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Model-based Operational Planning Using Coloured Petri Nets

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AUSTRALIA

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Outline

- DSTO and its Role to Support Operational Planning
- Operational Planning in the Australian Defence Force (ADF)
  - Overview of the process
  - Overview of DSTO modelling and analysis to support to operational planning
- Concepts of Model-based Operational Planning
- COA Scheduling Tool (COAST)
- Conclusions and Future Work

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Defence Science and Technology Organisation (DSTO)

- DSTO advises the Australian Defence Force on science and technology applications that will meet Australia's defence and security needs.
- DSTO research assists the Australian Defence Force by:
  - Investigating the use of future technologies for defence applications
  - Ensuring Australia is a smart buyer of defence equipment
  - Developing new defence capabilities
  - Enhancing existing capabilities by increasing performance and safety, and reducing costs

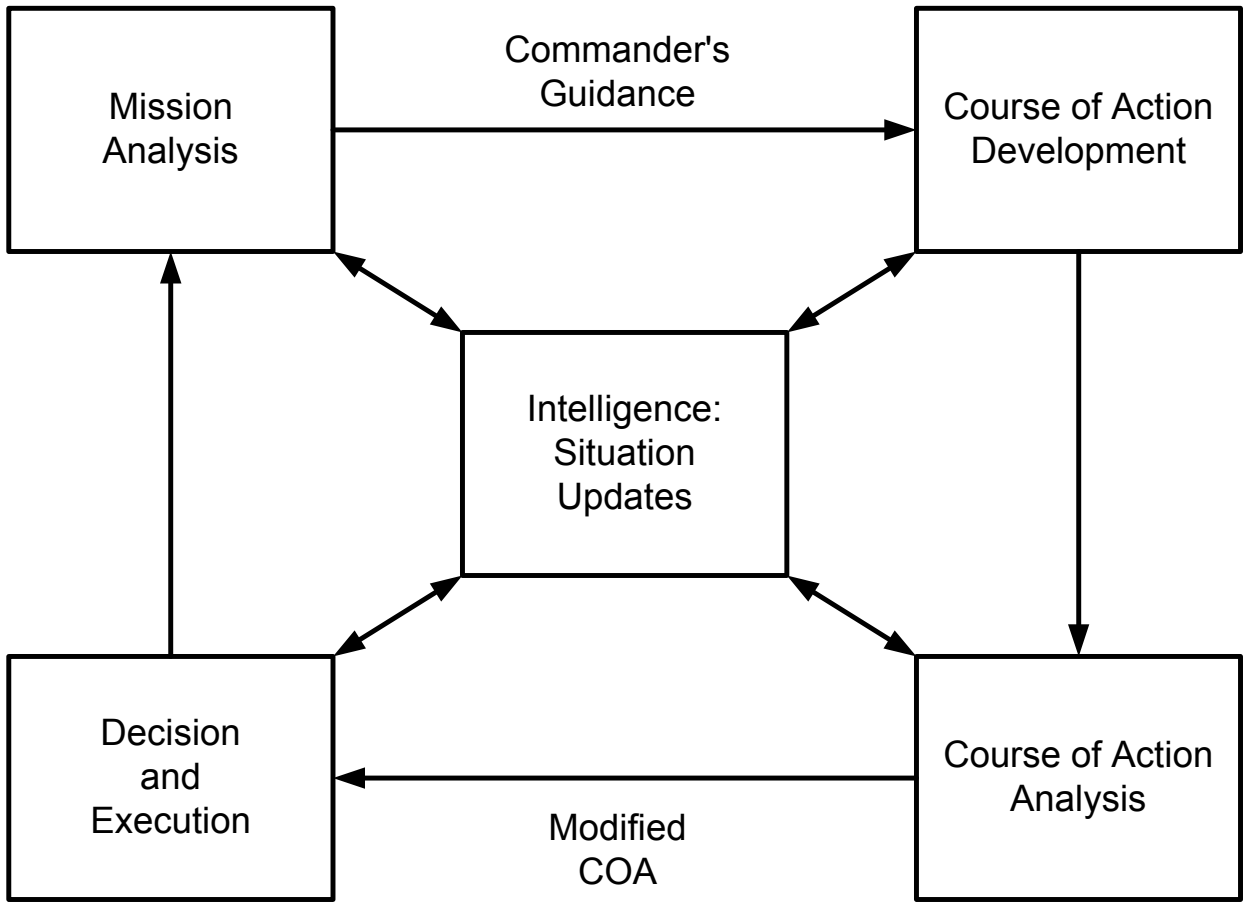
DSTO Support to Operational Planning

- DSTO is tasked by the Australian Defence Force to provide modelling, simulation and analysis support to military operational planning

What is Operational Planning

- Operational planning is the process of producing operational plans.
- An operational plan is a description of military operations, with a prescribed order, that are intended to achieve a desired *end state*.
- Operational planning is one of the functions in military command and control (C2).
- C2 is sometimes be seen as the military equivalent of business management.

The Process - Joint Military Appreciation Process (JMAP)



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JMAP Steps

Preliminary Scoping

1.Situation update
2. Strategic/higher direction
3. Commander's initial guidance
4. Establish planning timeline
5. Coordinate actions and allocation of responsibilities
6. Essential repositioning and alterations to readiness levels to meet timetime

Mission Analysis

1. Review the situation
2. Identify and analyse the superior commander's intent and mission
3. Identify and analyse tasks
4. Identify and analyse the freedom of action
5. Identify and analyse critical facts and assumptions
6. Confirm commander's guidance

1. Mission analysis brief
2. Commander's Guidance

COA Development

1. Confirm centre of gravity
2. Conduct critical capability analysis
3. Develop decisive points and lines of operation
4. Develop broad courses of action
5. Develop detailed course of action
6. Test course of action criteria

1. Threat Estimates
2. Critical Vulnerability Analysis
3. Analysis of operational environment
4. IPB updates

Intelligence

1. Define the battlespace environment
2. Describe the battlespace effects
3. Evaluate the threat
4. Determin threat COAs

1. Viable COAs
2. COA brief
3. Branches/sequels

1. Plan
2. Supporting plans and orders

Decision and Execution

1. Compare the COAs
2. Select the COA
3. Develop and issue the plan
4. Execute the plan

1. Modified COAs
2. COA analysis brief

COA Analysis

1. Determine the wargame start state
2. Select the wargame method
3. Select the wargame record
4. Conduct the wargame

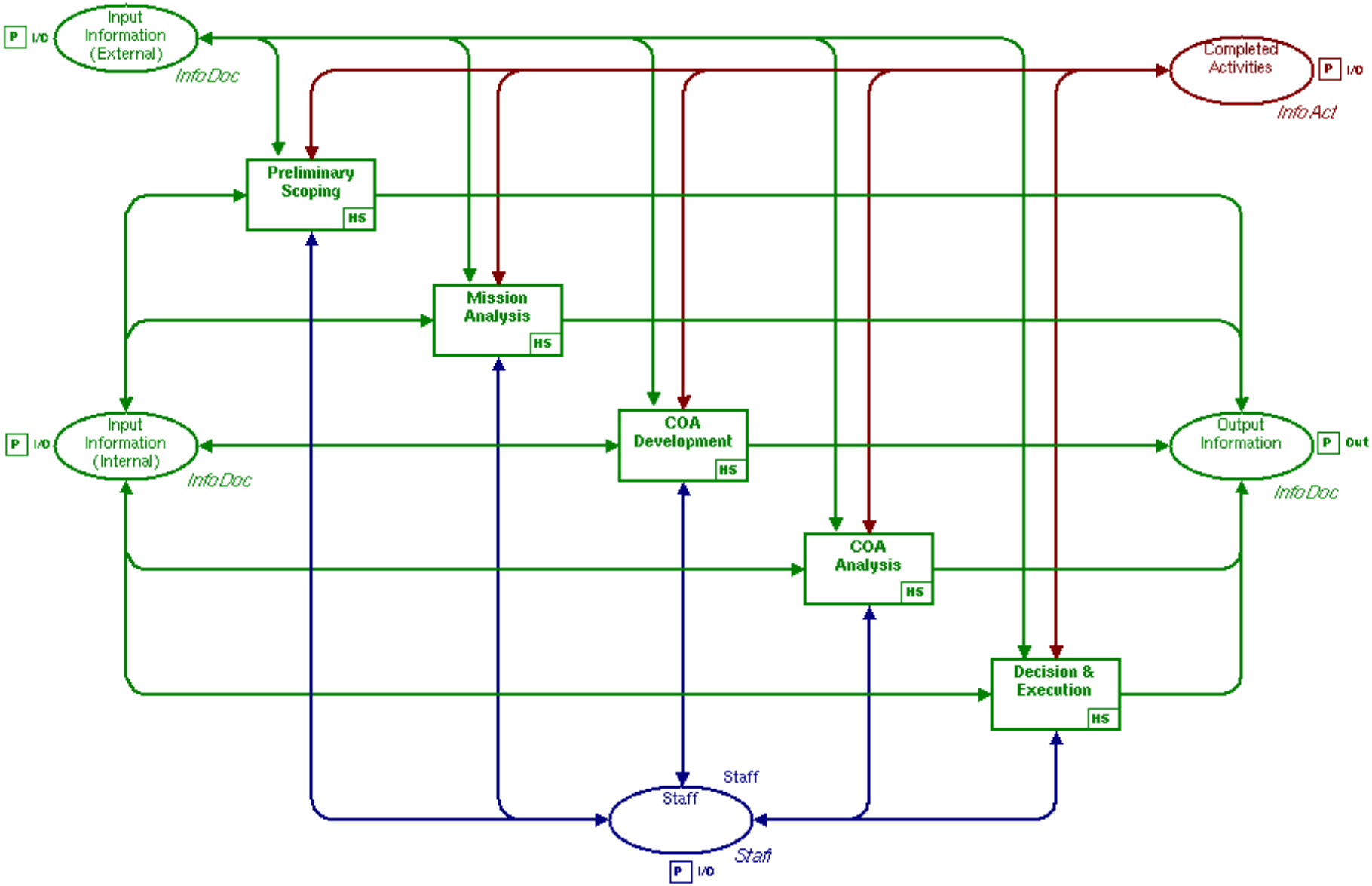
Problems with the Planning Process

- A typical planning exercise in a military Headquarters can involve up to 100 staff across 9 Branches
- It requires close interactions and collaboration between the staff officers and the commander, and between the planning Headquarters and its superior and subordinate Headquarters
- It involves enormous amount of information flow and intensive knowledge transfer in all forms: electronic documents, briefing, brainstorming meetings, etc.

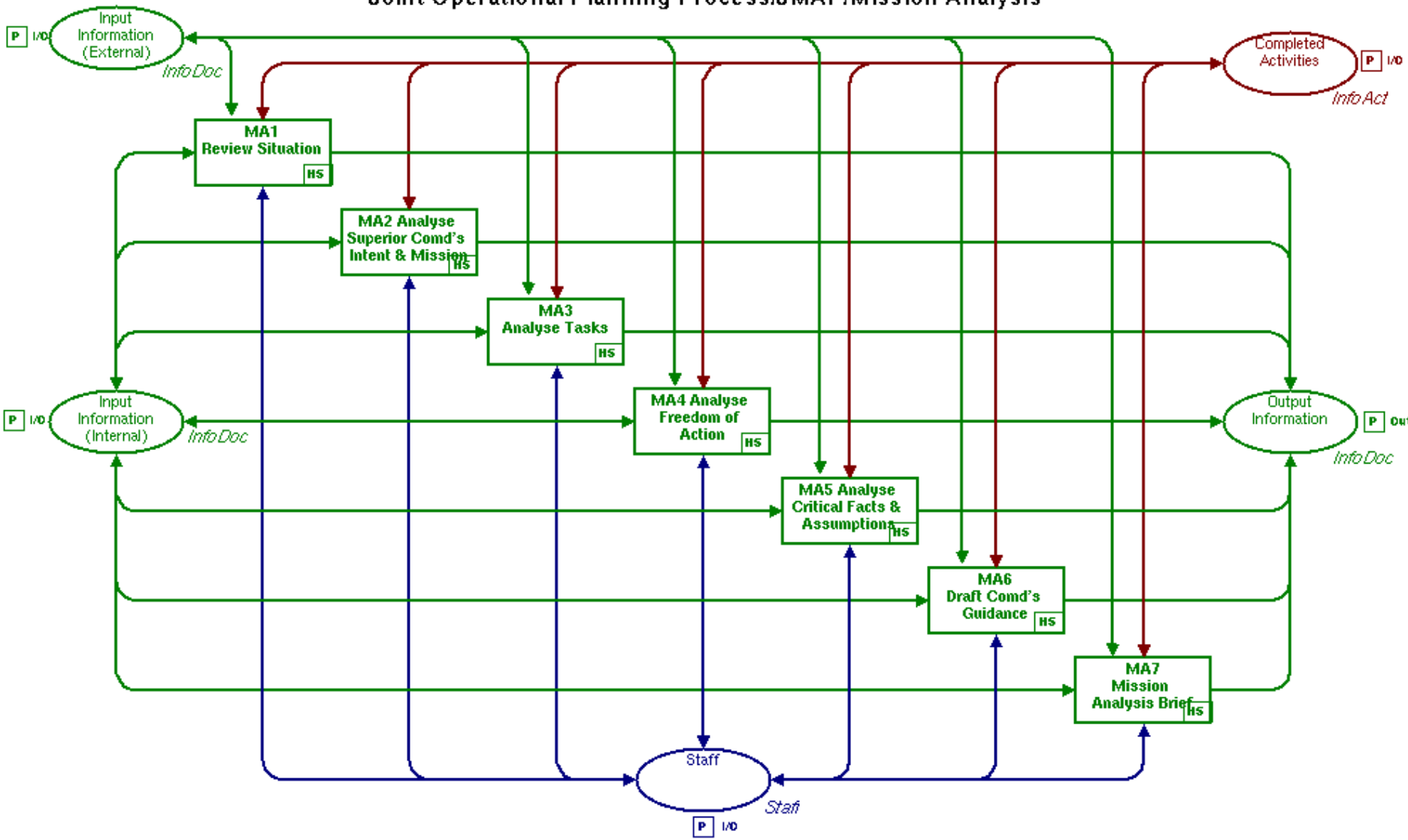
Possible Initiatives to Support the Process

- Data and knowledge management systems
  - General: Lotus Notes, …
  - Tailored: GEMS (DSTO), TOPFAS (NATO), PLANMAN (UK DSTL), …
- Groupware
  - General: Group System V
  - Tailored: GEMS, PLANMAN
- Workflow management system
  - Challenges
    - How much of the process can be formalised?
    - How much of it is computer-based?
- Tools for process design, monitoring and analysis
- A formal process model would benefit or enable the above initiatives

Joint Operational Planning Process/JMAP



Joint Operational Planning Process/JMAP/Mission Analysis



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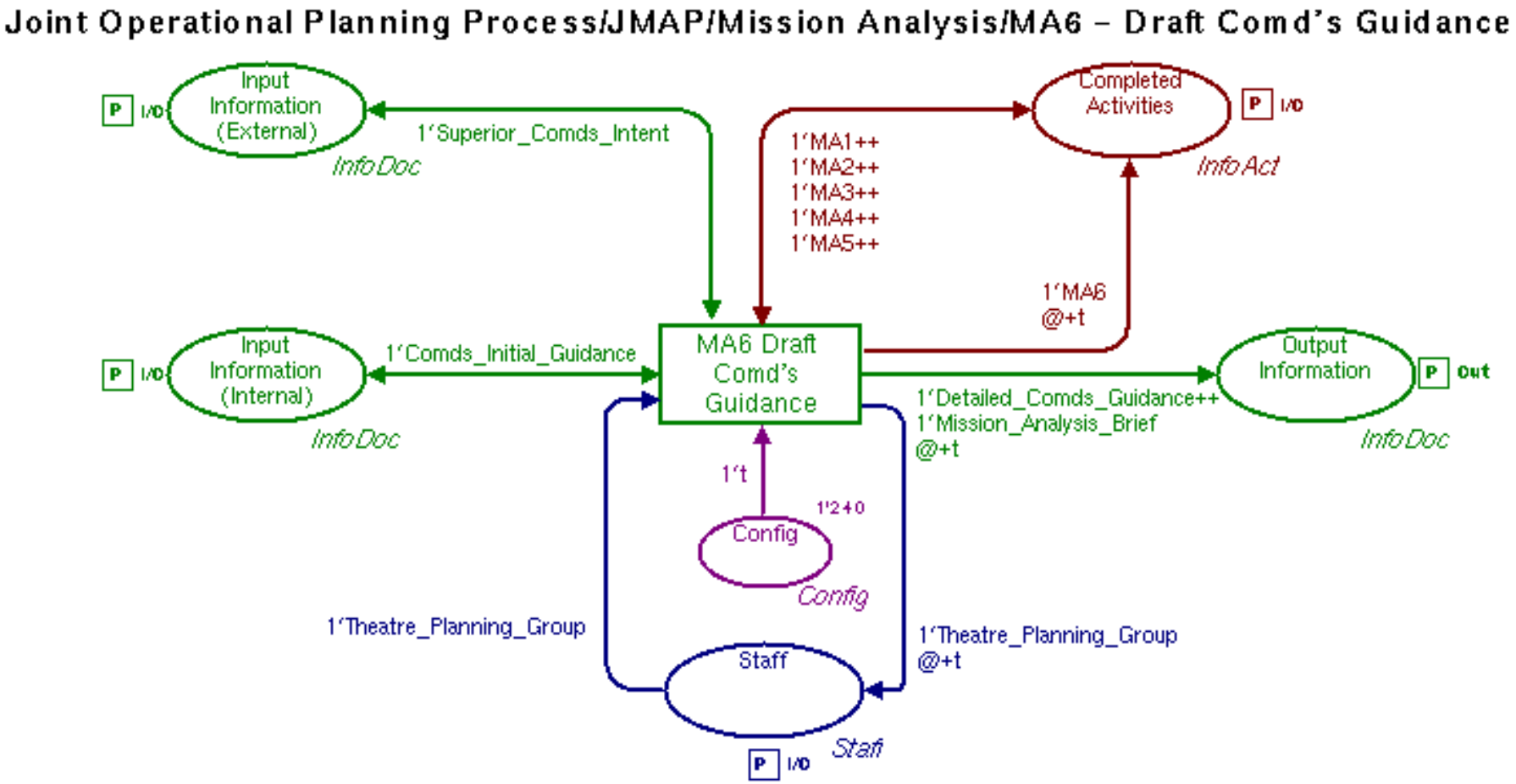
Draft Commander's Guidance



Process Analysis

- The CPN model of JMAP was populated with data observed from a planning exercise at an ADF Headquarters
- State space analysis was conducted to show
  - Staff activities over the planning period
  - Planning activity GANTT chart
  - Staff usage over time and activities
  - Number of times that certain staff were concurrently required by activities (an indicator for de-conflicting resource requirements)

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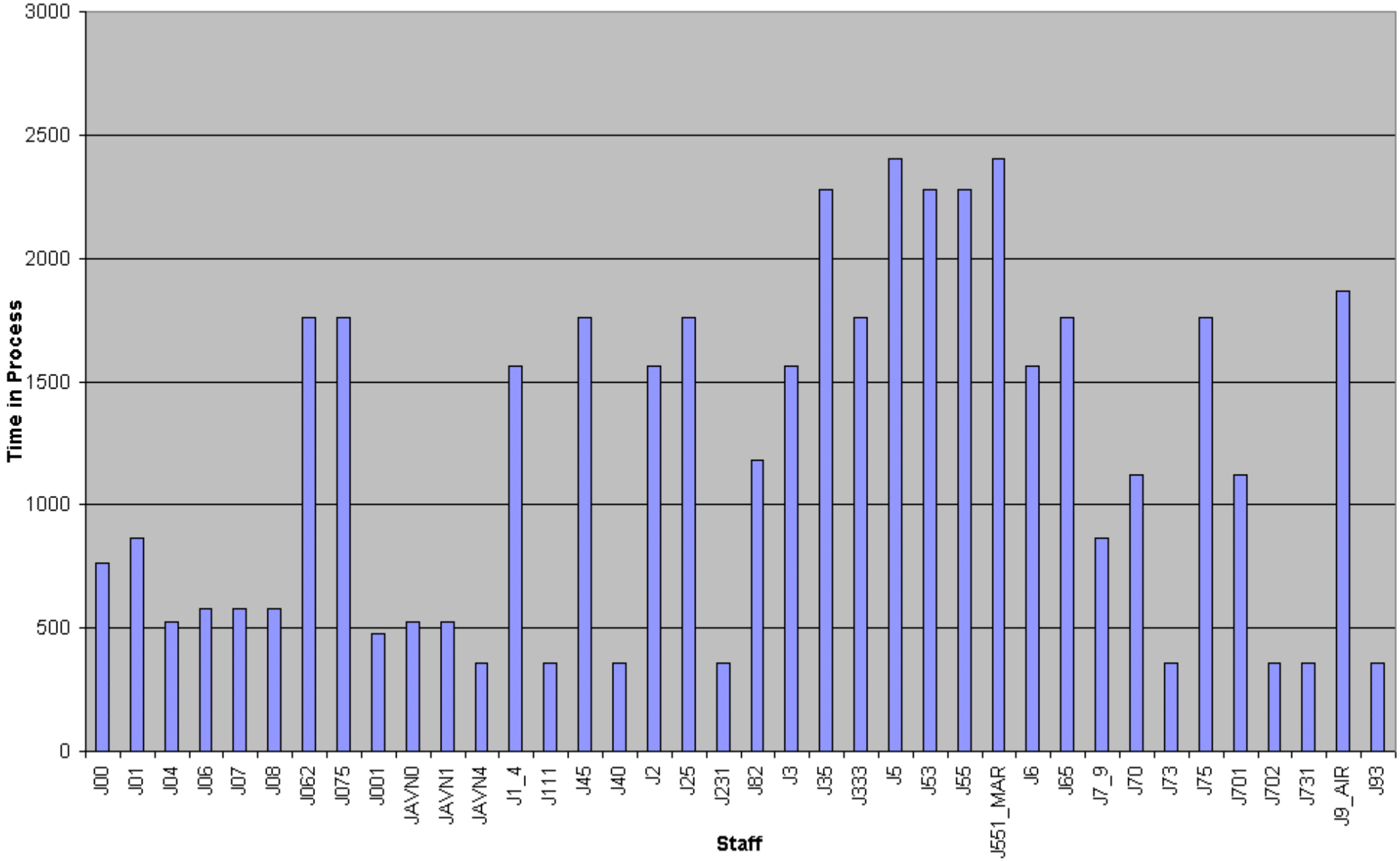
Staff Participation



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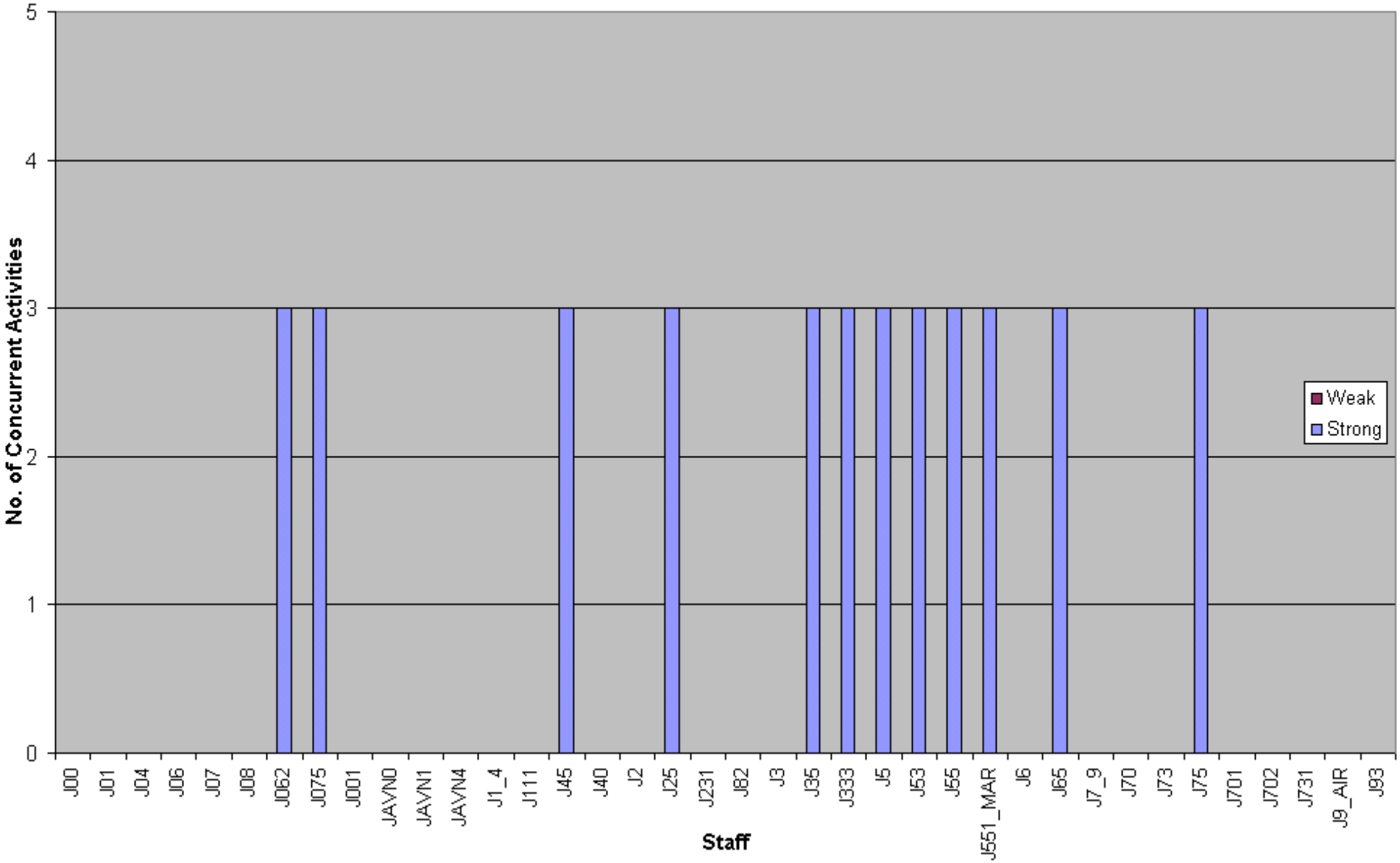
Instances of Staff Simultaneously Required by Multiple Activities



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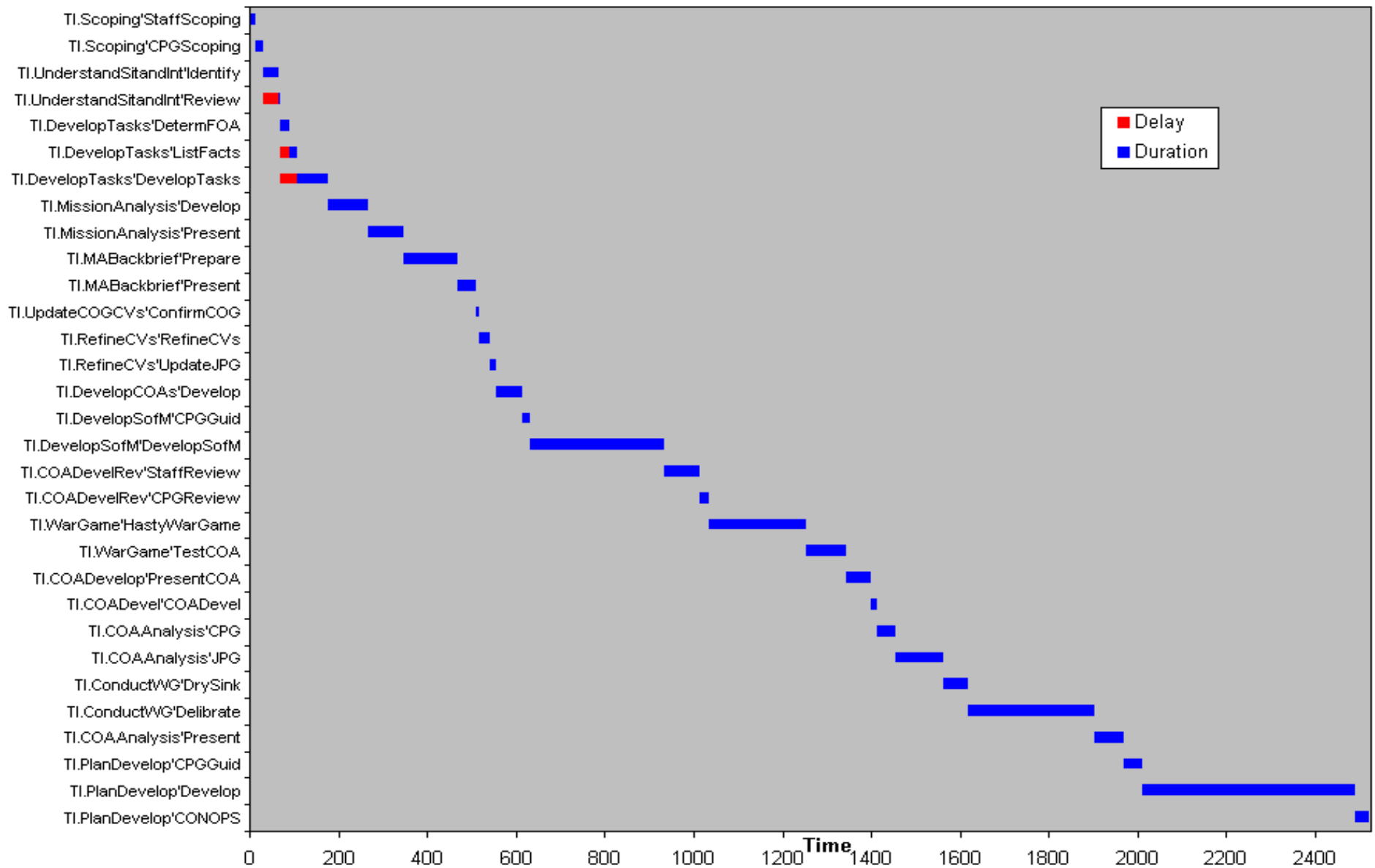
Activity GANTT chart



Other Benefits of Modelling the ADF Planning Process

- Provided the Chief of Staff with a means of designing and experimenting with the operational planning process
- Developed a capability of analysing operational level planning processes
- Provided feedback to the development of the ADF Joint operational planning doctrine and subsequent training

Future Work on Process Modelling

- Develop a highly parameterised model of operational planning processes to allow near real-time population of the model for analysis with state space techniques
  - Aiming to provide timely analysis results and feedback to the commander and planning staff
- Develop facilities to provide more intuitive visualisation of analysis results
  - To compensate for parameterisation of the model
- Develop a scheduling tool to support the planning, monitoring and analysis of planning processes
  - As requested from the Chief of Staff
- Support the design and specification of workflow

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Next, to Support the Development of Plans

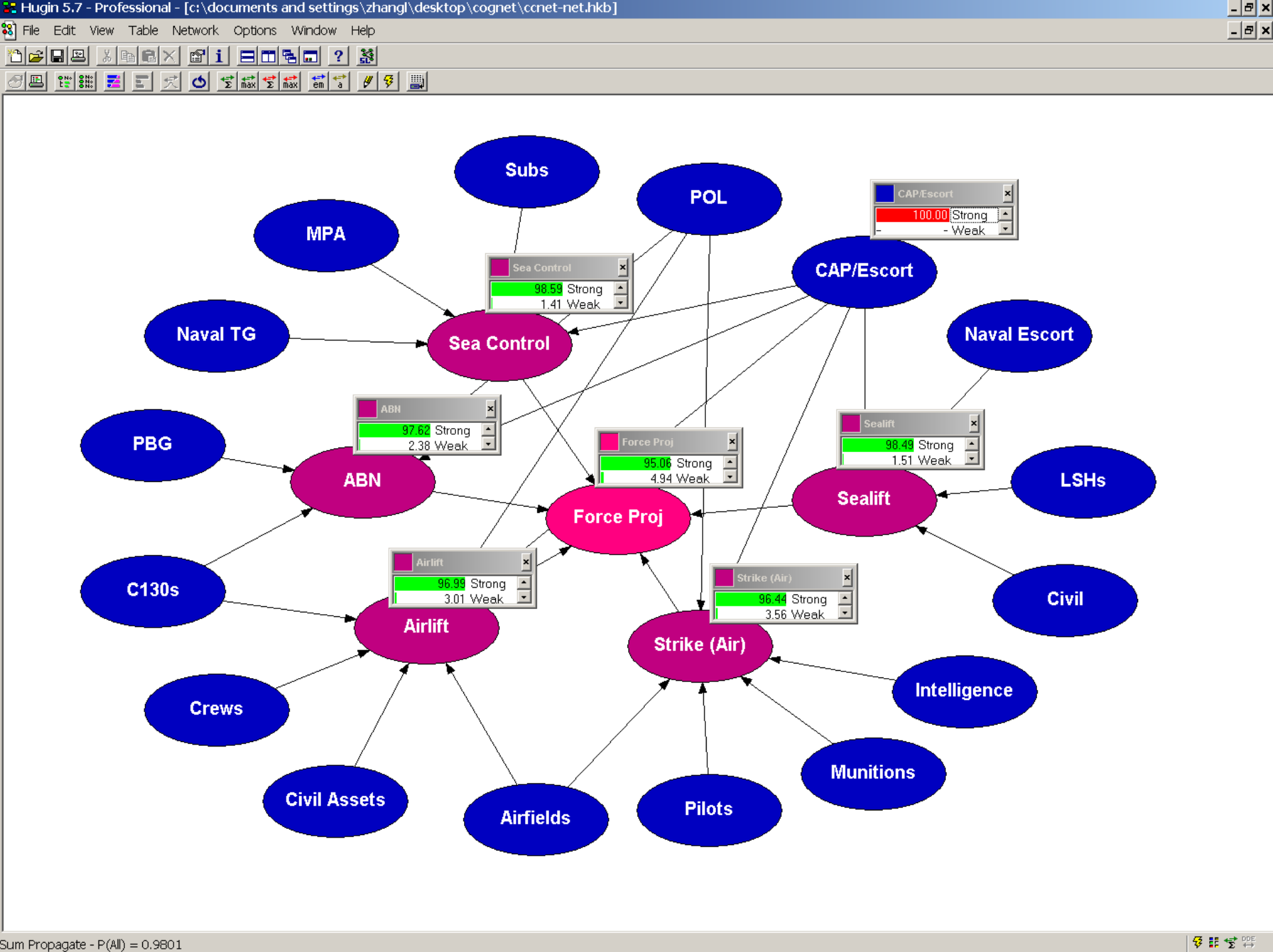
- **Operational Planning Remarks**
  - An operational plan is designed with an intention to reach a desired end state.
  - An operational plan normally consists of two logical parts:
    - a description of tasks (actions or operations), and
    - a prescribed (partial) order for the execution of tasks.
  - An operational plan answers three basic questions
    - Where are we now – initial state
    - Where do we want to be – desired end state
    - How to get there – suitable and feasible COA

Major Analytical Activities in Operational Planning

- Determine the desired end-state with constituent criteria and associated conditions
- Identify critical factors that can be influenced in order to achieve the desired end state
- Develop operational tasks to influence the identified critical factors to achieve the desired end state
- Sequence the tasks
- Analyse possible task sequences with a view to choosing the optimal sequence

How To Identify Critical Factors

- DSTO developed a software tool, Centre Of Gravity Network Effects Tool (COGNET), to help identify critical factors to be influenced for the achievement of the desired end state
- COGNET is a knowledge based decision support system for reasoning under uncertainty in the complex environment of operational planning
  - Based on the formalism of Bayesian Belief Networks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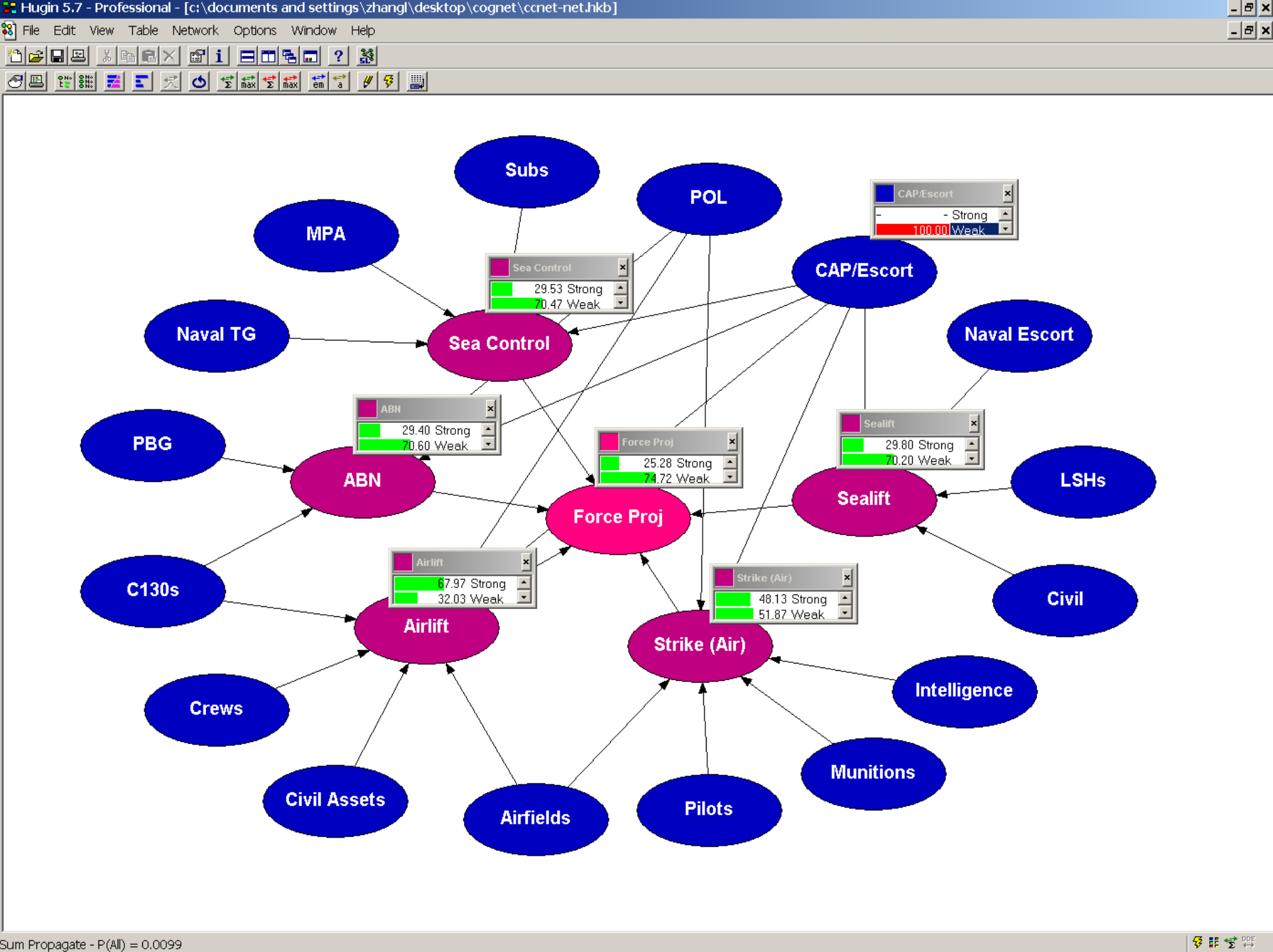
File Edit View Table Network Options Window Help
Subs
POL
MPA
CAP/Escort
100.00 Strong
- Weak
Sea Control
98.59 Strong
1.41 Weak
CAP/Escort
Naval TG
Sea Control
Naval Escort
ABN
97.62 Strong
2.38 Weak
PBG
ABN
Force Proj
95.06 Strong
4.94 Weak
Sealift
98.49 Strong
1.51 Weak
LSHs
Sealift
Force Proj
C130s
Airlift
96.99 Strong
3.01 Weak
Airlift
Strike (Air)
96.44 Strong
3.56 Weak
Civil
Strike (Air)
Crews
Intelligence
Civil Assets
Airfields
Pilots
Munitions
Sum Propagate - P(All) = 0.9801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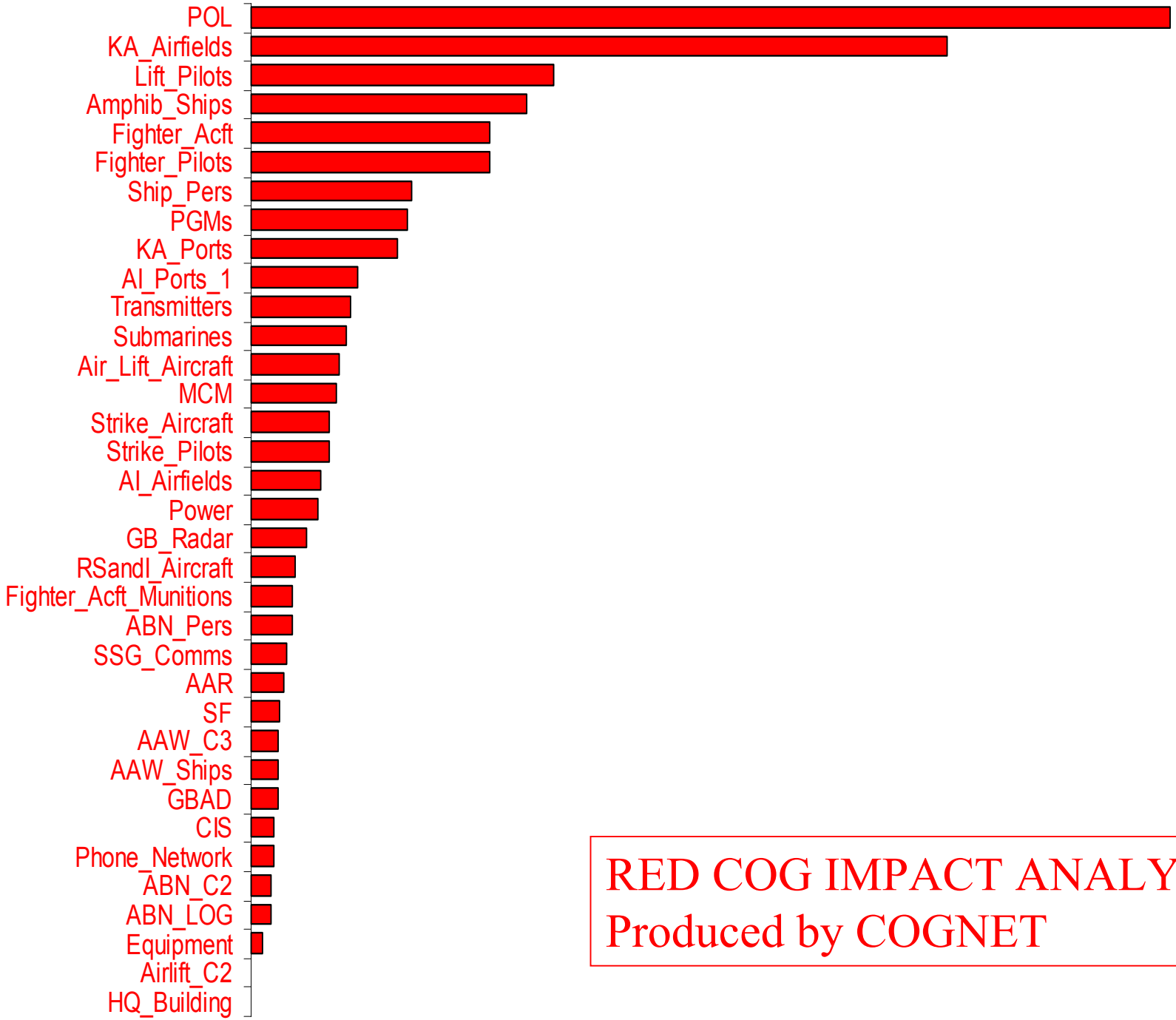
Subs
POL
MPA
CAP/Escort
- Strong
100.00 Weak
Sea Control
29.53 Strong
70.47 Weak
CAP/Escort
Naval TG
Sea Control
Naval Escort
ABN
29.40 Strong
70.60 Weak
PBG
ABN
Force Proj
25.28 Strong
74.72 Weak
Sealift
29.80 Strong
70.20 Weak
LSHs
Force Proj
Sealift
C130s
Airlift
67.97 Strong
32.03 Weak
Strike (Air)
48.13 Strong
51.87 Weak
Civil
Airlift
Strike (Air)
Crews
Intelligence
Civil Assets
Airfields
Pilots
Munitions
Sum Propagate - P(All) = 0.0099



RED COG IMPACT ANALYSIS
Produced by COGNET

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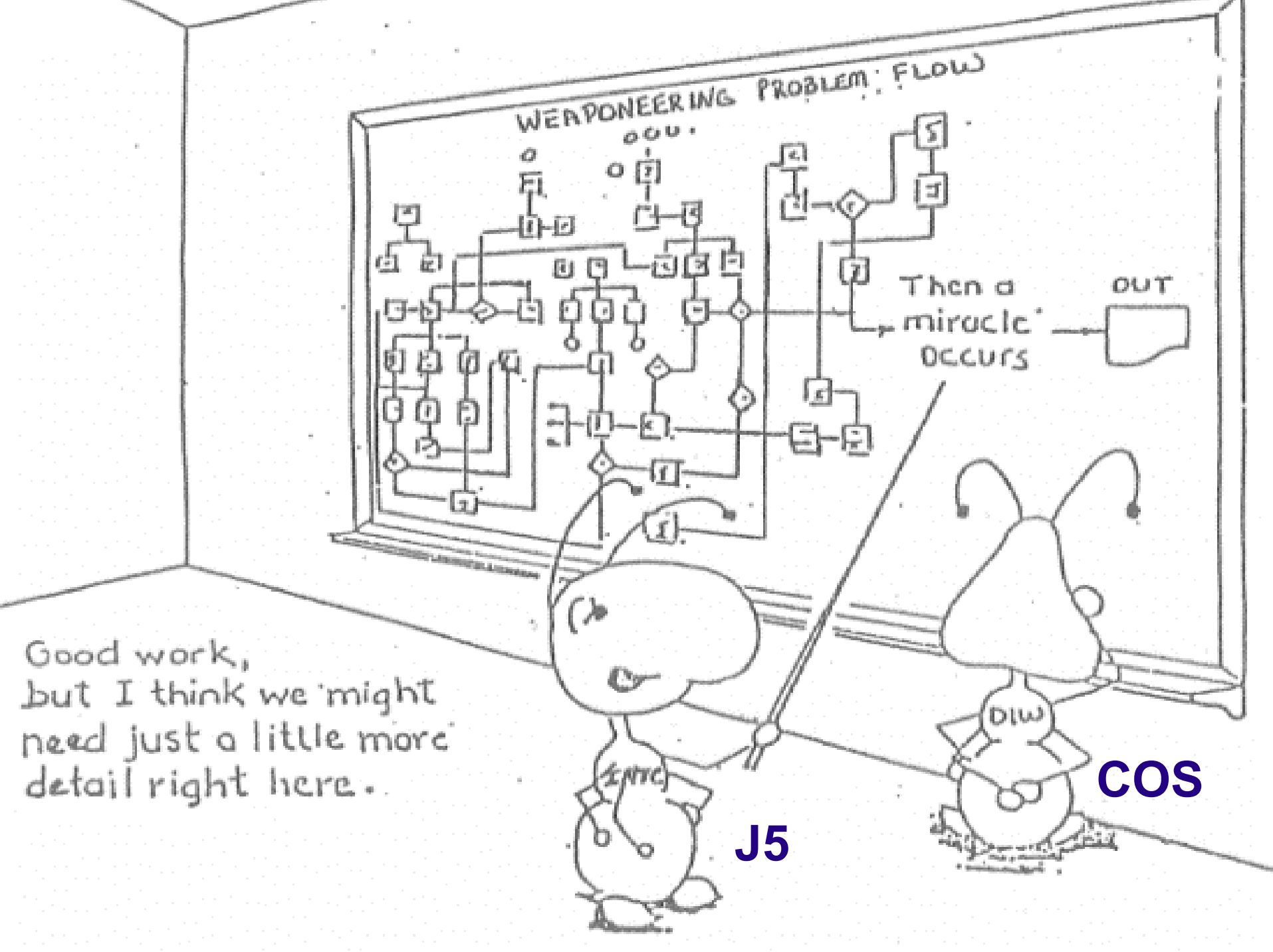
WEAPONEERING PROBLEM: FLOW
Then a miracle occurs
OUT
Good work, but I think we might need just a little more detail right here.
J5
COS

Major Analytical Activities in Operational Planning

- Determine the desired end-state with constituent criteria and associated conditions
- Identify critical factors that can be influenced in order to achieve the desired end state
- Develop operational tasks to influence the identified critical factors to achieve the desired end state
- Sequence the tasks
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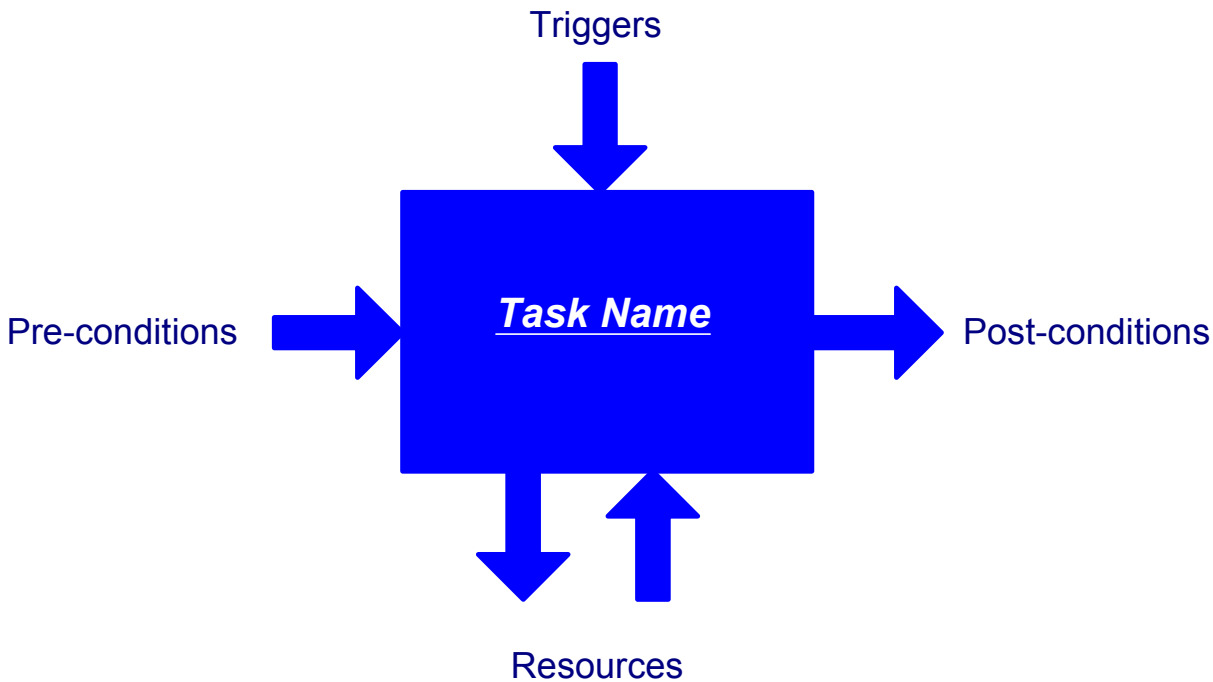
How To Develop and Sequence Operational Tasks

- Develop operational tasks to effect on the identified critical factors
- Qualify each operational task with
  - Triggers: external events that trigger the task
  - Pre-conditions: conditions that must exist for the task to execute
  - Post-conditions: conditions as a result of task execution
  - Resources: forces and other resources required for the task
    - Lost resources: resources that are lost due to task execution
  - Duration: estimated time for task execution
  - Probability of Success: probability of success given pre-conditions and resources
- Use formal methods to produce logical and feasible sequences of operational tasks (lines of operation)

Basic Operational Task Model

Task Information

- Task Duration
- Probability of Success



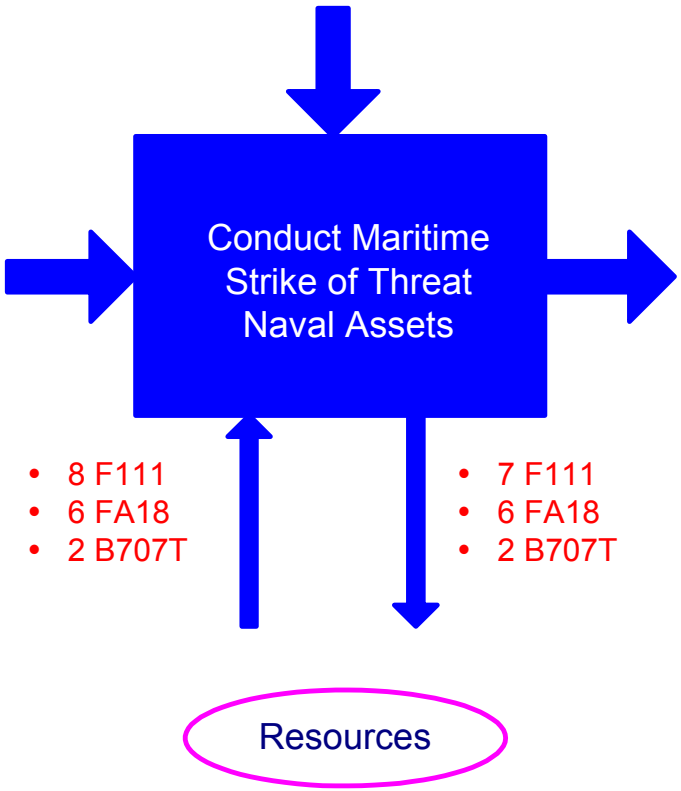
A Concrete Task Example

Task Information

Task Duration: 24 Hours
Probability of Success 80%

Trigger:

- H-Hour



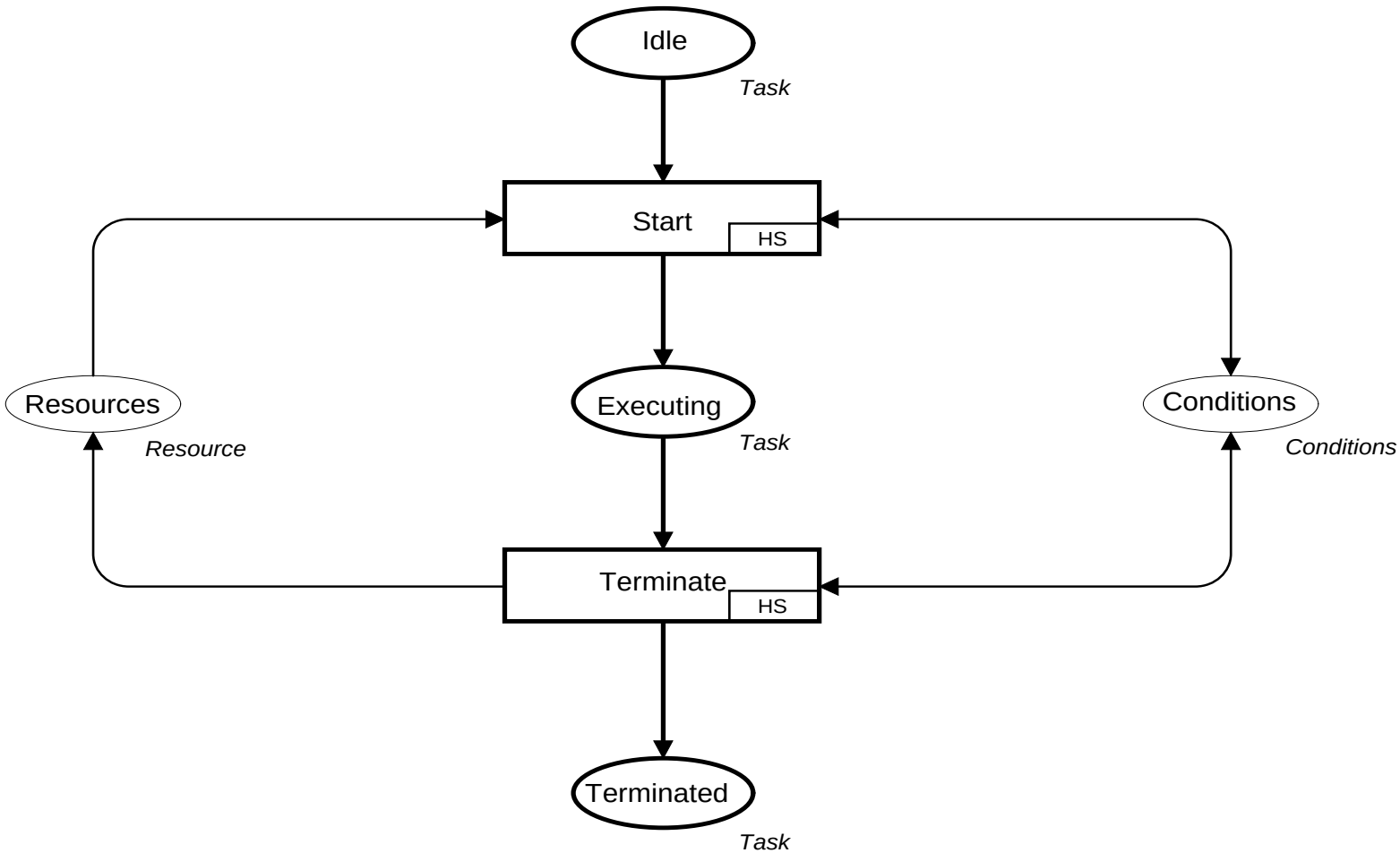
Pre-conditions:

- Intelligence on location of threat naval assets
- Establishment of FOB

Post-conditions:

- Threat naval assets neutralised

A CPN Task Execution Model



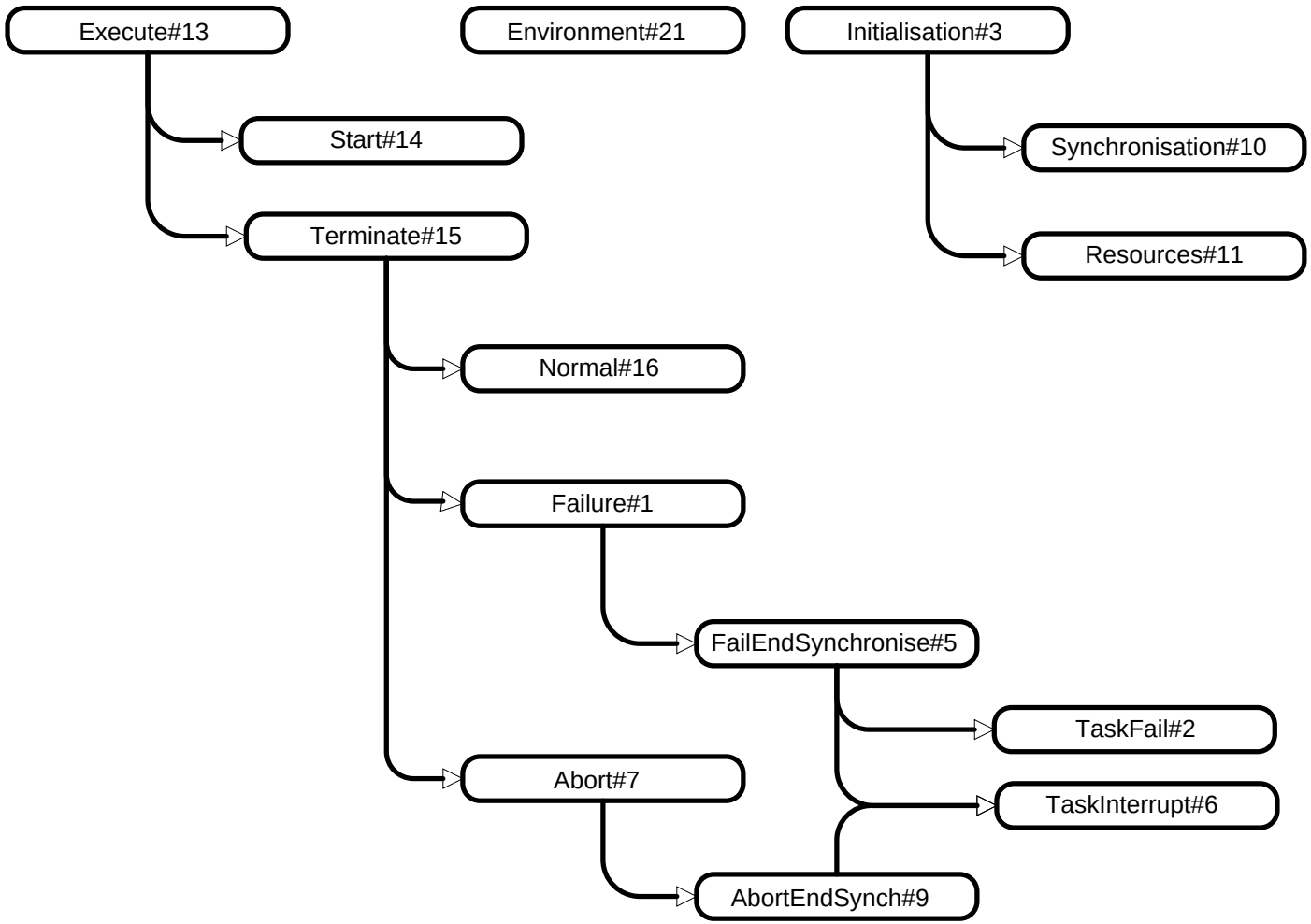
Summary of Our Approch

- Develop a highly parameterised generic model of tasks
- Formalise the generic model with CPNs
- Human operators (military planners) specify attributes of individual tasks (pre- and post- conditions, resources, synchronisation requirements, etc)
- The specified tasks become an input to the CPN model
- The CPN model is then executed to generate the state space to represent collective behavious of the tasks
- An analysis of the state space is conducted to generate lines of operations (logical and feasible sequences of tasks)
- Finally, the state space representation of lines of operations enables further analysis of lines of operation
  - From here on, COAs are mathematical, and optimisation is possible
  - Many views of COAs can be generated

Representing All Possible Task Behaviours

- Not a trivial matter!
- Types of pre-conditions
  - Start pre-conditions
  - Vanishing pre-conditions
  - Time vanishing pre-conditions
  - …
- Types of post-conditions
  - Start post-conditions
  - Duration post-conditions
  - …
- Synchronisation
  - Begin, end, timed, …
- Task termination:
  - Normal, Interrupted, Failed

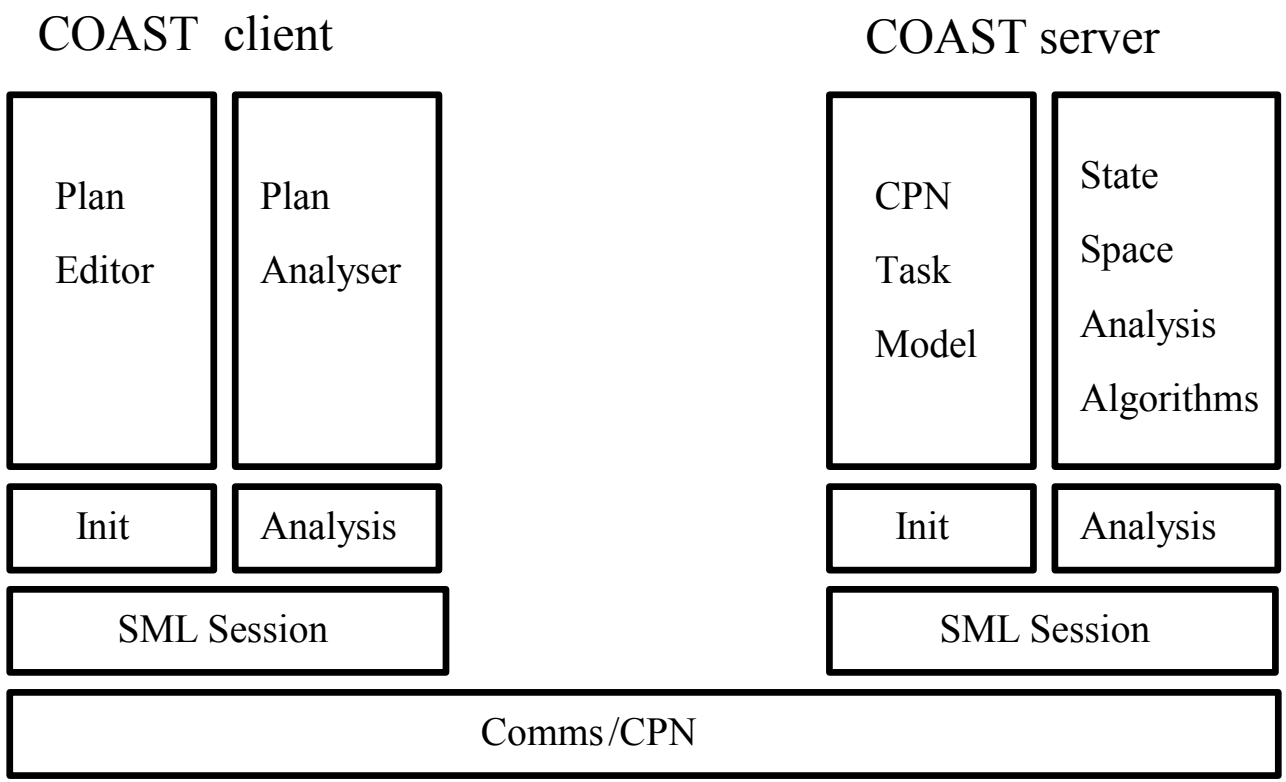
CPN Task Model Overview



COAST: Course Of Action Scheduling Tool

- **Motivations**
  - Facilitate task development through
    - a friendly task editing GUI, and
    - a comprehensive set of task templates
  - Support COA development through
    - generating lines of operations,
    - multiple views of lines of operations, and
    - quantitative analysis of lines of operation
  - Hide CPN formalism from users

Software Architecture of COAST



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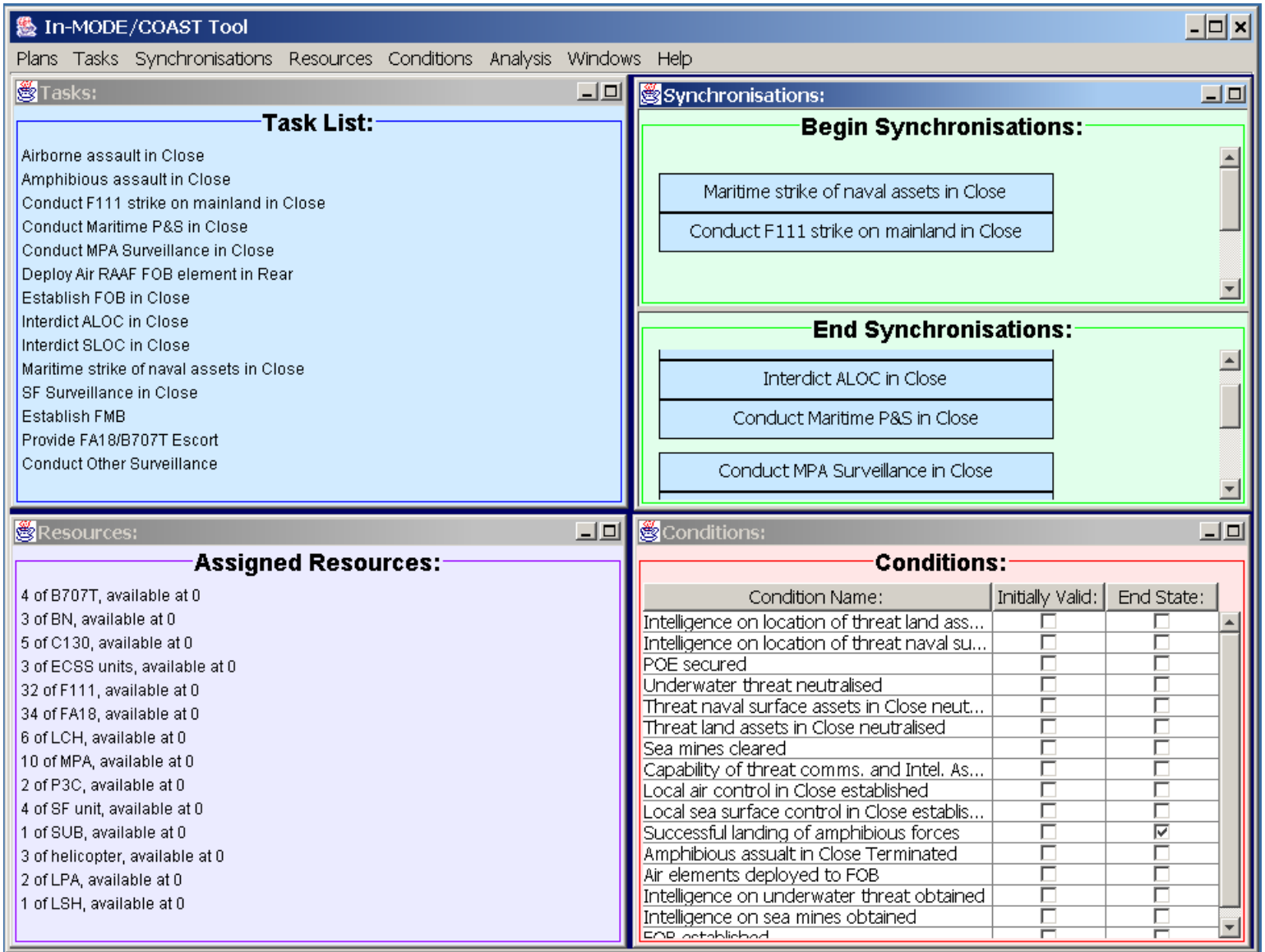
COAST Client



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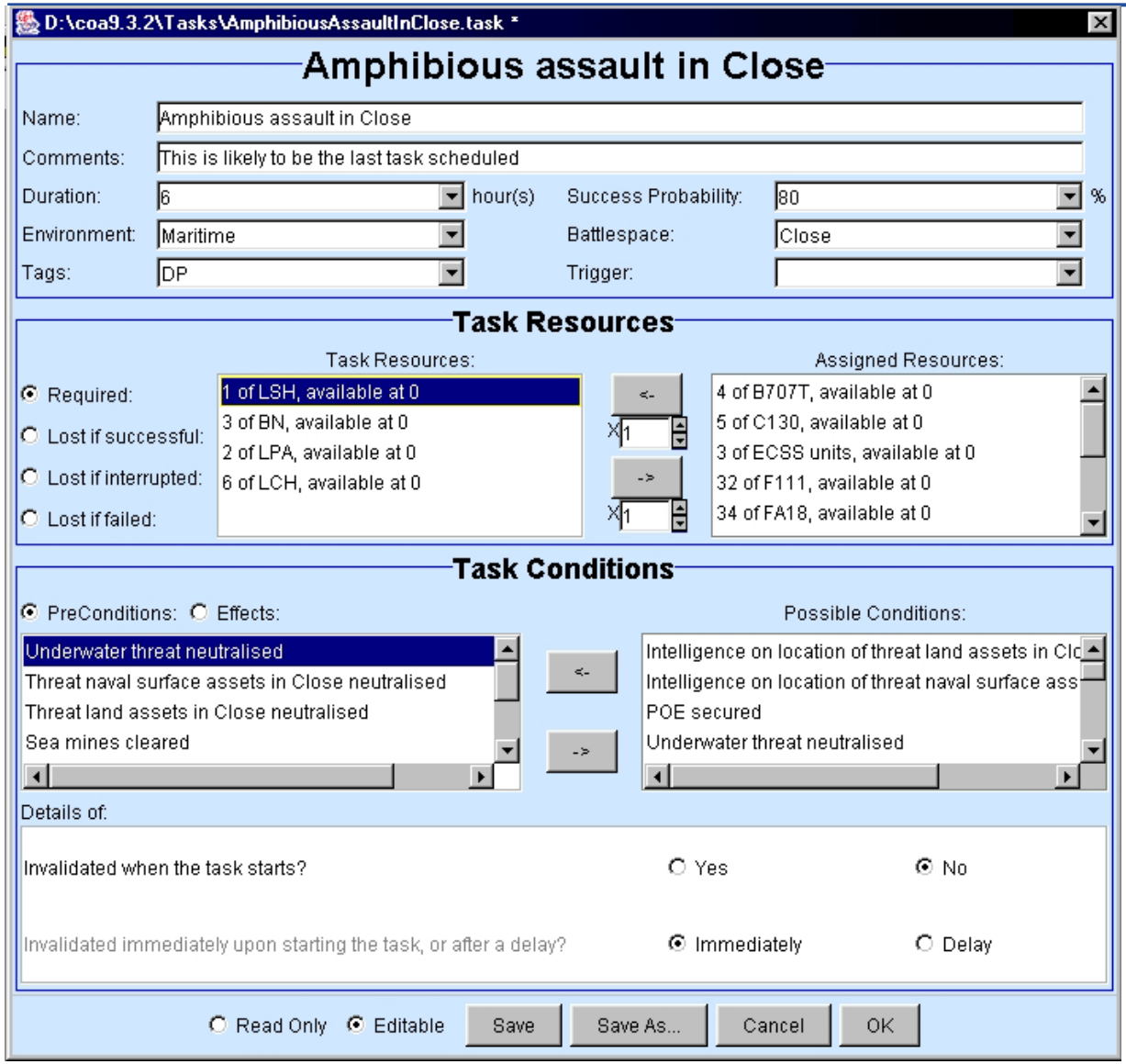
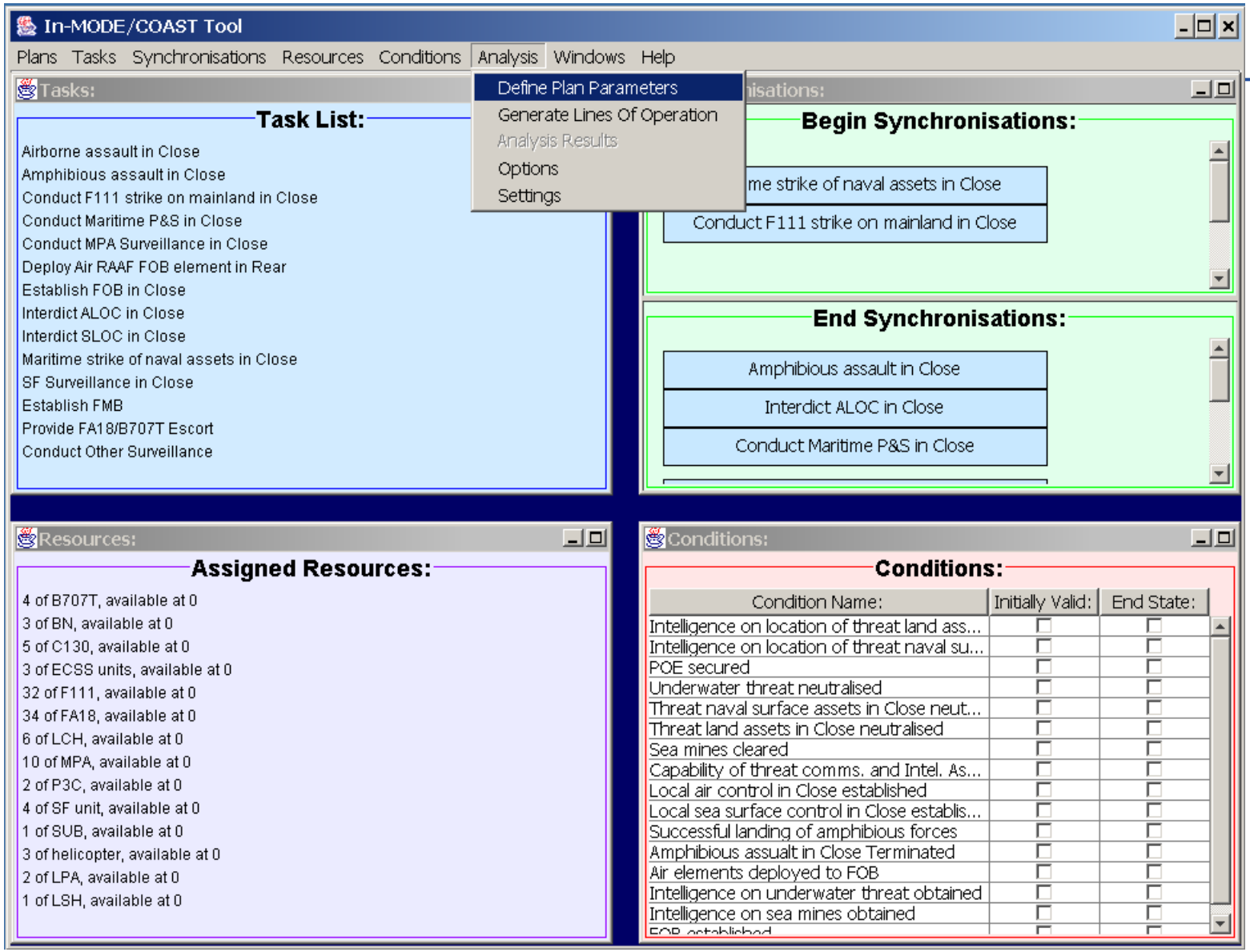
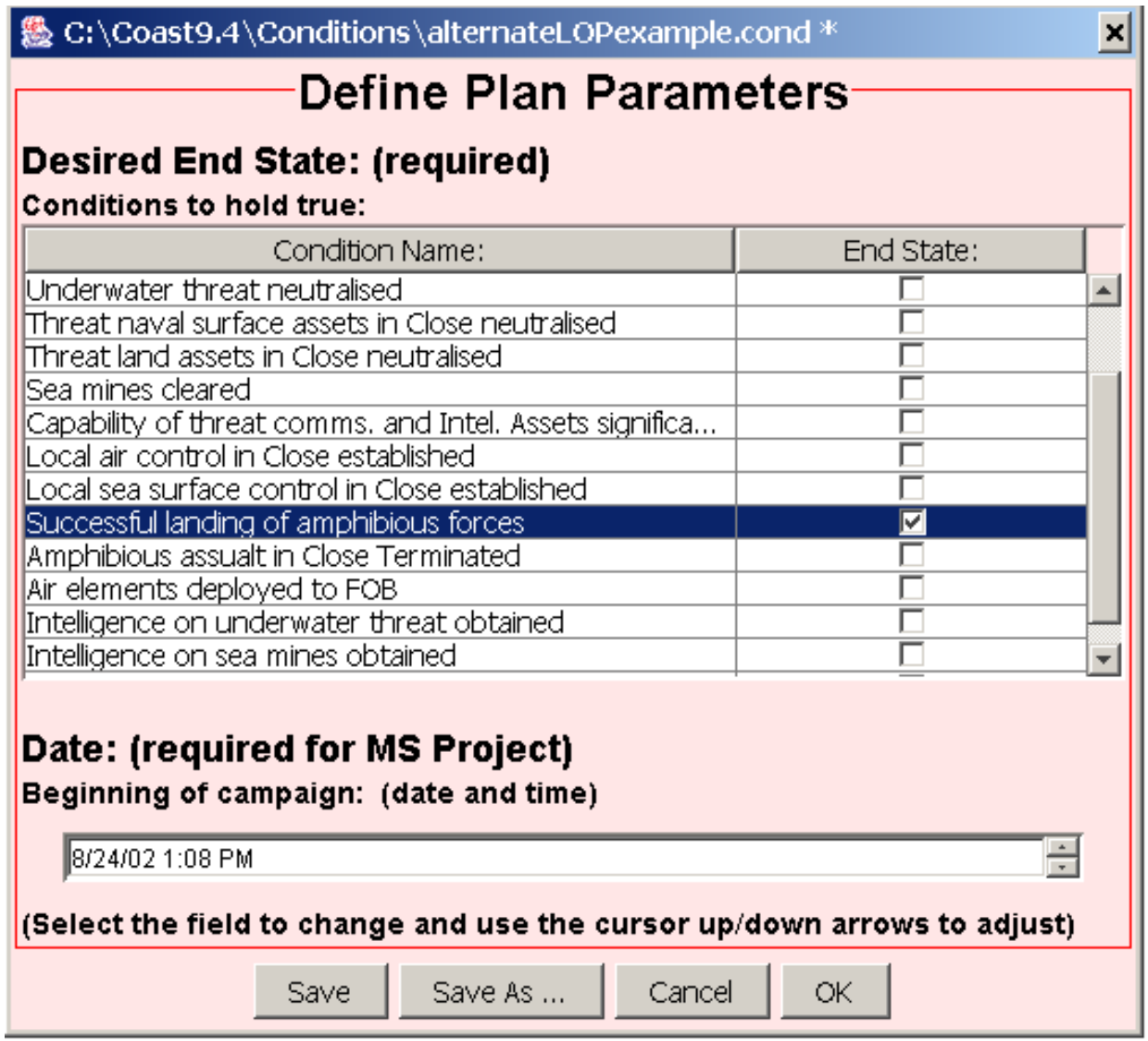
COAST Client: Task Editor




In-MODE/COAST Tool
Plans Tasks Synchronisations Resources Conditions Analysis Windows Help
Define Plan Parameters
Generate Lines Of Operation
Analysis Results
Options
Settings
Tasks:
Task List:
Airborne assault in Close
Amphibious assault in Close
Conduct F111 strike on mainland in Close
Conduct Maritime P&S in Close
Conduct MPA Surveillance in Close
Deploy Air RAAF FOB element in Rear
Establish FOB in Close
Interdict ALOC in Close
Interdict SLOC in Close
Maritime strike of naval assets in Close
SF Surveillance in Close
Establish FMB
Provide FA18/B707T Escort
Conduct Other Surveillance
Begin Synchronisations:
me strike of naval assets in Close
Conduct F111 strike on mainland in Close
End Synchronisations:
Amphibious assault in Close
Interdict ALOC in Close
Conduct Maritime P&S in Close
Resources:
Assigned Resources:
4 of B707T, available at 0
3 of BN, available at 0
5 of C130, available at 0
3 of ECSS units, available at 0
32 of F111, available at 0
34 of FA18, available at 0
6 of LCH, available at 0
10 of MPA, available at 0
2 of P3C, available at 0
4 of SF unit, available at 0
1 of SUB, available at 0
3 of helicopter, available at 0
2 of LPA, available at 0
1 of LSH, available at 0
Conditions:
Conditions:
Condition Name:
Initially Valid:
End State:
Intelligence on location of threat land ass...
Intelligence on location of threat naval su...
POE secured
Underwater threat neutralised
Threat naval surface assets in Close neut...
Threat land assets in Close neutralised
Sea mines cleared
Capability of threat comms. and Intel. As...
Local air control in Close established
Local sea surface control in Close establis...
Successful landing of amphibious forces
Amphibious assualt in Close Terminated
Air elements deployed to FOB
Intelligence on underwater threat obtained
Intelligence on sea mines obtained


C:\Coast9.4\Conditions\alternateLOPexample.cond *
Define Plan Parameters
Desired End State: (required)
Conditions to hold true:
Condition Name:
End State:
Underwater threat neutralised
Threat naval surface assets in Close neutralised
Threat land assets in Close neutralised
Sea mines cleared
Capability of threat comms. and Intel. Assets significa...
Local air control in Close established
Local sea surface control in Close established
Successful landing of amphibious forces
Amphibious assualt in Close Terminated
Air elements deployed to FOB
Intelligence on underwater threat obtained
Intelligence on sea mines obtained
Date: (required for MS Project)
Beginning of campaign: (date and time)
8/24/02 1:08 PM
(Select the field to change and use the cursor up/down arrows to adjust)
Save
Save As ...
Cancel
OK

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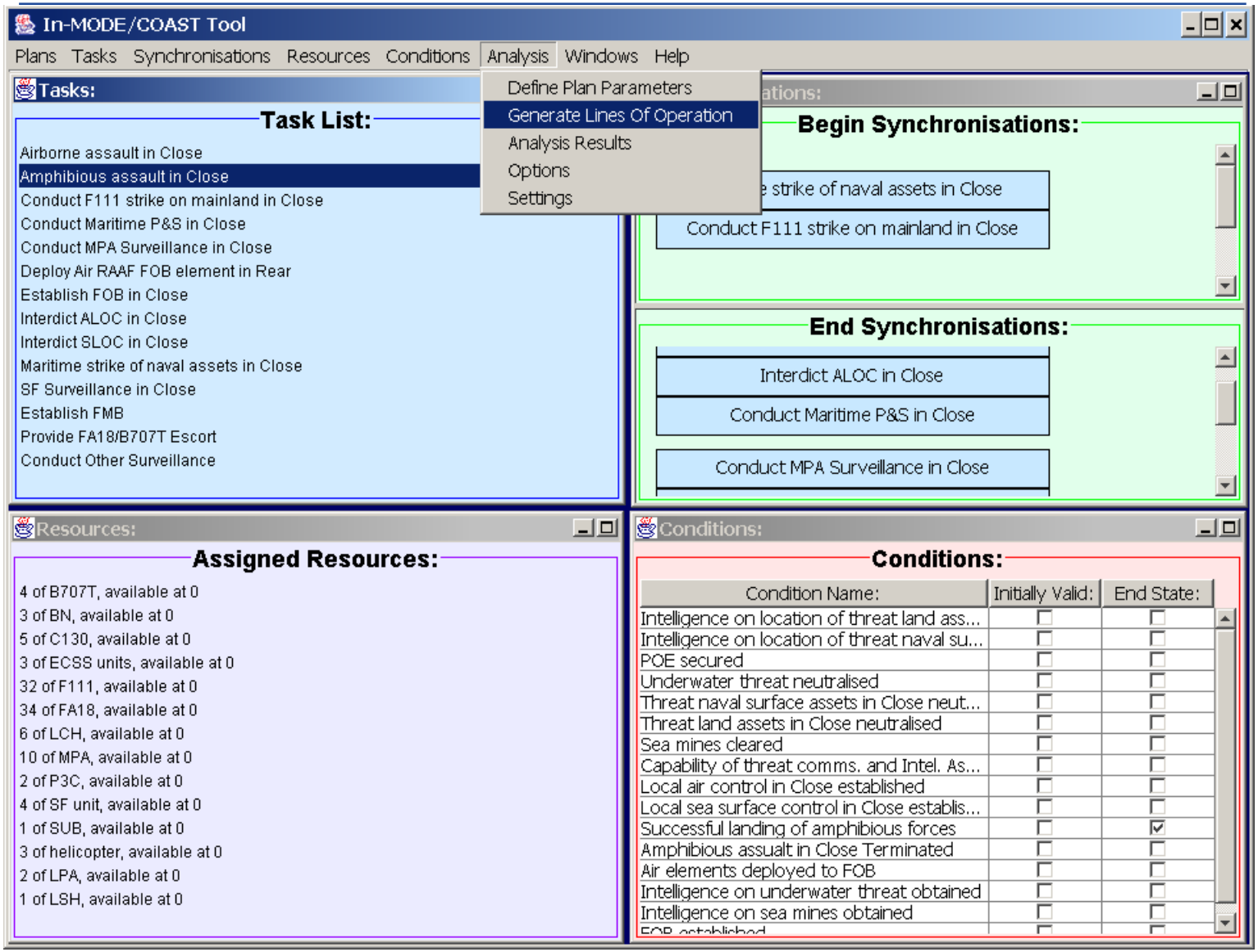
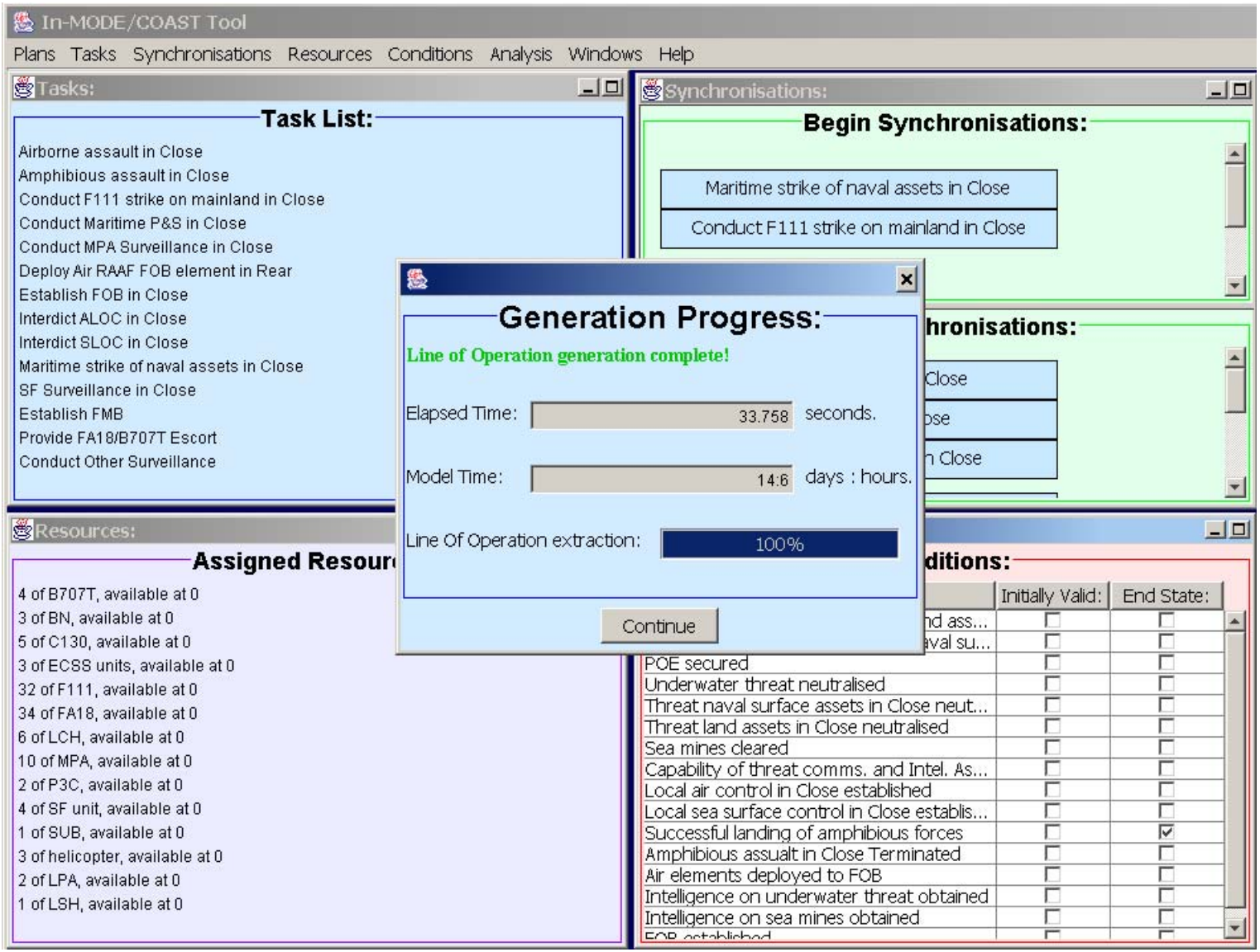
COAST Client

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Interdict SLOC in Close
Maritime strike of naval assets in Close
SF Surveillance in Close
Establish FMB
Provide FA18/B707T Escort
Conduct Other Surveillance
Synchronisations:
Begin Synchronisations:
Maritime strike of naval assets in Close
Conduct F111 strike on mainland in Close
Generation Progress:
Line of Operation generation complete!
Elapsed Time: 33.758 seconds.
Model Time: 14:6 days : hours.
Line Of Operation extraction: 100%
Continue
Resources:
Assigned Resour
4 of B707T, available at 0
3 of BN, available at 0
5 of C130, available at 0
3 of ECSS units, available at 0
32 of F111, available at 0
34 of FA18, available at 0
6 of LCH, available at 0
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1 of SUB, available at 0
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Initially Valid:
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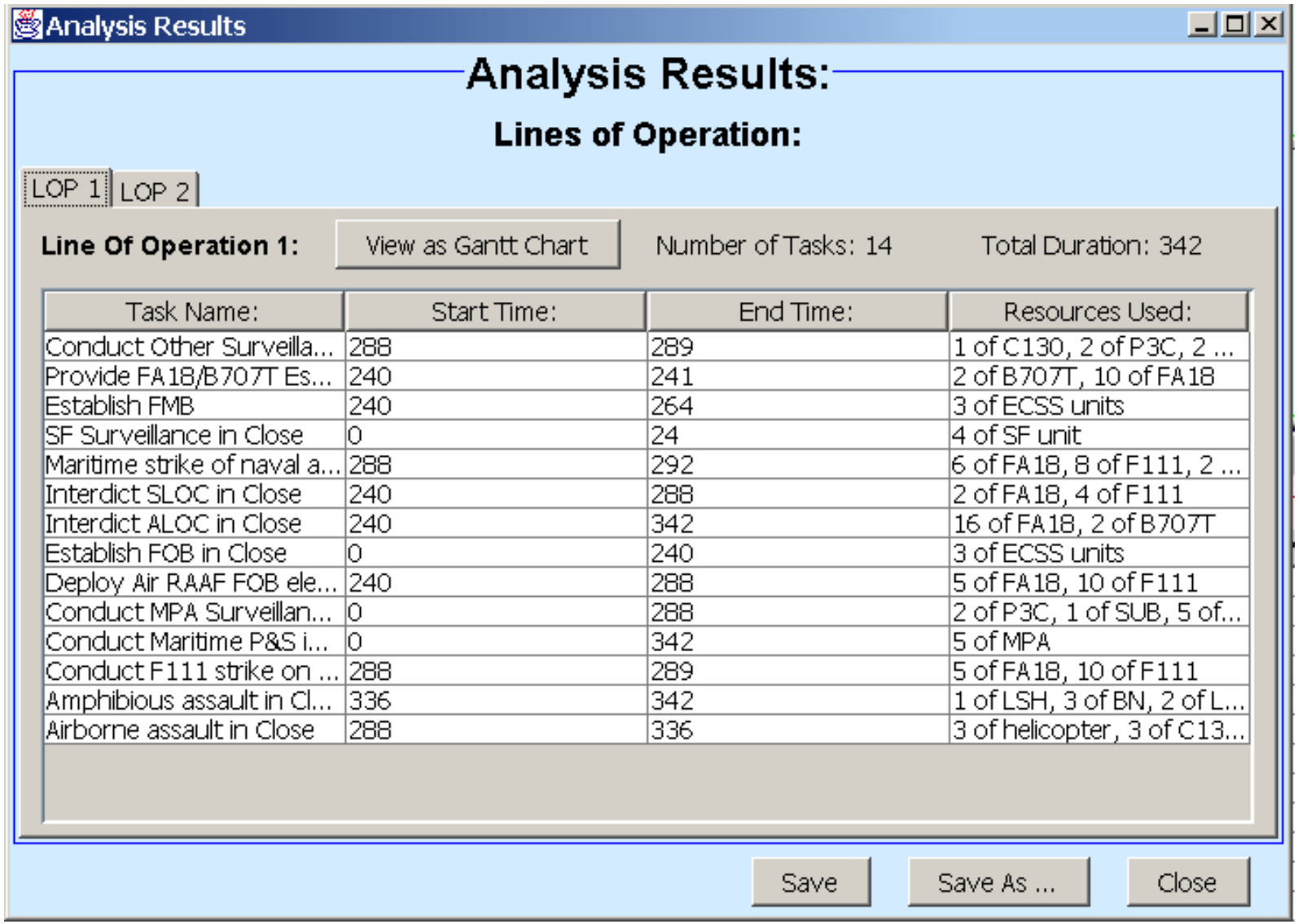
Analysis Results
Analysis Results:
Lines of Operation:
LOP 1
LOP 2
Line Of Operation 1:
View as Gantt Chart
Number of Tasks: 14
Total Duration: 342
Task Name:
Start Time:
End Time:
Resources Used:
Conduct Other Surveilla...
288
289
1 of C130, 2 of P3C, 2 ...
Provide FA18/B707T Es...
240
241
2 of B707T, 10 of FA18
Establish FMB
240
264
3 of ECSS units
SF Surveillance in Close
0
24
4 of SF unit
Maritime strike of naval a...
288
292
6 of FA18, 8 of F111, 2 ...
Interdict SLOC in Close
240
288
2 of FA18, 4 of F111
Interdict ALOC in Close
240
342
16 of FA18, 2 of B707T
Establish FOB in Close
0
240
3 of ECSS units
Deploy Air RAAF FOB ele...
240
288
5 of FA18, 10 of F111
Conduct MPA Surveillan...
0
288
2 of P3C, 1 of SUB, 5 of...
Conduct Maritime P&S i...
0
342
5 of MPA
Conduct F111 strike on ...
288
289
5 of FA18, 10 of F111
Amphibious assault in Cl...
336
342
1 of LSH, 3 of BN, 2 of L...
Airborne assault in Close
288
336
3 of helicopter, 3 of C13...
Save
Save As ...
Close

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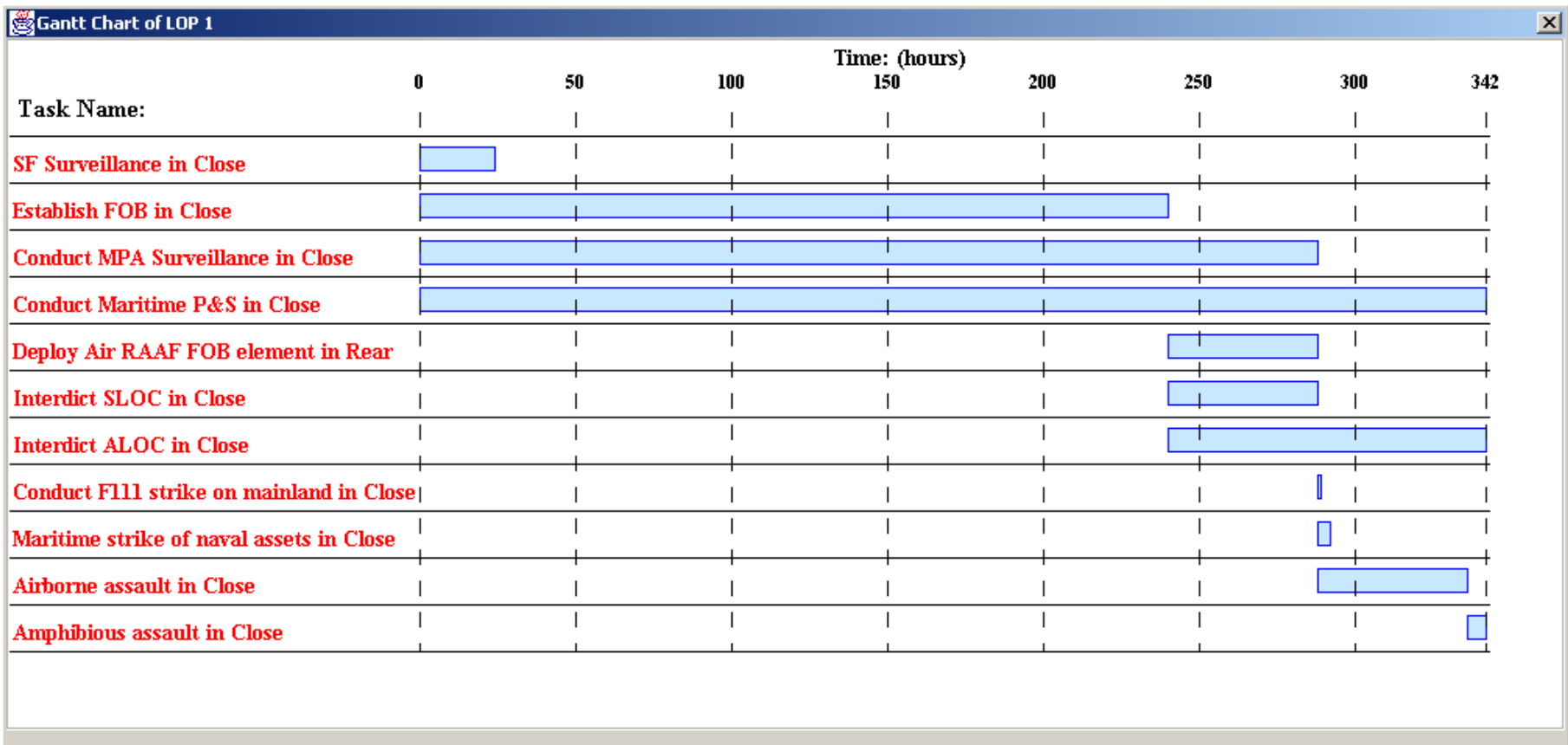
A GANTT Chart View of a Line of Operation (LOP1)



Analysis Results

Analysis Results:

Lines of Operation:

LOP 1 | LOP 2

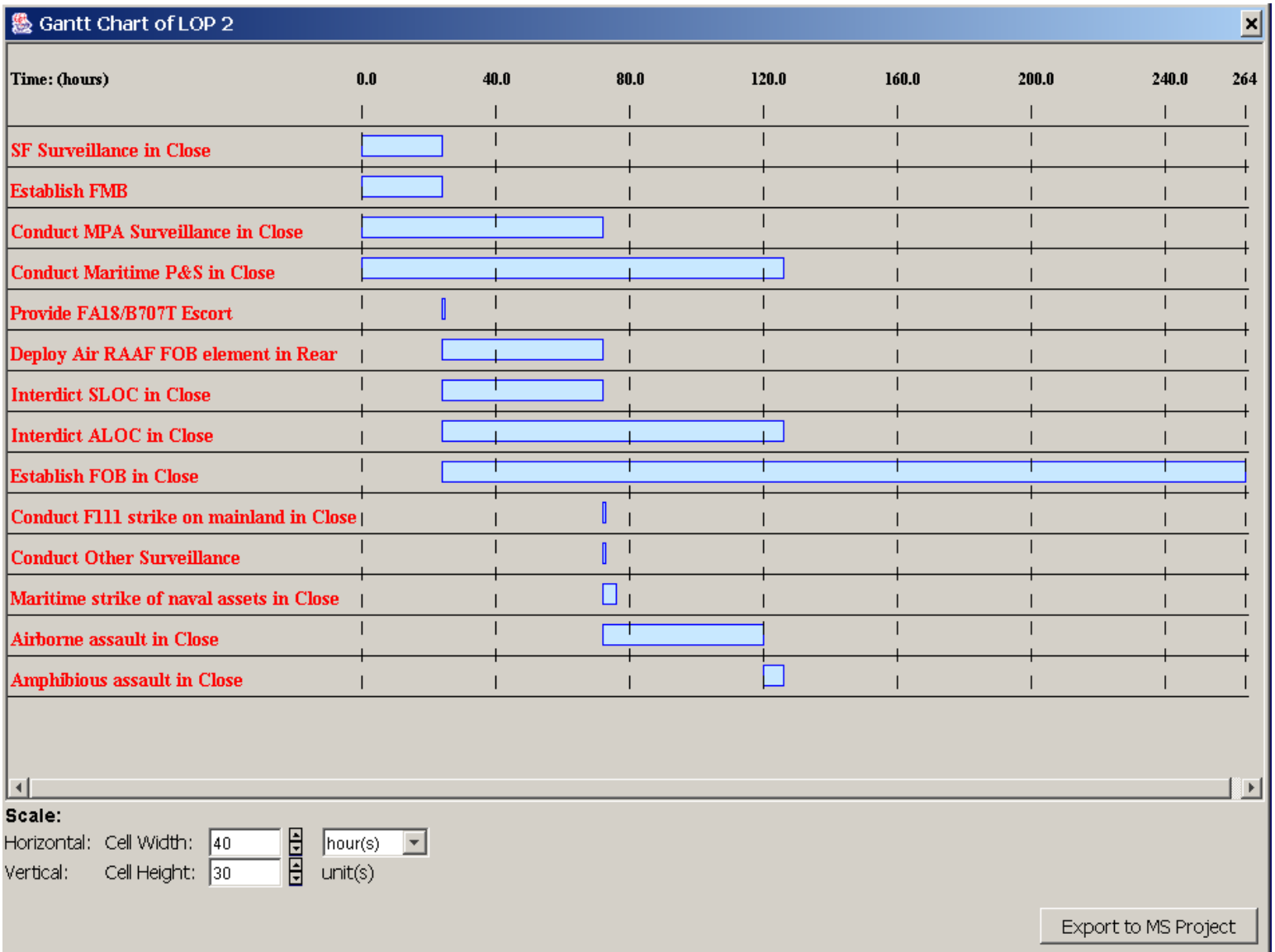
Line Of Operation 2: View as Gantt Chart Number of Tasks: 14 Total Duration: 264

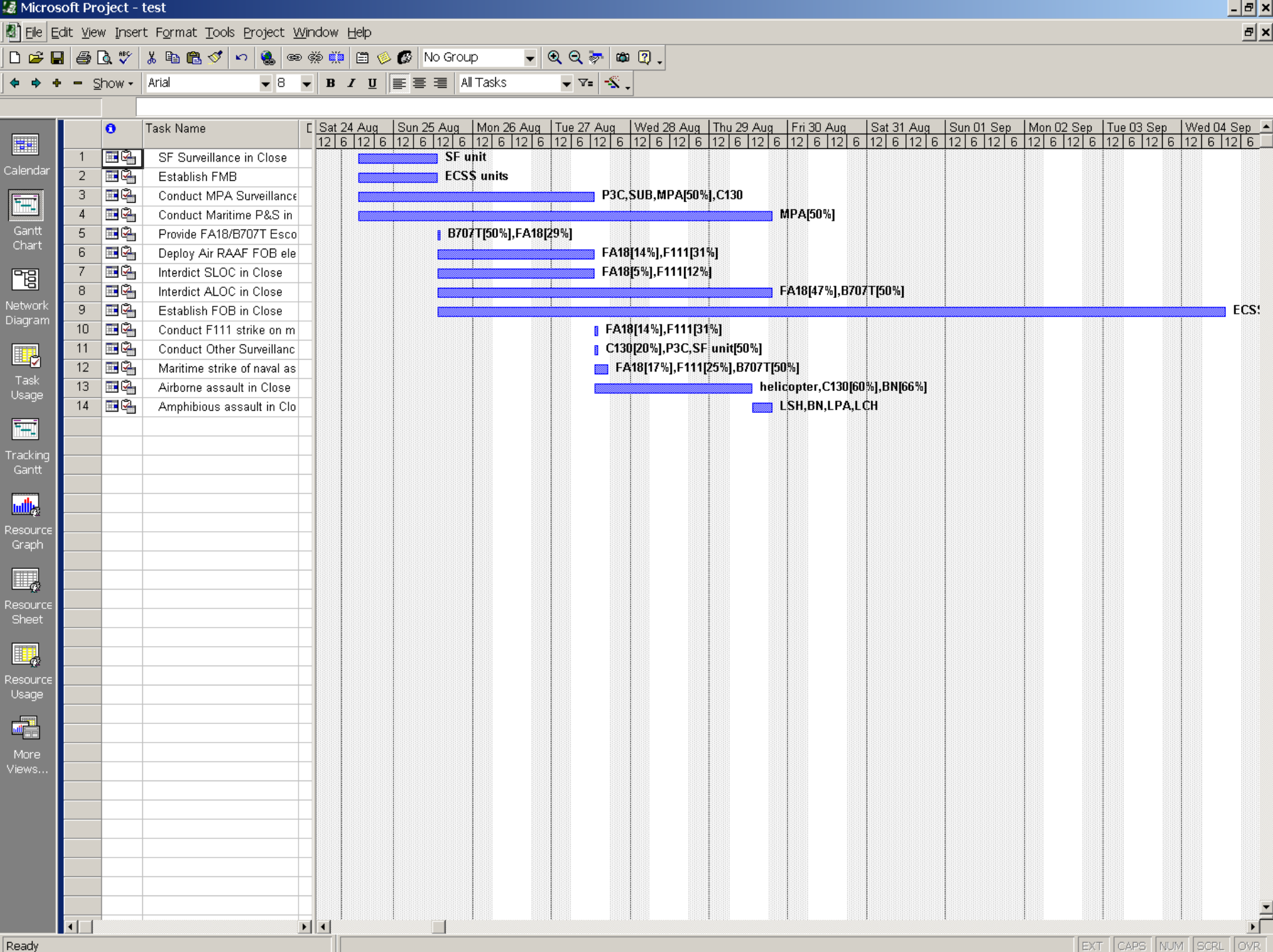
Task Name:	Start Time:	End Time:	Resources Used:
Conduct Other Surveilla...	72	73	1 of C130, 2 of P3C, 2 ...
Provide FA18/B707T Es...	24	25	2 of B707T, 10 of FA18
Establish FMB	0	24	3 of ECSS units
SF Surveillance in Close	0	24	4 of SF unit
Maritime strike of naval a...	72	76	6 of FA18, 8 of F111, 2 ...
Interdict SLOC in Close	24	72	2 of FA18, 4 of F111
Interdict ALOC in Close	24	126	16 of FA18, 2 of B707T
Establish FOB in Close	24	264	3 of ECSS units
Deploy Air RAAF FOB ele...	24	72	5 of FA18, 10 of F111
Conduct MPA Surveillan...	0	72	2 of P3C, 1 of SUB, 5 of...
Conduct Maritime P&S i...	0	126	5 of MPA
Conduct F111 strike on ...	72	73	5 of FA18, 10 of F111
Amphibious assault in Cl...	120	126	1 of LSH, 3 of BN, 2 of L...
Airborne assault in Close	72	120	3 of helicopter, 3 of C13...

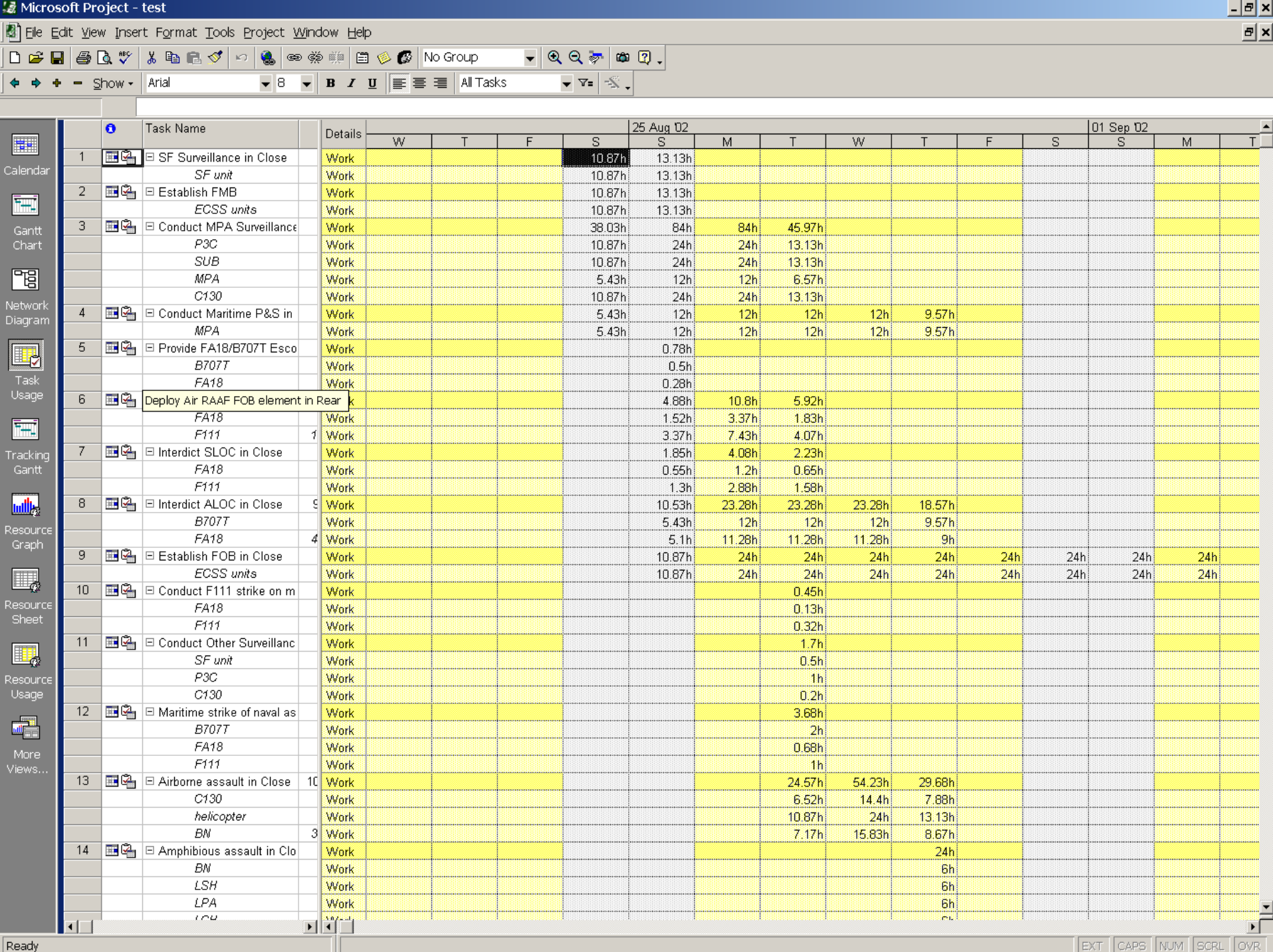
Save Save As ... Close

DEFENCE
SCIENCE & TECHNOLOGY

A GANTT Chart View of a Line of Operation (LOP2)




Microsoft Project - test
File Edit View Insert Format Tools Project Window Help
No Group
Show Arial 8 All Tasks
Calendar
Gantt Chart
Network Diagram
Task Usage
Tracking Gantt
Resource Graph
Resource Sheet
Resource Usage
More Views...
Task Name
1 SF Surveillance in Close
2 Establish FMB
3 Conduct MPA Surveillance
4 Conduct Maritime P&S in
5 Provide FA18/B707T Esco
6 Deploy Air RAAF FOB ele
7 Interdict SLOC in Close
8 Interdict ALOC in Close
9 Establish FOB in Close
10 Conduct F111 strike on m
11 Conduct Other Surveillanc
12 Maritime strike of naval as
13 Airborne assault in Close
14 Amphibious assault in Clo
Sat 24 Aug
Sun 25 Aug
Mon 26 Aug
Tue 27 Aug
Wed 28 Aug
Thu 29 Aug
Fri 30 Aug
Sat 31 Aug
Sun 01 Sep
Mon 02 Sep
Tue 03 Sep
Wed 04 Sep
SF unit
ECSS units
P3C,SUB,MPA[50%],C130
MPA[50%]
B707T[50%],FA18[29%]
FA18[14%],F111[31%]
FA18[5%],F111[12%]
FA18[47%],B707T[50%]
ECS
FA18[14%],F111[31%]
C130[20%],P3C,SF unit[50%]
FA18[17%],F111[25%],B707T[50%]
helicopter,C130[60%],BN[66%]
LSH,BN,LPA,LCH
Ready
EXT CAPS NUM SCRL OVR


Microsoft Project - test
File Edit View Insert Format Tools Project Window Help
No Group
Show
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8
All Tasks
Calendar
Gantt Chart
Network Diagram
Task Usage
Tracking Gantt
Resource Graph
Resource Sheet
Resource Usage
More Views...
Task Name
Details
25 Aug '02
01 Sep '02
W T F S S M T W T F S S M T
1 SF Surveillance in Close Work 10.87h 13.13h
SF unit Work 10.87h 13.13h
2 Establish FMB Work 10.87h 13.13h
ECSS units Work 10.87h 13.13h
3 Conduct MPA Surveillance Work 38.03h 84h 84h 45.97h
P3C Work 10.87h 24h 24h 13.13h
SUB Work 10.87h 24h 24h 13.13h
MPA Work 5.43h 12h 12h 6.57h
C130 Work 10.87h 24h 24h 13.13h
4 Conduct Maritime P&S in Work 5.43h 12h 12h 12h 12h 9.57h
MPA Work 5.43h 12h 12h 12h 12h 9.57h
5 Provide FA18/B707T Esco Work 0.78h
B707T Work 0.5h
FA18 Work 0.28h
6 Deploy Air RAAF FOB element in Rear Work 4.88h 10.8h 5.92h
FA18 Work 1.52h 3.37h 1.83h
F111 1 Work 3.37h 7.43h 4.07h
7 Interdict SLOC in Close Work 1.85h 4.08h 2.23h
FA18 Work 0.55h 1.2h 0.65h
F111 Work 1.3h 2.88h 1.58h
8 Interdict ALOC in Close 9 Work 10.53h 23.28h 23.28h 23.28h 18.57h
B707T Work 5.43h 12h 12h 12h 9.57h
FA18 4 Work 5.1h 11.28h 11.28h 11.28h 9h
9 Establish FOB in Close Work 10.87h 24h 24h 24h 24h 24h 24h 24h 24h
ECSS units Work 10.87h 24h 24h 24h 24h 24h 24h 24h 24h
10 Conduct F111 strike on m Work 0.45h
FA18 Work 0.13h
F111 Work 0.32h
11 Conduct Other Surveillanc Work 1.7h
SF unit Work 0.5h
P3C Work 1h
C130 Work 0.2h
12 Maritime strike of naval as Work 3.68h
B707T Work 2h
FA18 Work 0.68h
F111 Work 1h
13 Airborne assault in Close 10 Work 24.57h 54.23h 29.68h
C130 Work 6.52h 14.4h 7.88h
helicopter Work 10.87h 24h 13.13h
BN 3 Work 7.17h 15.83h 8.67h
14 Amphibious assault in Clo Work 24h
BN Work 6h
LSH Work 6h
LPA Work 6h
Ready
EXT CAPS NUM SCRL OVR

Conclusions

- Military operations planning is a complex process that requires support in process management, reasoning under uncertainty, and automated sequencing, scheduling and analysis
- CPN process models were developed to support the management and analysis of the process
- A Centre of Gravity Effects Tool (COGNET) was developed to support reasoning under uncertainty
- A Course of Action Scheduling Tool (COAST) was developed to support automated sequencing, scheduling and analysis of operational tasks to form suitable and feasible lines of operation

Conclusions Specific to COAST

- Developed a planning interface consistent with the military planning doctrine and intuitive to the operators
  - Our customers were very impressed with the tool
- Formulated the military planning problem suitable for the application of formal methods
  - Developed a conceptual military task model capturing the behaviour of individual tasks
- Formalised the conceptual task model with CPNs
- Extracted the CPN model in executable form from Design/CPN and embedded it into COAST
- With COAST, military officers will be able to plan operations with more efficiency and rigour
  - Executable models and mathematical representations of COA are constructed and analysed as the military officers plan

Future Work for COAST

- Support diagnosis and iteration of lines of operation
  - Interpretation of the state space to the domain
- Research and apply state space reduction and traversal techniques
  - Prepare for more complex operations (therefore more complex state spaces)
- Utilise the state space representation for further quantitative analysis and optimisation
  - Risk, impact, cost, distinguishability
- Transition of the COAST Server to CPN Tools
- Support simulation and wargame
  - Can CPN task models and the resulting state spaces interact as if they represent opposing forces?

Questions