Holonic Scheduling Concepts for C2 Organizational Design for MHQ with MOC

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- **Two Coordinating Decision Layers**
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  - Operational – Tactical Level Control (OLC-TLC) Layer
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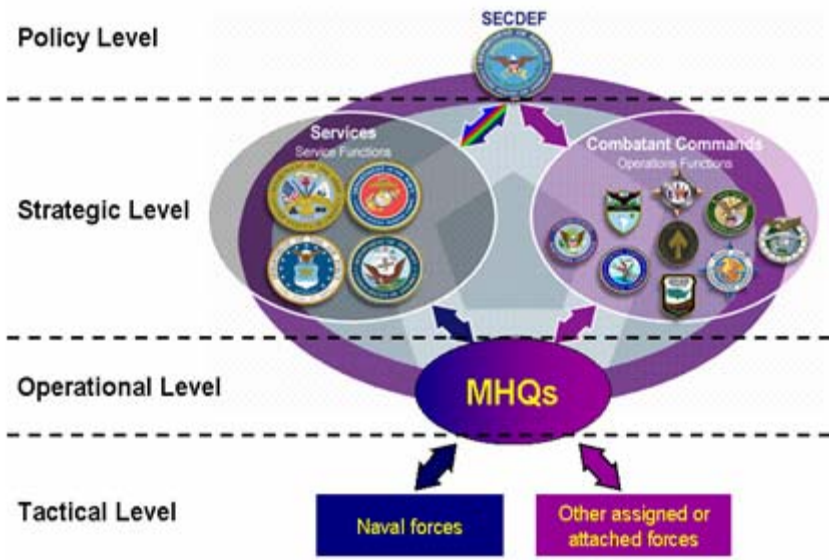
- **Summary**

Introduction

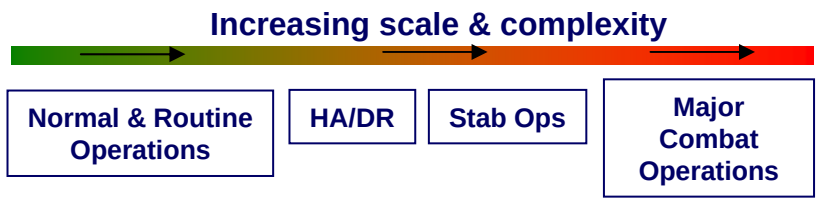
- **Motivation**
  - Maritime Headquarters with Maritime Operations Center (MHQ/MOC) motivated by identified C^2 gaps in recent national-level crises, e.g., September 11, operation Iraqi freedom (OIF), and humanitarian assistance and disaster relief (HA/DR) during Katrina
  - MHQ/MOC* is the Navy's new concept at the **operational level** with the capability to *assess*, *plan*, and *execute* multiple missions

- **Objectives**:
  - How to **sequence** multiple missions and **coordinate** tasks across a range of military operations**?
  - How to **link tactical**, **operational** and **strategic** levels in assessing, planning and executing multiple missions?

*** MHQ/MOC**

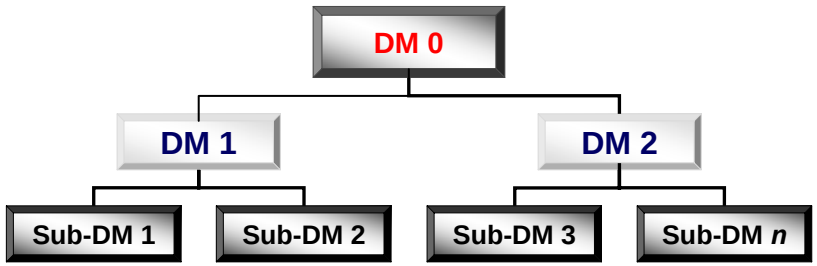


**** Range of military operations**

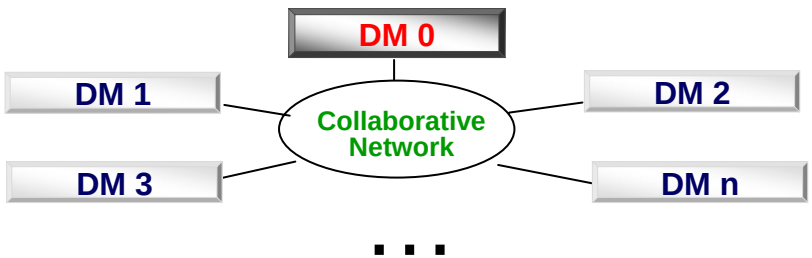


Holonic C2 Structure

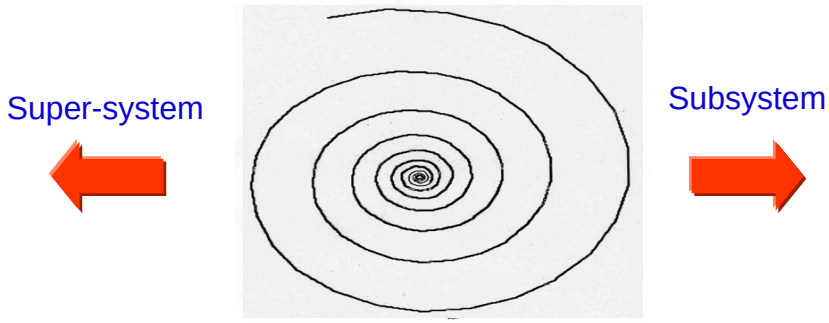
- **Traditional C2 Structures**
  - **Hierarchy**
    - **Pros**: provides **unity of command**
    - **Cons**: slow response and limited immediate intelligent actions due to a multi-level bureaucratic structure



  - **Heterarchy**
    - **Pros**: provides **fast response** to local disturbances
    - **Cons**: limited performance due to absence of global information

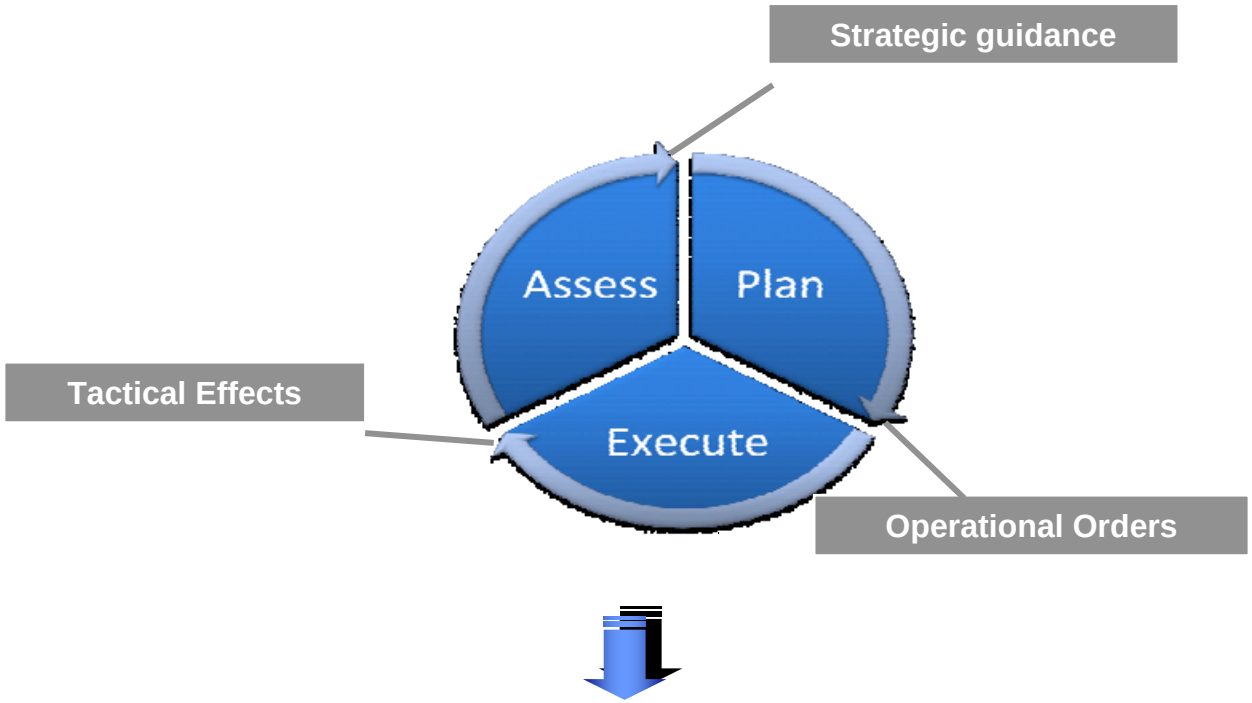


- **Holonic C2 Structure**: overcomes drawbacks of hierarchy and heterarchy
  - **Holons** are **autonomous self-reliant units**: have a degree of **independence** and **handle contingencies** without asking higher authorities for instructions
  - **Advantages**
    - Enables the creation of very complex systems ⇒ complex organizations such as MHQ/MOC
    - Highly resilient to the internal and external disturbances
    - Adapts to the changes in the environment with which it interacts ⇒ dynamic changes in the mission and/or organization
    - Maintains **unity of command**



C2 Requirements for MHQ/MOC

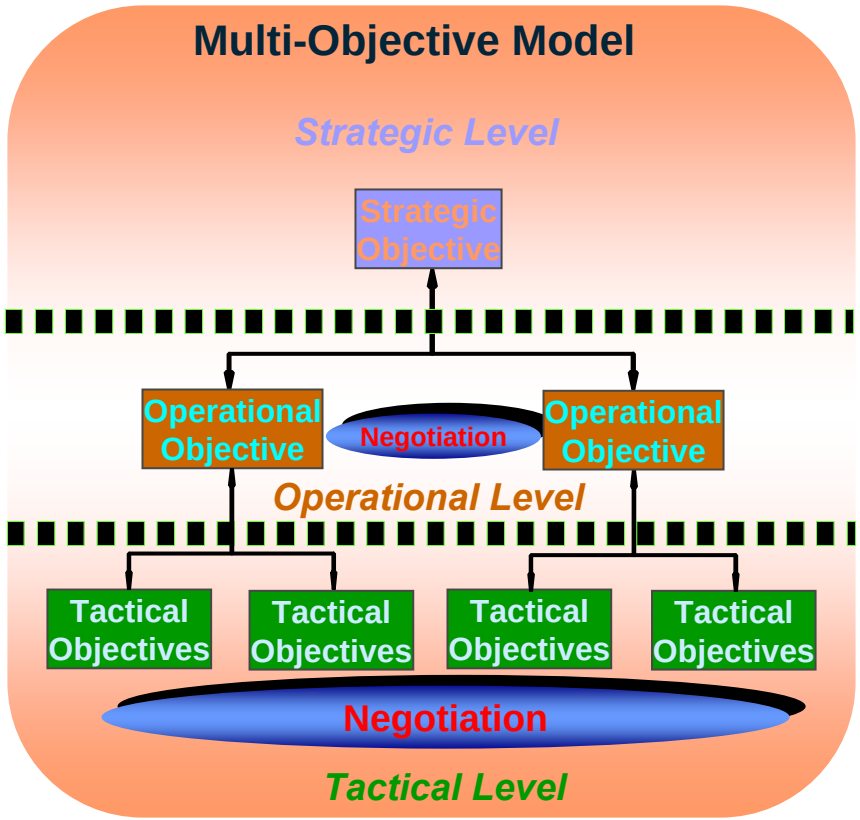
- **C2 Requirements for MHQ with MOC**
  - Centralized assessment
  - Networked distributed planning
  - Decentralized execution



Key MHQ/MOC issue: how to link tactical, operational and strategic levels

Holonic Reference Architecture

- **Strategic-level control (SLC)**
  - Centralized assessment / guidance, mission assignment
  - Provides a structure for establishing mission objectives and guidance for future plans
- **Operational-level control (OLC)**
  - Networked distributed collaborative planning /dynamic and adaptive re-planning
  - Provides facilities for mission decomposition (i.e., generating the task graph), deliberate planning, command, inter-holon coordination/ negotiation
- **Tactical-level control (TLC)**
  - Decentralized execution
  - Encapsulates the functional holons that execute the assigned tasks

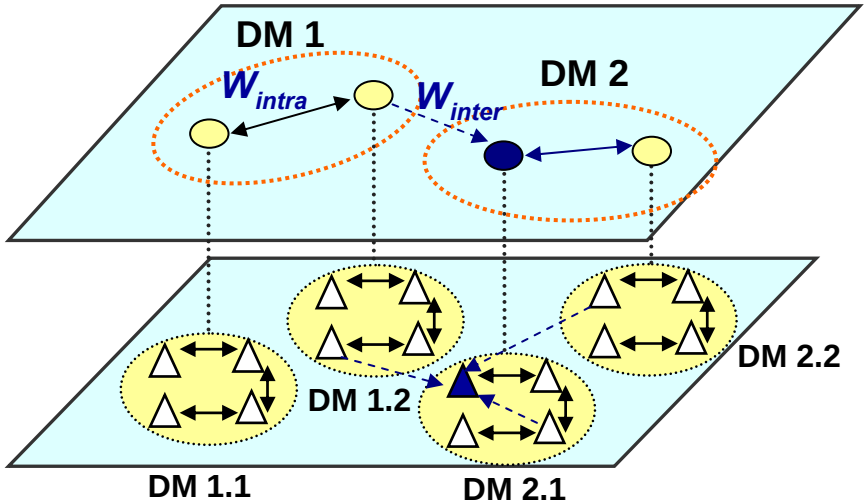


Two Coordinating Decision Layers

- **SLC-OLC layer**: coordinates multiple missions (simultaneous or sequential)
  - If missions are in conflict at the OLC, the OLC requests the SLC to obtain strategic guidance to resolve the conflict and yet achieve long-term strategic objectives
- **OLC-TLC layer**: performs asset allocation for each mission and resolves conflicts in task scheduling
  - Task status reports from subordinate holons at the TLC are sent up to holons at the OLC
  - Monitor and supervise mission progress and promulgate adjustments to tactical actions to lower-level holons

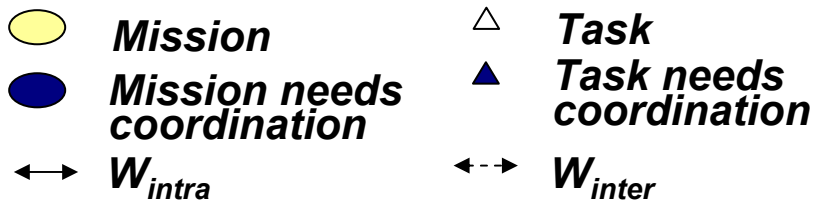
Key issue: **multi-mission sequence**

SLC-OLC layer



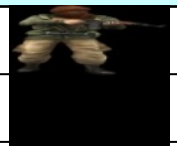
OLC-TLC layer

Key issue: **task-asset assignment**



SLC-OLC Layer

- **Key Issue:** How to sequence multiple missions?
- **Approach:** Formulated as a Markov decision problem
  - **State:** combination of missions

State	HA/DR	Stability Ops.	Major combat Ops.
x_1			
x_2			
x_3			
x_4			
x_5			
x_6			
x_7			
x_8			

- **Action**: process missions in *sequential* or *parallel* mode
- **Policy**: The best action to take in each state at each decision epoch

- **Overall Transition probability**: from constituent mission transition probabilities

$$P(x(k+1)\,|\,x(k),u(k)) = \prod_{i=1}^{M} P(z_i(k+1)\,|\,z_i(k),u(k))$$

where M is the number of missions

- **Reward Structure**: Surrogate measure to the probability of mission success in terms of the national level resources

$$R(x(k),u(k)) = \sum_{i=1}^{M} R(z_i(k),u(k))$$

x_h	Simultaneous	Sequential	x_h	Simultaneous	Sequential
x_1	12.00	10.80	x_5	8.50	7.65
x_2	7.50	6.75	x_6	4.00	3.60
x_3	8.00	7.20	x_7	4.50	4.05
x_4	3.50	3.15	x_8	0.00	0.00

- **The expected reward of policy π starting at $x(0)$:**

$$J_\pi(x) = E[R(x(N)) + \sum_{k=0}^{N-1} R(x(k),u(k))]$$

where N is the number of decision epochs

OLC-TLC Layer

- **Key Issue:** How to allocate assets for each mission and resolve conflicts in task scheduling?
- **Approach:** use group technology and nested generic algorithm to assign assets to tasks (Yu *et al.* IEEE T-SMCA, January 2006)
  - Tasks are assigned to assets based on the fit between the resource requirements* of tasks and the resource capabilities** of assets
  - Tasks are assigned to decision makers (DMs) based on the fit between the resource requirements of tasks and the resource capabilities** of DMs
  - In order to minimize the overall task completion time, synchronization delays should be minimized
  - Minimizing the inter-DM coordination delay (**between group delay**) outweighs the intra-DM coordination delay (**within group delay**), since there is a larger **barrier** between any two DM cells
  - A tradeoff between internal and external coordination workload is the key here

*** Resource Requirements**

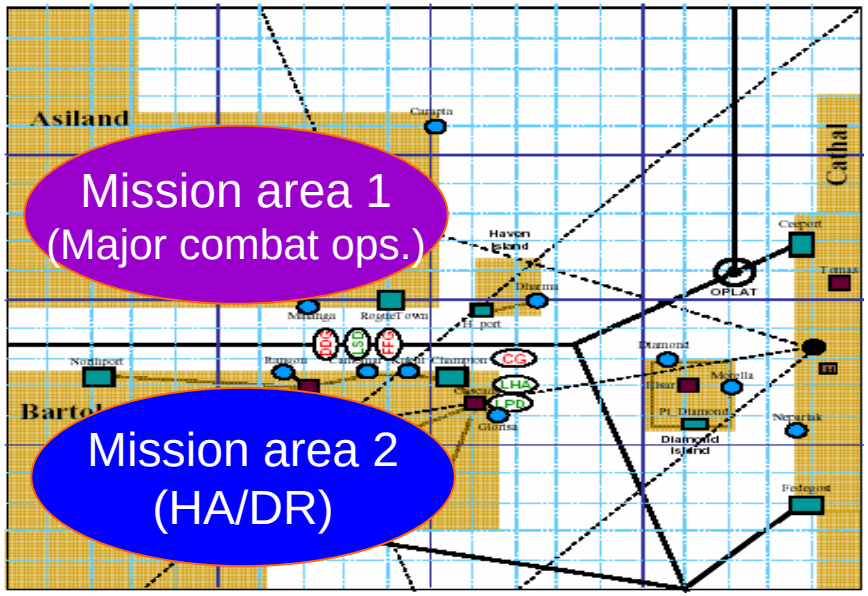
		Resource Requirements				
ID	Task Name	R1	R2	R3	time	locations
1	T1	1	0	1	1	(0,0)
2	T2	1	0	1	1	(2,1)
3	T3	1	1	0	1	(1,1)
4	T4	1	1	0	1	(1,0)
5	T5	0	1	1	1	(2,0)
6	T6	0	1	1	1	(0,1)

**** Resource Capabilities**

		Resource Capabilities			
ID	Asset Name	R1	R2	R3	velocity
1	A1	1	0	0	1
2	A2	1	0	0	1
3	A3	0	1	0	1
4	A4	0	1	0	1
5	A5	0	0	1	1

Multi-mission Sequencing

Mission Space



Future Plans

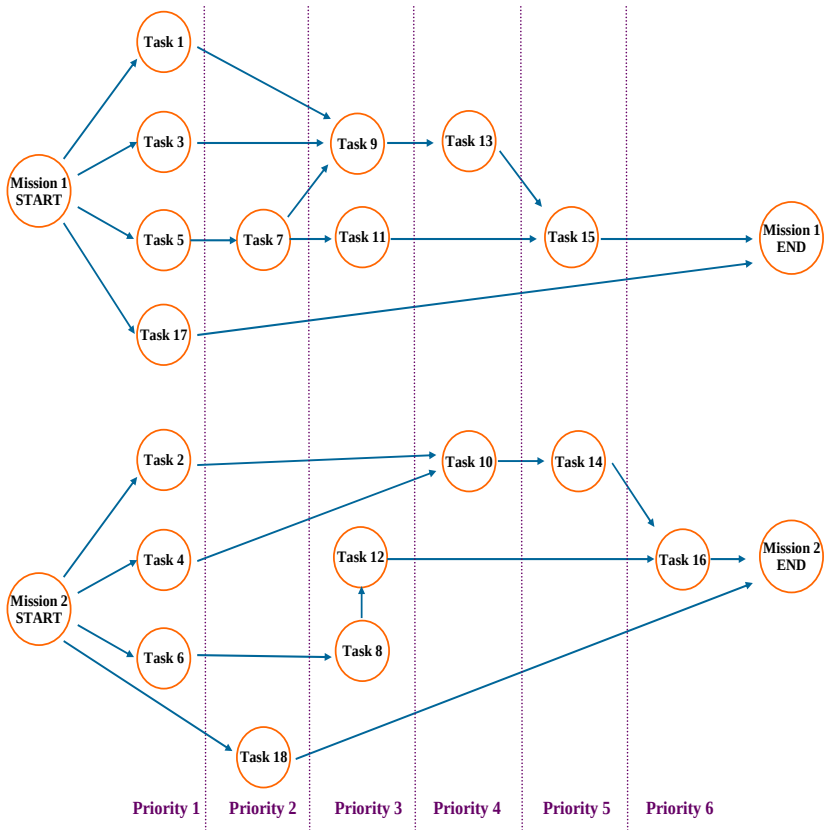
- Multi-mission sequencing provided by SLC-OLC layer: **parallel** execution of both missions

mission 1

mission 2

Mission Decomposition

- Operational holon at the OLC decomposes the mission as a task precedence graph



Task-Asset Assignment

- **Task-Asset Assignment Solution**
  - Conflicts in Task-asset assignment are resolved by OLC-TLC layer

Time Unit

Missions	Taks Units	Assets	0	1	2	3	4	5	6	7	8	9	10	11
M1	TU1	1	T3								T15			
		18									T15			
		19									T15			
	TU2	7			T17		T11	T13						
		11												
		14			T5		T11							
		17			T17			T13						
	TU3	2	T1											
		10	T1											
		12	T1											
		16	T1											
		4			T5									
		5				T7								
		6												
		8			T5	T7								
		9				T7								
		13					T9							
M2	TU1	1				T18								T16
		15				T18								
		18				T18								T16
		19												T16
	TU2	3	T6											
		7	T6								T12		T14	
		11												
		14									T12			
		17				T18							T14	
		20	T6											
	TU3	2					T2							
		10					T2							
		12					T2							
	TU4	5						T8						
		6												
		8	T4					T8						
		9						T8				T10		
		13										T10		

Feasible Schedule

Feasible Schedule Coordinating Schedule

Handling Mission Contingencies

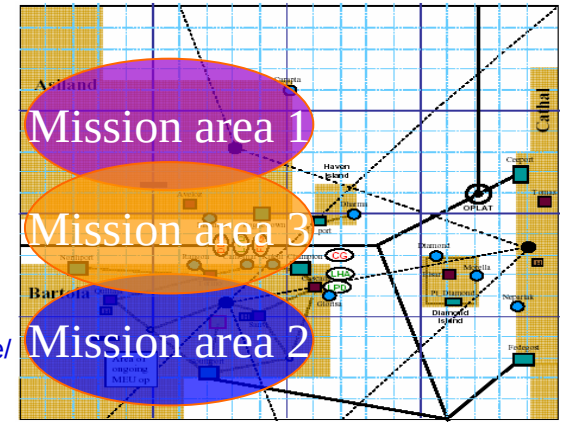
- **Contingencies**: a new military mission is added to ongoing missions at time 3
  - **Mission 3** (**stability operations**): Provide security in the unstable mission area 2
  - **Asset breakdown**: assets 2, 10, 12 and 16 were disabled during the execution of task 1 of mission 1; but, task 1 is completed

- **Mission space**

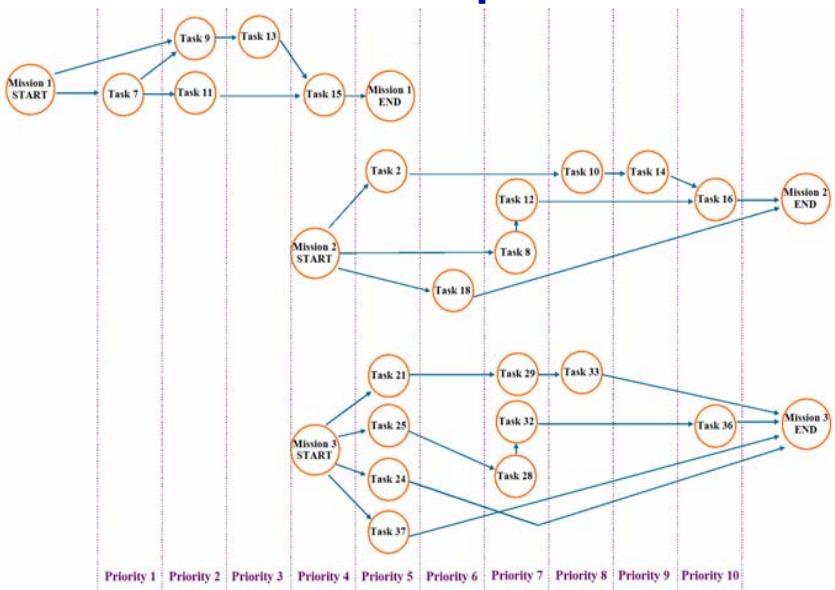
Major combat operation

Stability operation

HA/DR
(humanitarian assistance/ disaster relief)



- **Multi-mission sequence solution**



- **Task-asset assignment solution**

Summary

- We showed that the proposed C^2 holonic reference architecture (HRA) can be applied to the Navy's new MHQ with MOC linking tactical, operational and strategic level controls
  - Strategic Level Control (SLC): centralized assessment
  - Operational Level Control (OLC): networked distributed planning
  - Tactical level control (TLC): decentralized execution
- The C^2 HRA provides an approach to the multi-mission planning problem at the operational level
- A multi-mission scenario showed that the C^2 HRA exhibits the capability to detect and recover from schedule infeasibility and to adapt to contingencies, such as the onset of new missions and asset breakdowns