
<td></td>
<td>• Local sub-surface control established (SP)</td>
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</tr>
<tr>
<td>T7 Establish FOB</td>
<td>• FOB established (PE)</td>
<td>• 1 ECSS</td>
<td>60 Hours</td>
<td></td>
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</tr>
<tr>
<td>T8 Establish FARP</td>
<td>• FARP established (PE)</td>
<td>• 1 Eng Coy</td>
<td>40 Hours</td>
<td></td>
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</tr>
<tr>
<td>T9 Provide AAR</td>
<td>• FOB established (NP)</td>
<td>• En route refueling provided (SE)</td>
<td>• 4 AAR</td>
<td></td>
<td></td>
<td>As required</td>
</tr>
<tr>
<td></td>
<td>• AAR aircraft deployed to the AO (NP)</td>
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</tbody>
</table>
Modelling and Analysis of COAs

- Using Coloured Petri Nets
  - Discrete Event System with formal mathematical semantics and rigorous analysis capabilities
- Why Coloured Petri Nets?
  - Concurrent systems
  - Resource allocation
  - State based system
  - Generation of possible events from any given state
  - Event Duration and System Time
  - Formal mathematical modelling language
  - Analysis capabilities through state space analysis
The CPN model formally captures the execution of COA:
- Tasks and their attributes (pre-conditions, effects, duration, required resources)
- Set of currently valid conditions
- Available resources

The state of the system is represented by:
- Set of tasks (idle, executing, or done)
- Set of currently valid conditions
- Set of currently available resources

An event in the system could be:
- Start/Termination of Tasks
- Change of valid conditions
- Change of available resources
Modelling and Analysis of COAs
Modelling and Analysis of COAs

1. Conditions
   - Conditions 1: [CONDITION(\("E1\", true\)), CONDITION(\("E2\", false\)), CONDITION(\("E3\", false\)), CONDITION(\("E4\", false\)), CONDITION(\("E5\", false\)), CONDITION(\("E6\", false\))]

2. Resources

3. Tasks

4. Initialise
   - Initialise HS

5. Execute
   - Execute HS

6. Status
   - Status Task x Res x Status

Environment

HS
Modelling and Analysis of COAs

- CPN model ensures the line of operation is suitable (logical) and feasible (resource conflicts)
- Input: Set of tasks, Initially Valid Conditions, Available Resources
- Output: Lines of operation (start and end times for all tasks leading to the end state)
- Method: State Space Analysis of the CPN model
Modelling and Analysis of COAs
Modelling and Analysis of COAs

- 2 phases of LOP generation
  - Depth-first
  - Breadth-first
COAST Overview

- COAST – Coast Of Action Scheduling Tool
- COA Development and Analysis
- Task scheduling must be suitable (logical) and feasible (resources)
- Client-Server Architecture
Course Of Action Scheduling Tool (COAST)
Course Of Action Scheduling Tool (COAST)
Course Of Action Scheduling Tool

Conduct amphibious assault (T1)

Name: Conduct amphibious assault (T1)

Comments:

Start Time:
- Start At: [Date Picker]
- Start At or After: [Time Picker]
- On: [Date Picker]
- D-Day: [Date Picker]
- W: [Weekday Picker]
- D: [Day of Month Picker]
- H: [Hour Picker]

Start Time: 01/05/04 15:30

Duration:
- As Required
- As Long As Possible

Duration: 0W 0D 4H

Multiplicity:
- Fixed Number of Repetitions: 1

More Details:

Task Conditions: Task Resources: Task Synchronisations: Other Attributes:

Task Conditions

PreConditions:
- En route sea mines cleared
- POE established
- Local air control established
- Local sea surface control established
- Local sea sub-surface control established

Details of:
- None

Possible Conditions:
- Local air control established
- Local sea surface control established
- Local sea sub-surface control established
- En route sea mines cleared
- POE established
Course Of Action Scheduling Tool (COAST)

Relationships
- Normal Pre-Condition/Effect
- Sustaining Pre-Condition/Effect
**Course Of Action Scheduling Tool (COAST)**

<table>
<thead>
<tr>
<th>Time: (hours)</th>
<th>0.0</th>
<th>24.0</th>
<th>48.0</th>
<th>72.0</th>
<th>96.0</th>
<th>120</th>
</tr>
</thead>
<tbody>
<tr>
<td>Establish FARP (T8)</td>
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<tr>
<td>Establish FOB (T7)</td>
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<tr>
<td>Conduct airborne operations (T4)</td>
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<tr>
<td>Conduction combat air patrol (T2)</td>
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<tr>
<td>Provide AAR (T9)</td>
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<tr>
<td>Conduct mine clearance operation (T6)</td>
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<tr>
<td>Conduct ASW operations in the AO (T3)</td>
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<tr>
<td>Conduct maritime escort operation (T5)</td>
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<tr>
<td>Conduct amphibious assault (T1)</td>
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</tbody>
</table>

**Scale:**
- Horizontal: Cell Width: 24 hour(s)
- Vertical: Cell Height: 30 unit(s)
Summary

- Formal representation of the planning domain
- Modelling and Analysis using Coloured Petri Nets
- Prototype tool with client/server architecture
- COAST client captures the planning problem (INPUT)
- COAST server returns suitable and feasible LOPs (OUTPUT)
Current and Future Work

• Tool experimentation
• Multiple Servers
• Extension of features in current client and server
Questions?