

Defence Operational Analysis Symposium 2003

Scheduling Operational-Level Courses of Action

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Outline

- Introduction
 - Characteristics of operational-level planning
 - Motivation of this work
- Operational-level course of action (COA) modelling
 - A conceptual task model
 - Formalising the conceptual model with Coloured Petri Nets
- Model Execution and Analysis
 - COAST demonstration
- Conclusions and future work

Characteristics of Operational-Level Planning

- Operational-level planning is concerned with the orchestration of tactical actions to achieve strategic objectives
- Operational-level planning is characterised with
 - Ambiguity
 - National interest, political aims, strategic objectives, commander's intent, mission
 - Uncertainty
 - Fog of war at the operational-level: own and friendly forces, strategic environment, threat
 - Complexity
 - Coalition operations, NGOs, whole of government approach – other agencies, possible inconsistency and interference between concurrent operations, sequencing and scheduling operations

Major Analytical Steps in Operational-Level Planning

- Determine a desired end-state with constituent conditions
- Develop tasks to achieve the desired end state
- Schedule the tasks
- Analyse options of task schedules for an optimal plan

Motivation

- Develop an appropriate representation of operational-level courses of action (COA) to enable formal analysis for COA sequencing, scheduling and optimisation
- Develop a COA Scheduling Tool (COAST) to demonstrate the formal modelling and analysis concepts
 - And make the formalism transparent to the user

What Is Also Important But **NOT** Included Here

- Coordination of planning processes
 - Process modelling and analysis
 - process synchronisation techniques
- Information and knowledge management
 - Collaborative planning systems
 - Workflow systems
- Development and Analysis of COA strategies
 - Influence networks, Bayesian networks, policy analysis, COGNET
- COA Simulation (COA Sim) and War Games

A Simple Planning Example

- End State
 - Amphibious forces successfully landed
- Tasks
 - Conduct amphibious assault
 - Conduct combat air patrol
 - Conduct ASW operations in the AO
 - Conduct airborne operations
 - Conduct maritime escort operation
 - Conduct mine clearance operation
 - Establish FOB
 - Establish FARP
 - Provide AAR
- Problem
 - How to sequence and schedule the tasks with assigned resources to achieve the desired end state?

Modelling Considerations

- A well defined military *task* has a *duration*, *preconditions* and *effects*
- A task may require *resources*
 - For example, military forces and logistics
 - Some tasks may consume resources
- The military user may wish to impose *synchronisation* constraints among tasks
- A military end state can be expressed as a set of *conditions*
 - So can concepts such as decisive points (DP)
 - Preconditions, effects and conditions are of the same type

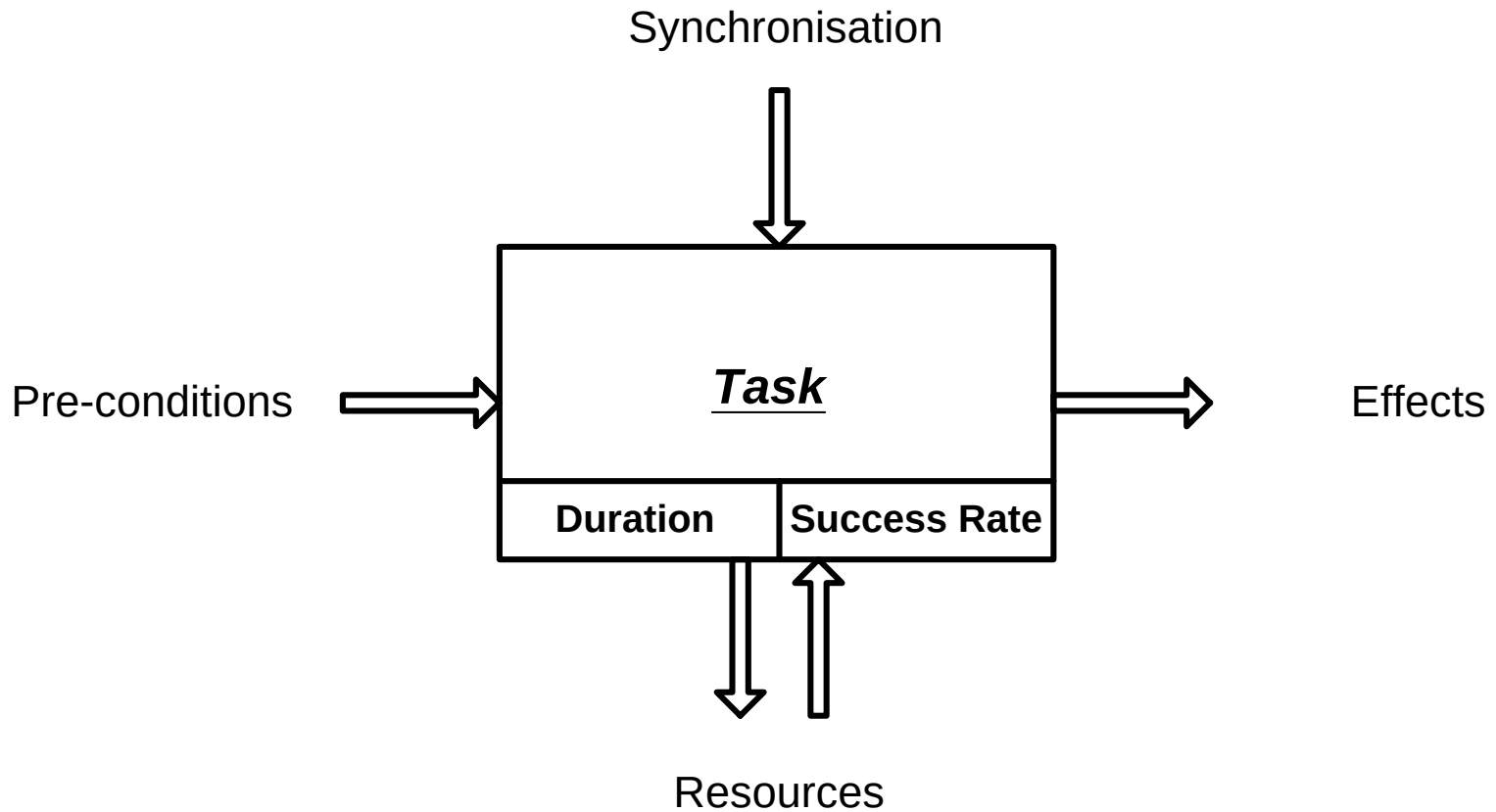
Modelling Considerations (cont.)

- A suitable and feasible course of action (COA) is a (partial) sequence of tasks that are
 - related through preconditions and effects,
 - constrained with resource and synchronisation considerations, and
 - lead to the achievement of conditions set in the end state.
- The COA is considered suitable because the execution of its tasks logically leads to the achievement of an end state
- The COA is considered feasible because the resource constraints are satisfied
- Note that temporal considerations for conditions and resources must also be captured for scheduling

Consistent with the Planning Doctrine (ADDP.5.0.1)

COG	CC	CR	CV	Effect	Method	Indicative Force Assignment	Pre-Conditions
Force Projection	Strategic Lift Capability	Transport A/C	CAP	Neutralise	OCA	FA18, A4, AAR	Intelligence SEAD
					Air Strike	F111	Intelligence Escort SEAD
					SF Strike	Commando	Intelligence SF deployed
				Interdict	DCA	FA18, AAR	Continuous ISR SADOX / Tactical Air C2)
			Airfields	Cannot effect ROE	NIL	NIL	NIL
			Ports	Blockade	MIO	NTG-FFH & Subs	Air defence
					Mining	MCM Ships	Air Defence Surface control Subsurface control

A Conceptualisation of Tasks





Conduct amphibious assault

Task Information

Task Duration: 4 Hours

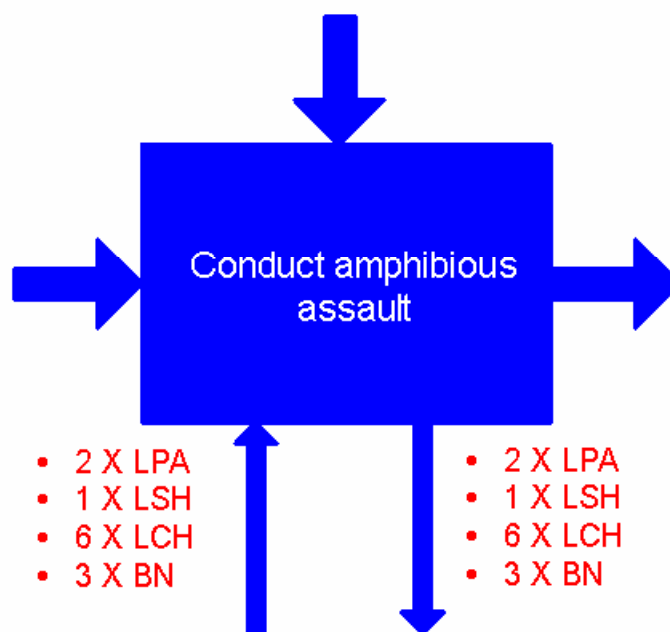
Probability of Success 90%

Synchronisation:

- H-Hour

Preconditions:

- Local air control established
- Local sea surface control established
- Local sea sub-surface control established
- En route sea mines Cleared
- POE established

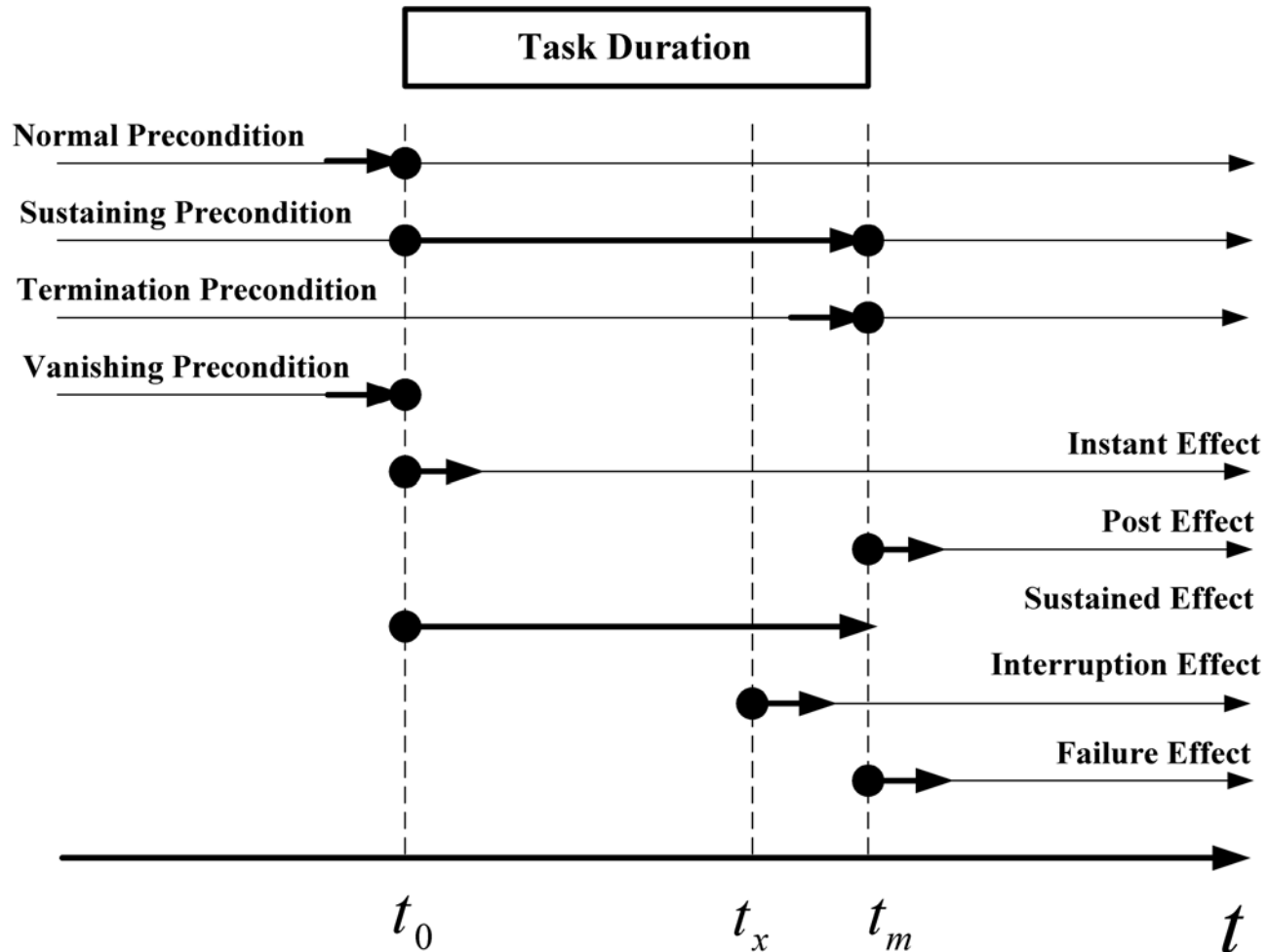


Assigned Forces

Effects:

- Amphibious forces succesful landed

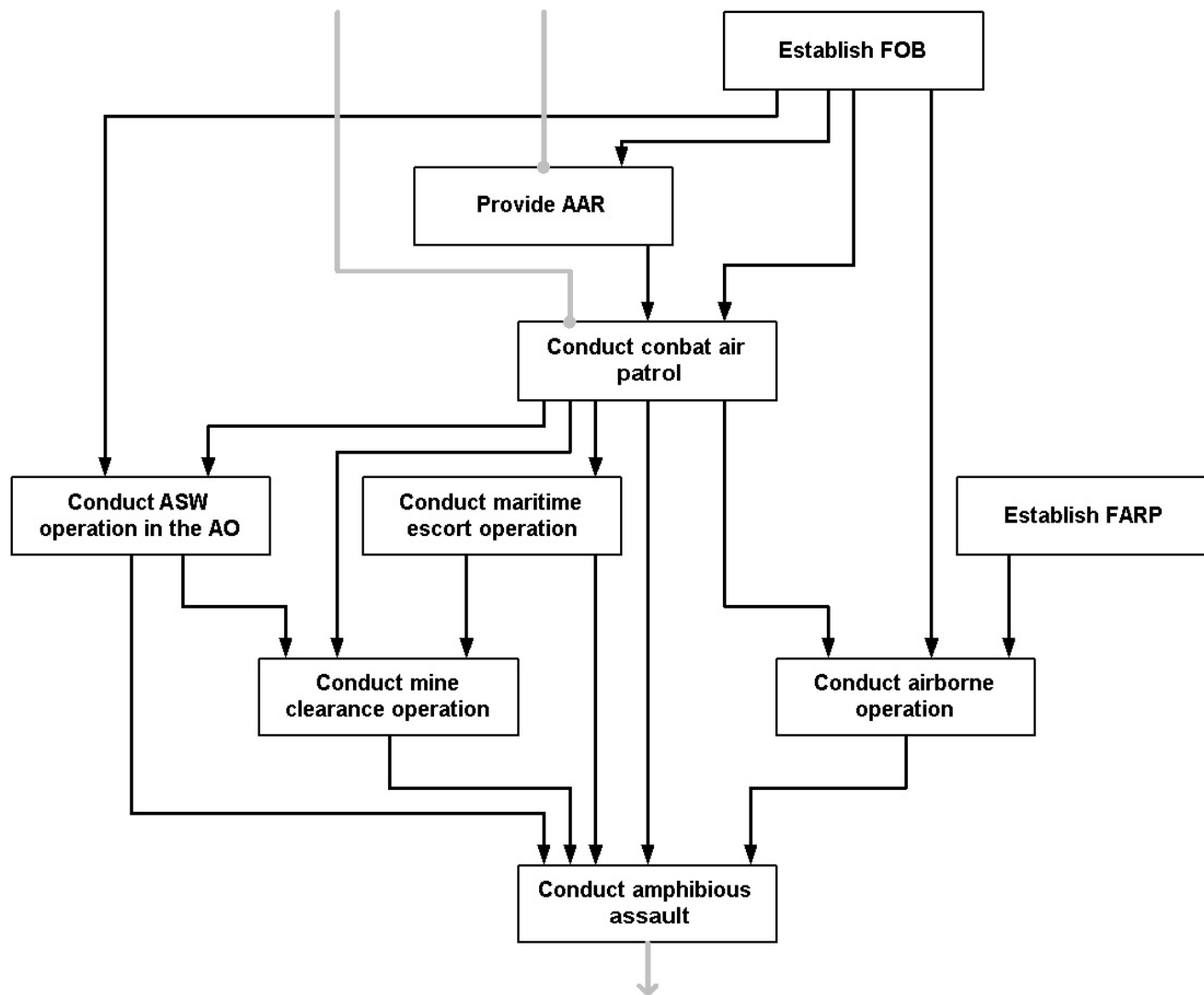
Temporal Aspects of Conditions



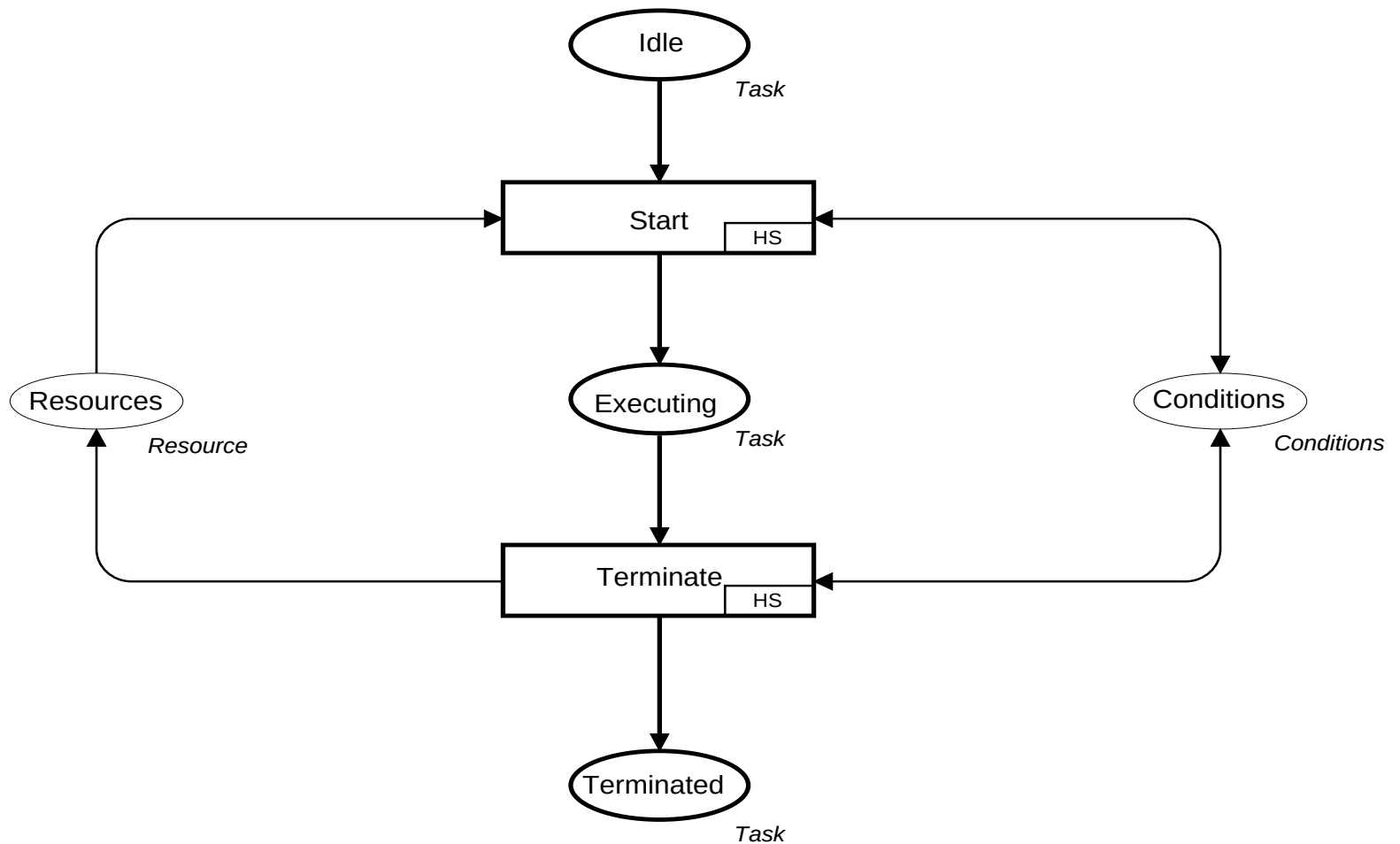
Instantiated Task Samples

Task name	Preconditions	Effects	Resources	Lost Res.	Duration	Sync. Info.	Success Rate
Conduct amphibious assault	- Local air control established (SP) - Local sea surface control established (SP) - Local sea sub-surface control established (SP) - En route sea mines cleared (NP) - POE established (NP)	Amphibious forces successfully landed (PE)	2 LPA 1 LSH 6 LCH 3 BN		4 Hours	H-Hour	90%
Conduct combat air patrol	- FOB established (NP) - Fighter aircraft deployed to the AO (NP) - En route refueling provided (SP)	Local air control established (SE)	12 FA 18	2 FA 18	As required		95%
Conduct ASW operations in the AO	- FOB established (NP) - Local air control established (SP)	Local sea sub-surface control established (SE)	2 MPA		As required		95%
Conduct airborne operations	- Local air control established (SP) - FOB established (NP) - FARP established (NP)	POE secured (PE)	12 Blackhawk 2 ABN BN	2 Blackhawk			95%
Conduct maritime escort operation	Local air control established (SP)	Local sea surface control established (SE)	4 FFH		As required		95%
Conduct mine clearance operation	- Local air control established (SP) - Local sea surface control established (SP) - Local sea sub-surface control established (SP)	En route sea mines cleared (PE)	4 Mine Hunters		48 Hours		80%
Establish FOB		FOB established (PE)	1 ECSS		60 Hours	Now	100%
Establish FARP		FARP established (PE)	1 Eng Coy		40 Hours	Now	100%
Provide AAR	- FOB established (NP) - AAR aircraft deployed to the AO (NP)	En route refueling provided (SE)	4 AAR		As required		99%

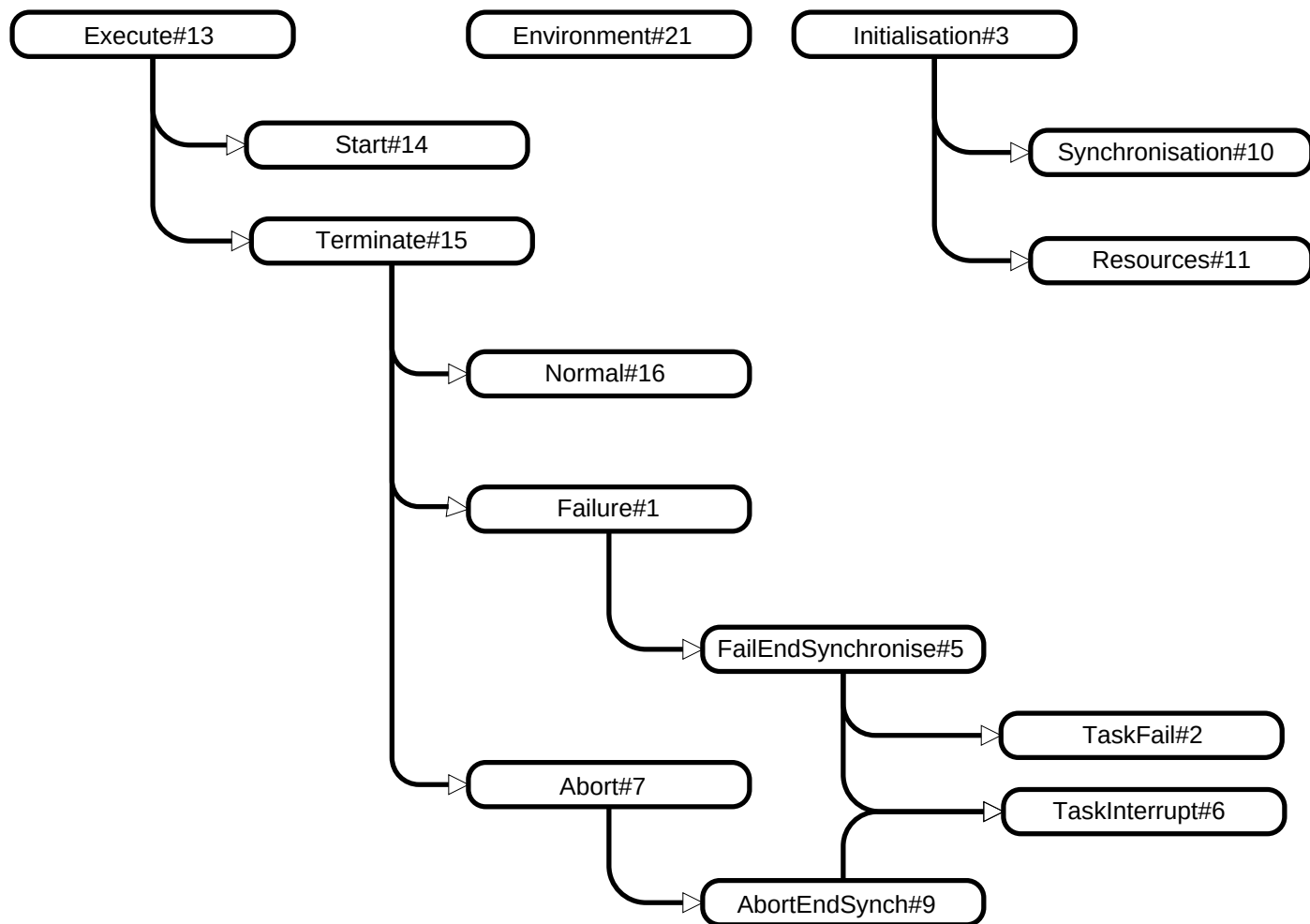
A Partial Sequence of COA Tasks



Formalising the Conceptual Model with Coloured Petri Nets



An Overview of the CPN Model



Model Execution and Analysis

- A Course of Action Scheduling Tool (COAST) was developed to perform model execution and analysis
- COAST has a client-server architecture
 - The client consists of a graphical user interface (GUI) that supports the COA task instantiation and conducts static analysis, i.e. consistency analysis and cause-effect analysis
 - The server uses the instantiated CPN model of COA tasks to conduct state space analysis for generating sequences and schedules of COA
- Novel state space analysis algorithms have been implemented in the COAST server

Tasks:

Task List:

Task ID:	Task Name:	Include:
T1	Conduct amphibious assault	☒
T2	Conduct combat air patrol	☒
T3	Conduct ASW operations in the AO	☒
T4	Conduct airborne operations	☒
T5	Conduct maritime escort operation	☒
T6	Conduct mine clearance operation	☒
T7	Establish FOB	☒
T8	Establish FARP	☒
T9	Provide AAR	☒

Resources:

Assigned Resources:

ID:	Numb...	Resource Name:	Availability:
R1	5	LPA	[0,Rest of Campaign]
R2	5	LSH	[0,Rest of Campaign]
R3	8	LCH	[0,Rest of Campaign]
R4	10	BN	[0,Rest of Campaign]
R5	24	FA 18	[0,Rest of Campaign]
R6	20	MPA	[0,Rest of Campaign]
R7	16	Blackhawk	[0,Rest of Campaign]
R8	5	ABN BN	[0,Rest of Campaign]
R9	5	FFH	[0,Rest of Campaign]
R10	5	Minehunter	[0,Rest of Campaign]
R11	6	ECSS	[0,Rest of Campaign]
R12	3	ENG COY	[0,Rest of Campaign]
R13	6	AAR	[0,Rest of Campaign]

Conditions:

Conditions:

ID:	Condition Name:	Initially Valid:	End St...
C1	Amphibious forces successfully landed	☐	☒
C2	Local air control established	☐	☐
C3	Local sea surface control established	☐	☐
C4	Local sea sub-surface control established	☐	☐
C5	En route sea mines cleared	☐	☐
C6	POE established	☐	☐
C7	FOB established	☐	☐
C8	Fighter aircraft deployed to AO	☒	☐
C9	En route refuelling provided	☐	☐
C10	FARP established	☐	☐
C11	AAR Aircraft deployed to the AO	☒	☐

Name:

Expression:

Synchronisations:

Begin Synchronisations:

End Synchronisations:

Plans Tasks Synchronisations Resources Conditions Plan

Tasks Resources Conditions Synchronisations

Tasks:

Task List:

Task ID:	Task Name:
T1	Conduct amphibious assault
T2	Conduct combat air patrol
T3	Conduct ASW operations in the AO
T4	Conduct airborne operations
T5	Conduct maritime escort operation
T6	Conduct mine clearance operation
T7	Establish FOB
T8	Establish FARP
T9	Provide AAR

Conditions:

Conditions:

ID:	Condition Name:	Init
C1	Amphibious forces successfully landed	
C2	Local air control established	
C3	Local sea surface control established	
C4	Local sea sub-surface control established	
C5	En route sea mines cleared	
C6	POE established	
C7	FOB established	
C8	Fighter aircraft deployed to AO	
C9	En route refuelling provided	
C10	FARP established	
C11	AAR Aircraft deployed to the AO	

Name:

Expression:

Conduct amphibious assault

Name: Conduct amphibious assault

Comments:

Start Time: 0 W 0 D 0 H Duration: 0 W 0 D 4 H
☐ As Required

Success Probab. ... 90 Environment: Joint

Battlespace: Close Trigger:

Start Location: End Location:

0 0 0 N LAT 0 0 0 N LAT
 0 0 0 E LON 0 0 0 E LON

Task Resources

Task Resources: Assigned Resources:

☒ Required: 2 of LPA 3 of LPA
☐ Lost if successful: 1 of LSH X 1 4 of LSH
☐ Lost if interrupted: 6 of LCH 2 of LCH
☐ Lost if failed: 3 of BN 7 of BN
 X 1 24 of FA18

Task Conditions

☒ PreConditions: ☐ Effects:

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

Possible Conditions:
 Amphibious forces successfully landed
 Local air control established
 Local sea surface control established
 Local sea sub-surface control established

Details of:

Invalidated when the task starts? ☐ Yes ☒ No
 Must be satisfied for task to be executed? ☒ Yes ☐ No
 Must be satisfied for task to be terminated? ☐ Yes ☒ No

☐ Read Only ☒ Editable

Save

Save As...

Cancel

OK

Tasks:

Task List:

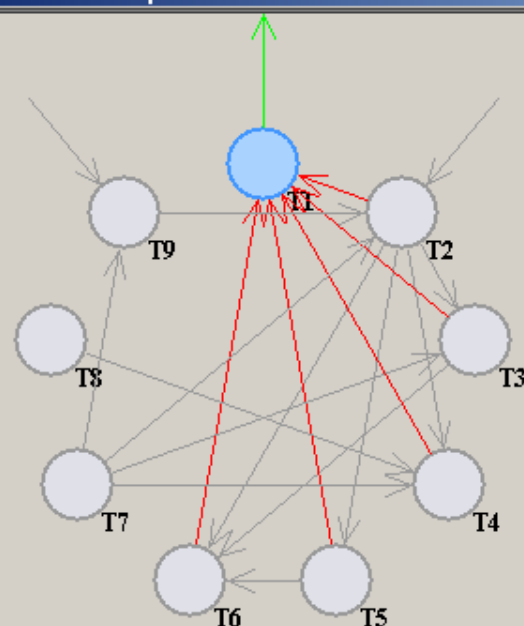
Task ID:	Task Name:	Include:
T1	Conduct amphibious assault	☒
T2	Conduct combat air patrol	☒
T3	Conduct ASW operations in the AO	☒
T4	Conduct airborne operations	☒
T5	Conduct maritime escort operation	☒
T6	Conduct mine clearance operation	☒
T7	Establish FOB	☐
T8	Establish FARP	☐
T9	Provide AAR	☐

Resources:

Assigned Resources:

ID:	Numb...	Resource Name:	Availability:
R1	5	LPA	[0,Rest of Campaign]
R2	5	LSH	[0,Rest of Campaign]
R3	8	LCH	[0,Rest of Campaign]
R4	10	BN	[0,Rest of Campaign]
R5	24	FA 18	[0,Rest of Campaign]
R6	20	MPA	[0,Rest of Campaign]

Cause-Effect Graph of



Warnings:

Tasks Without Effects:
None.

Tasks Without Causes:
T7 - Establish FOB
T8 - Establish FARP

Disjoint Tasks:
None.

Selected item(s):

Task Selected: T1 - Conduct amphibious assault

Incoming Arcs:

From Task T2 - Conduct combat air patrol
- Local air control established

From Task T3 - Conduct ASW operations in the AO
- Local sea sub-surface control established

From Task T4 - Conduct airborne operations
- POE established

Conditions:

ID:	Conc
C1	Amphibious force
C2	Local air control e
C3	Local sea surface
C4	Local sea sub-sur
C5	En route sea min
C6	POE established
C7	FOB established
C8	Fighter aircraft de
C9	En route refuelling
C10	FARP established
C11	AAR Aircraft depl

Name:

Expression:

Zoom In

Zoom Out

Reset Zoom

Refresh Graph

Analysis Results

Post LOP Analysis Results: Complete Lines of Operation

LOP 1 | LOP 2

Line Of Operation 1:

View as Gantt Chart

Number of Tasks: 9

Display Time Conditions Matrix

Total Duration: 112

Probability of Success:

Percentage of Resources used:

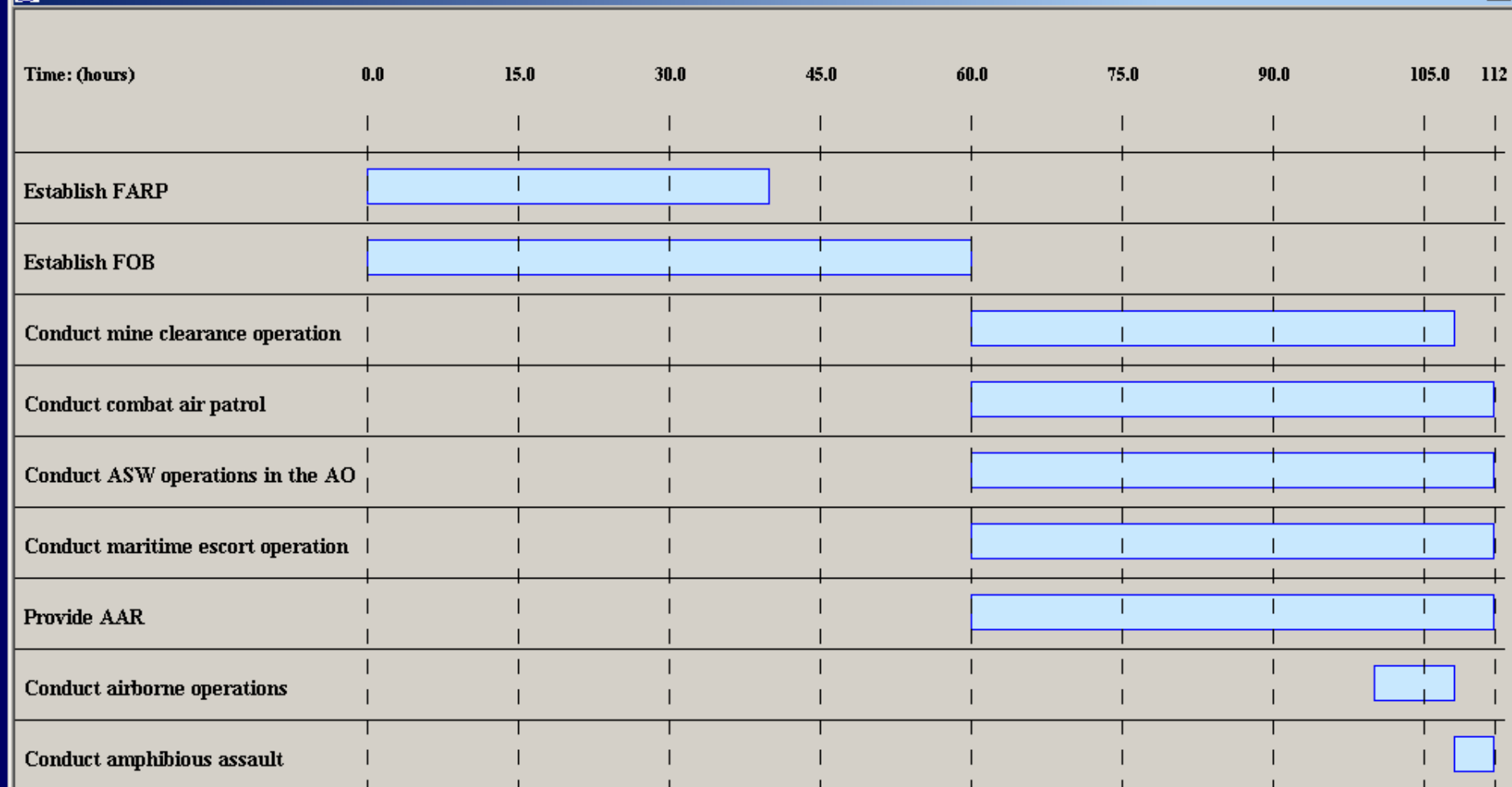
Task ID:	Task Name:	Start Time:	End Time:	Resources Used:
T9	Provide AAR	60	112	4 of AAR
T8	Establish FARP	0	40	1 of ENG COY
T7	Establish FOB	0	60	1 of ECSS
T6	Conduct mine clearance o...	60	108	4 of Minehunter
T5	Conduct maritime escort o...	60	112	4 of FFH
T4	Conduct airborne operations	100	108	12 of Blackhawk, 1 of ABN ...
T3	Conduct ASW operations i...	60	112	4 of MPA
T2	Conduct combat air patrol	60	112	12 of FA18
T1	Conduct amphibious assault	108	112	2 of LPA, 1 of LSH, 6 of LC...

Save

Save As ...

Close

Gantt Chart of LOP 1



Scale:

Horizontal: Cell Width: 15 hour(s)

Vertical: Cell Height: 47 unit(s)

Export to MS Project

COAST and MS Project

Functions and Features			MS Project	COAST
Scheduling	Per causal relationships		-	+
	Per temporal relationships		+	+
	Per resource constraints		-	+
	Multiple lines of operation		-	+
Analysis	Probability of Success		-	↑
	Risk to capabilities		-	↑
	Critical path		+	+
	Cost		+	+
Optimisation	Per above criteria, i.e., probability of success, risk, cost		-	↑
Views	GANTT		+	+
	PERT		+	+
	Tailored Views	Cause-Effect Diagrams	-	+
		Decisive Points	-	↑
		Decision Points	-	↑
		Desired military end state	-	+

Legend

+ Available

- Unavailable

↑ Under development

Note: COAST Schedules can be exported to MS Projects for analysis, views and reporting.

Discussions

- A method of describing operational level COA in terms of an end state, timed tasks, required and consumed resources, preconditions and effects of tasks
- A method of analysing tasks to determine if a desired military end state can be achieved given the assigned resources
- Methods of generating plans that can achieve the desired end state;
- A user interface that does not rely on an understanding of the formal methods employed by the tool; and
- A mathematical representation of COA lending to quantitative COA analysis and optimisation

Future Work

- Characterisation of the dynamic system realised from the CPN model, e.g., how does it relate to timed automata
- Stochastic overlay and characterisation
- Metrics of operational-level COA, e.g., probability of success, cost, loss of capabilities
- Quantitative analysis and optimisation
 - Dynamic programming techniques
 - AI planning techniques