An Optimization-based Multi-level Asset Allocation Model for Collaborative Planning

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Introduction

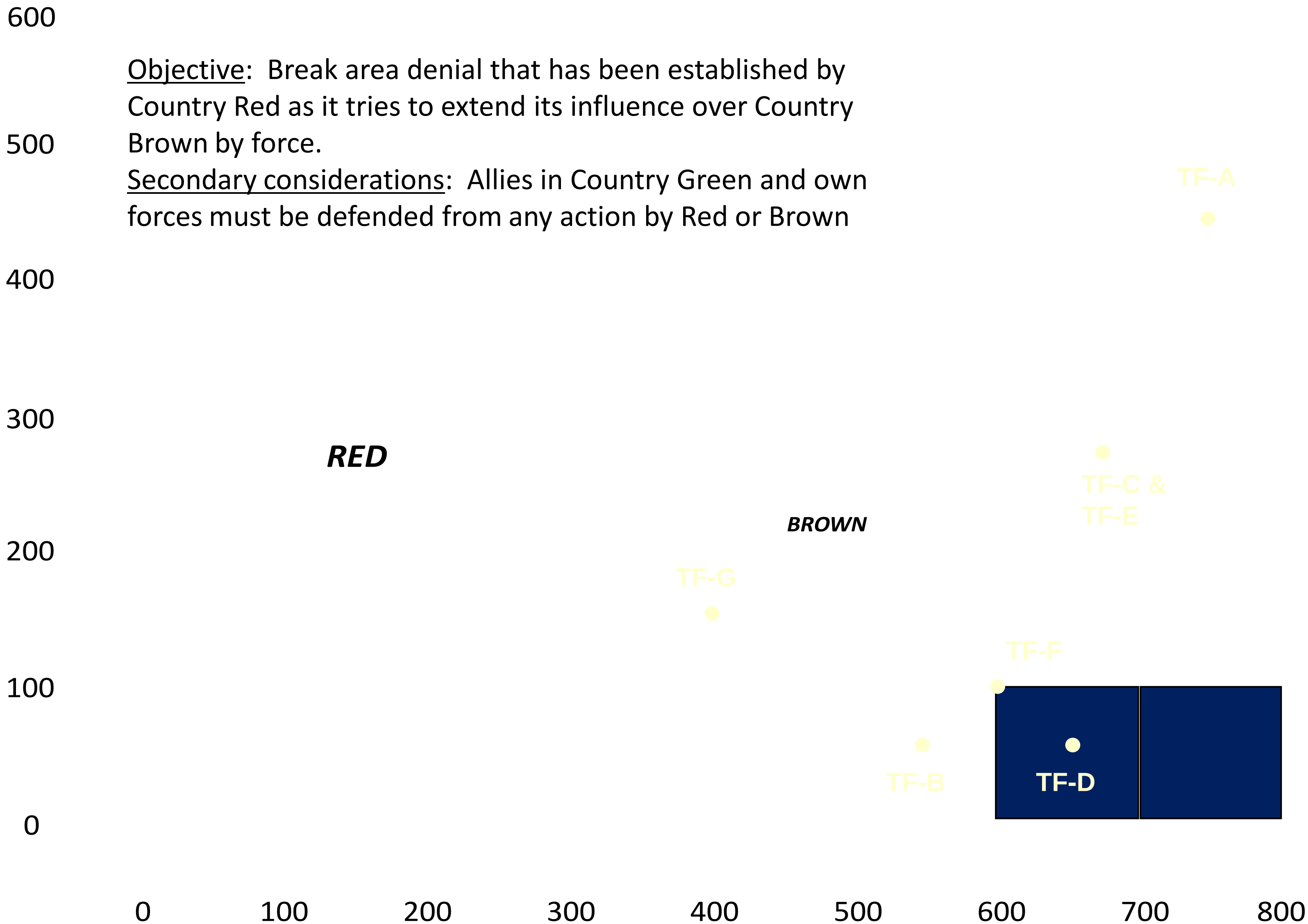
- Motivation:
  - Networked distributed planning capabilities in maritime operations centers (MOC)
  - Mixed-initiative decision making
  - Multi-level asset-to-task allocation
  - Planning/re-planning based on dynamics of mission environment
  - Assessing the efficiency and planning performance of integrated and isolated team structures (MOC-2010 experiment at NPS)
- Previous research: optimization-based modules for MOC-2009 experiment
  - Future operations (FOPS) module
    - Provide a list of *N*-best asset packages to maximize the task execution accuracy subject to constraints on maximum number of tasks per asset
  - Current operations (COPS) module
    - Analysis the risk of redirecting assets from an ongoing task to perform intelligence, surveillance, and reconnaissance (ISR) tasks
  - Scheduling (offline) module
    - Assist experimental designer to set the conditions for the mission planning activity (e.g., asset types and numbers, task requirements and asset capabilities)

Q: **Can we develop a general purpose distributed planning software for Team-in-the-loop planning experiments?**

Geographic Layout

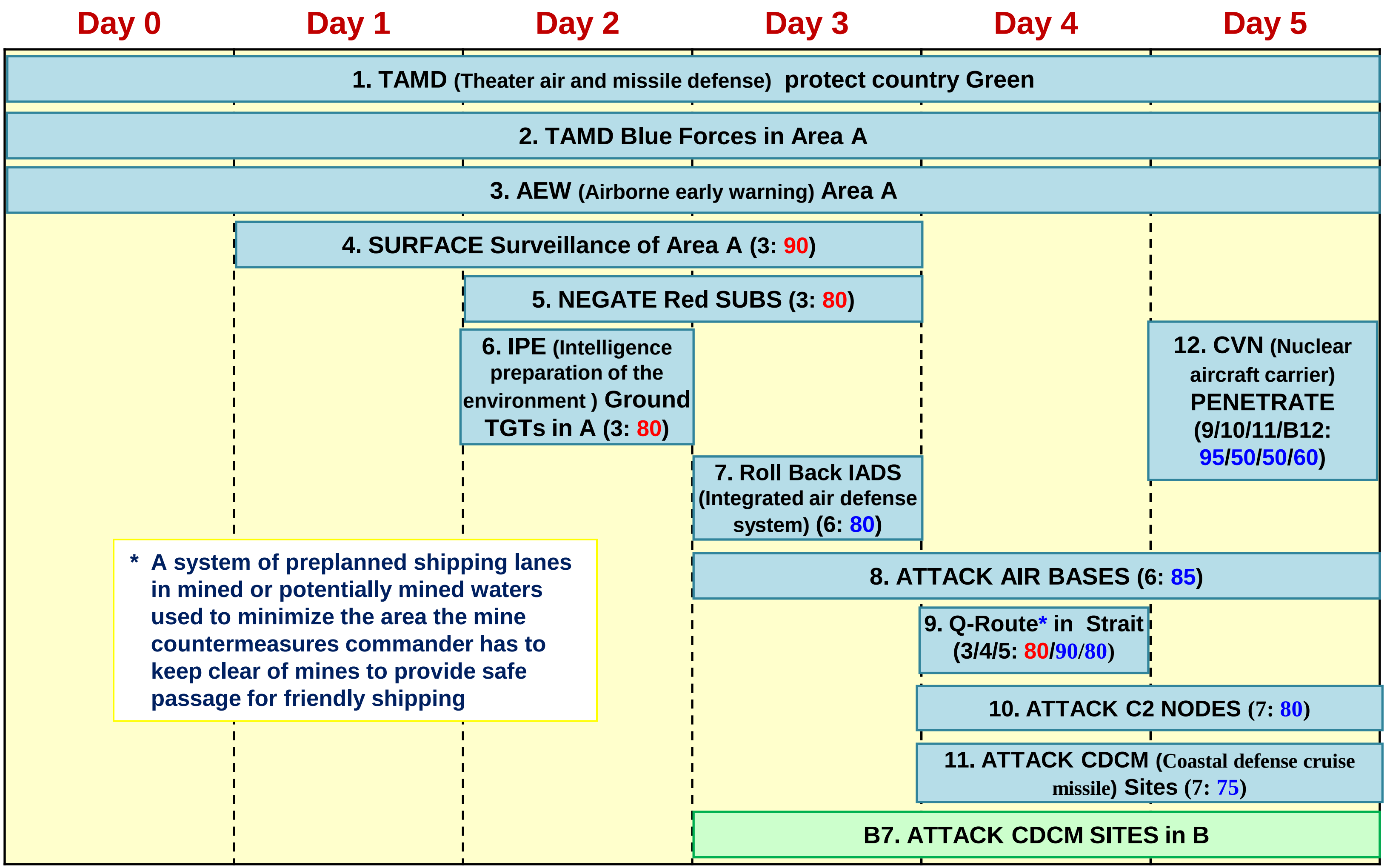
Objective: Break area denial that has been established by Country Red as it tries to extend its influence over Country Brown by force.

Secondary considerations: Allies in Country Green and own forces must be defended from any action by Red or Brown



Mission Scenario for MOC-2010 Experiment

- **Task Graph**(What needs to done by what time?)



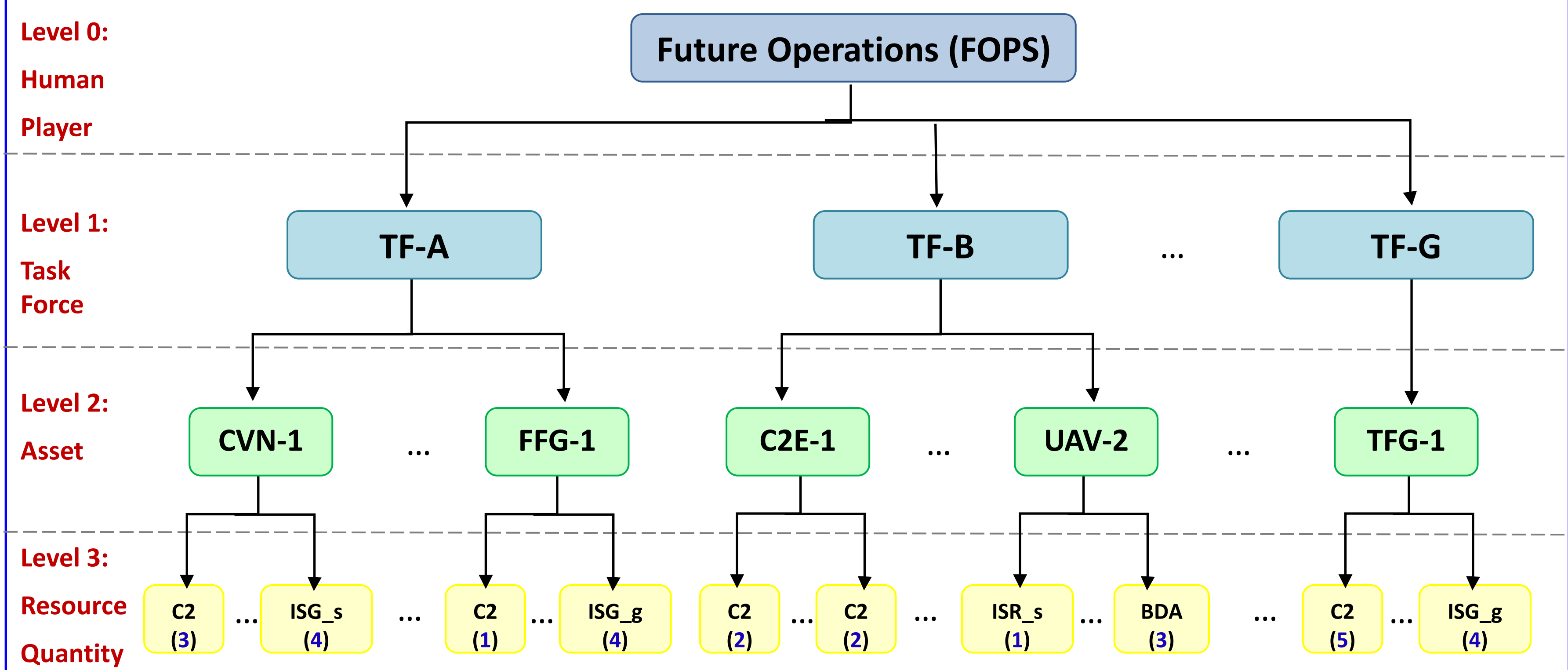
- Similar mission courses of action (COA) exists for Area B
- Overall <15 Tasks per Day
- 25 Tasks of the mission

( ): Precedence task (task #: Accuracy or % Completion desired)

Force Structure for MOC-2010 Experiment

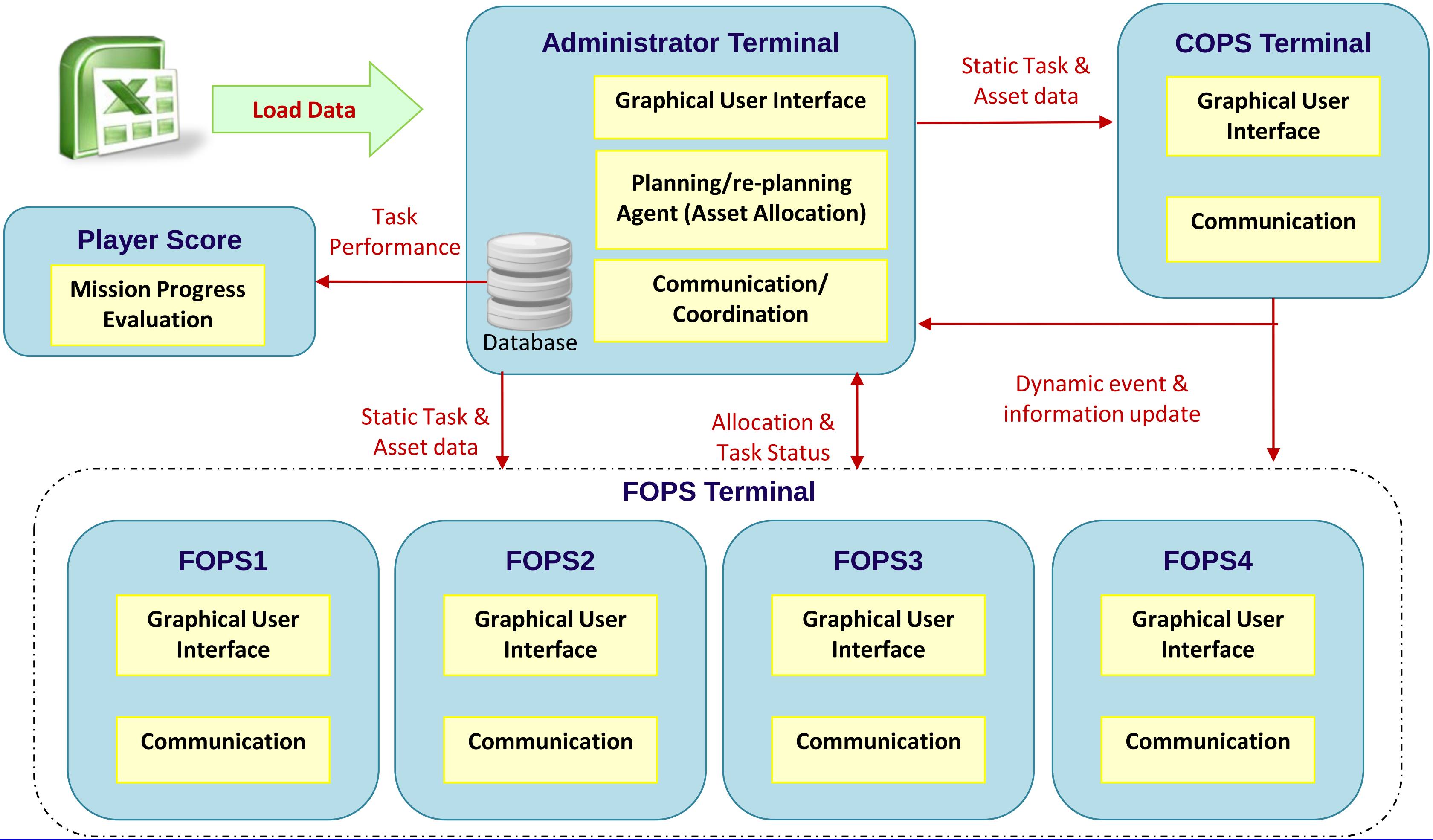
- **Planning Hierarchy** (Specifies who does what and with which resources)

4 FOPS at Level 0: Assign Task Forces - Tasks with Supporting-Supported relationships with a desired performance criteria
7 Task Forces at Level 1: an ESG,CSG, etc., specified with a geographical location
42 Assets at Level 2: specified with an arrival time to denote when the asset engaged to the mission
331 Resource Quantities at level 3: virtual entities with specified capabilities of each warfare area, e.g., C2, STRK, AW, etc.



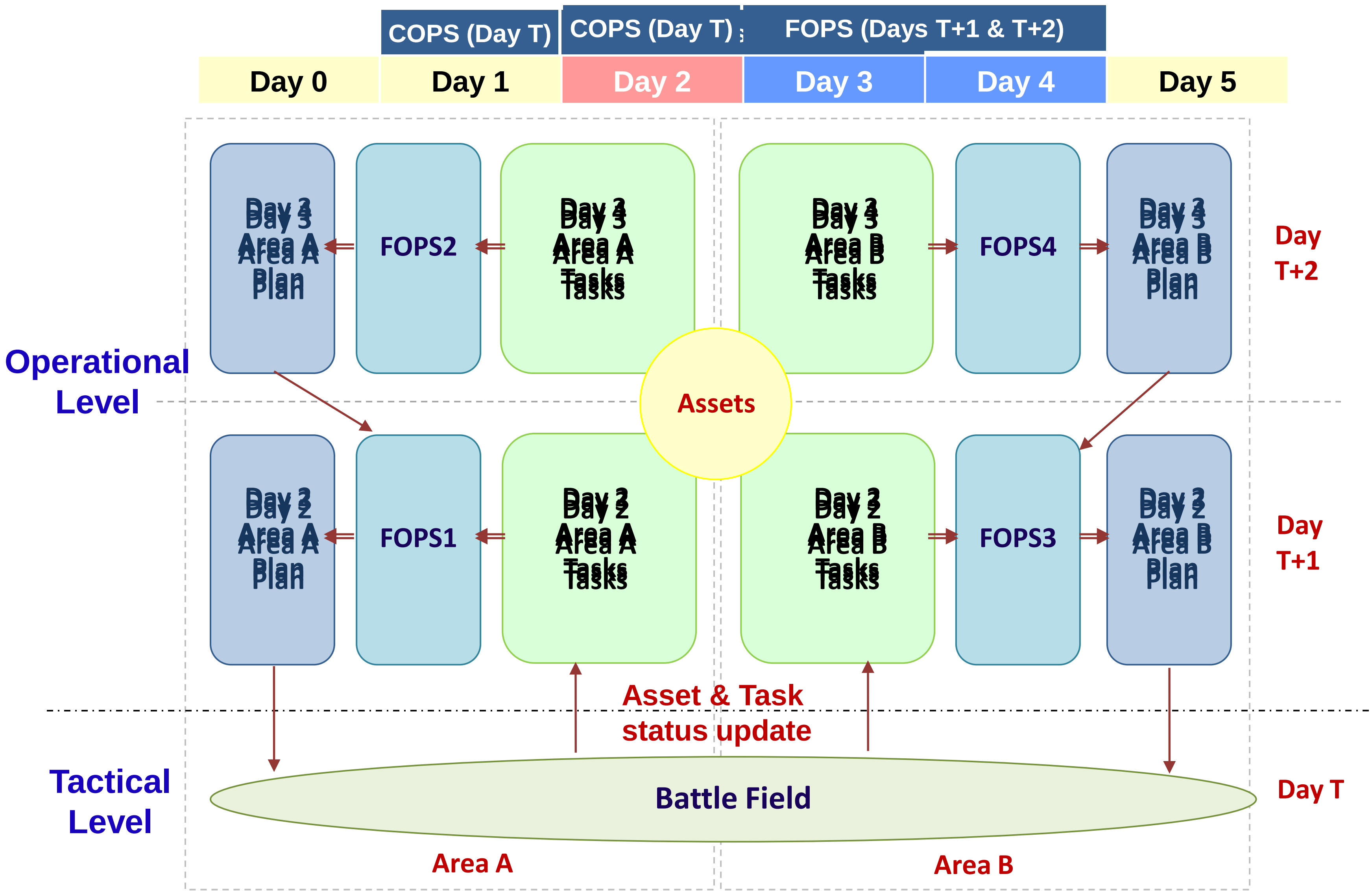
Collaborative Planning Module

- **The planning module interacts with human players to**
  - establish joint or individual commitments to tasks
  - monitor the execution of tasks and acknowledge the latest information
  - broadcast task performance and to re-plan the task



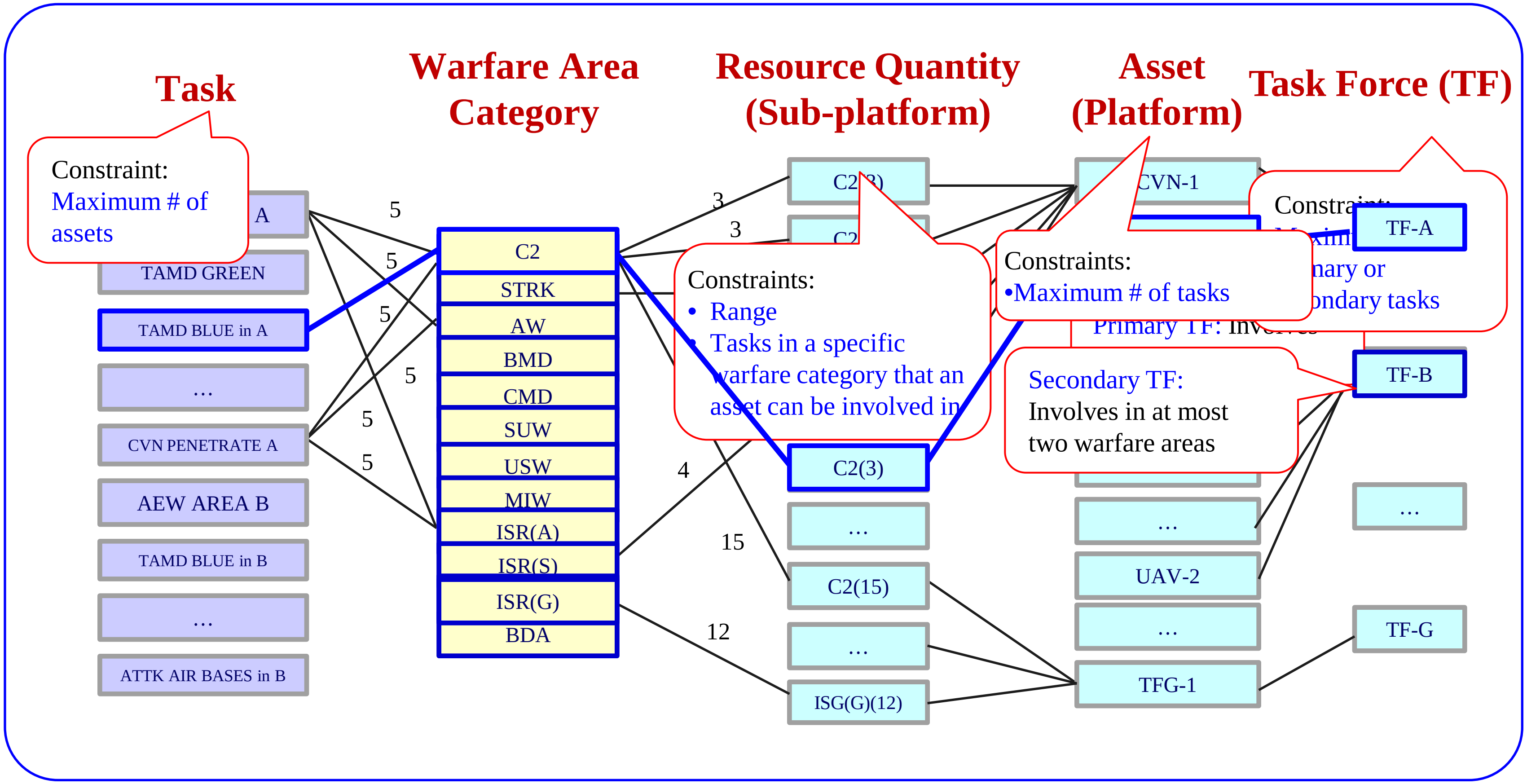
Collaborative Planning Process

■ Moving Time Horizon Planning



Multi-level Asset Task Allocation

- **Problem Objective:** Minimize the cumulative difference between the **desired performance**(percentage completion/accuracy set by the human players) and **the expected performance**(generated by the planning agent based on allocation) over all the tasks



Decision variable: TF-Asset-Resource Quantity-Warfare Area-Task assignment array

Planning Agent Problem Formulation

$$\text{obj: } \min \sum_{i=1}^{I} \rho_i \frac{1}{M} \sum_{m=1}^{M} \Big| \sum_{k \in prmr(i) \cup scnd(i)} \sum_{l=1}^{L(k)} \sum_{p=1}^{P(k,l,m)} \frac{\alpha_{klmp} z_{iklmp}}{R_{im}} - X_i \Big|$$

$\cdots$ minimize the weighted tasks' deviation from the desired performances

$$\text{s.t} \quad \frac{\sum_{p=1}^{P(k,l,m)} \alpha_{klmp} z_{iklmp}}{r_{klm}} \leq y_{iklm} \quad \forall\ i, k, l \text{ and } m$$

$\cdots$ assignment array between task and asset's specific warfare category

$$\sum_{m=1}^{M} y_{iklm} \leq M x_{ikl} \quad \forall\ i$$

$\cdots$ assignment array between task and asset

$$\sum_{k \in prmr(i) \cup scnd(i)} \sum_{l=1}^{L(k)} x_{ikl} \leq \text{max\_assets} \quad \forall\ i\ ;$$

...constraint on the maximal # of assets for a single task

$$\sum_{i=1}^{I} x_{ikl} \leq \text{max\_tasks} \quad \forall\ k \text{ and } l$$

...constraint on the maximal # of tasks for a single asset

$$\sum_{i=1}^{I} y_{iklm} \leq \text{max\_warfare\_tasks} \quad \forall\ k,\ l \text{ and } m;$$

$\cdots$ constraint on the maximal # of tasks for a single asset in specific warfare category

$$z_{iklmp} = 0 \quad \forall\ i,\ \ k \in scnd(i),\ \ 1 \leq l \leq L(k),\ \ m \in \phi(k,i),\ \ 1 \leq p \leq P(k,l,m)$$

$\cdots$ constraint on the secondary TF's supporting warfare categories

$$z_{iklmp} = 0 \quad \forall\ k,\ 1 \leq l \leq L(k),\ \ \forall\ m,\ 1 \leq p \leq P(k,l,m),\ i \in \zeta(k,m)$$

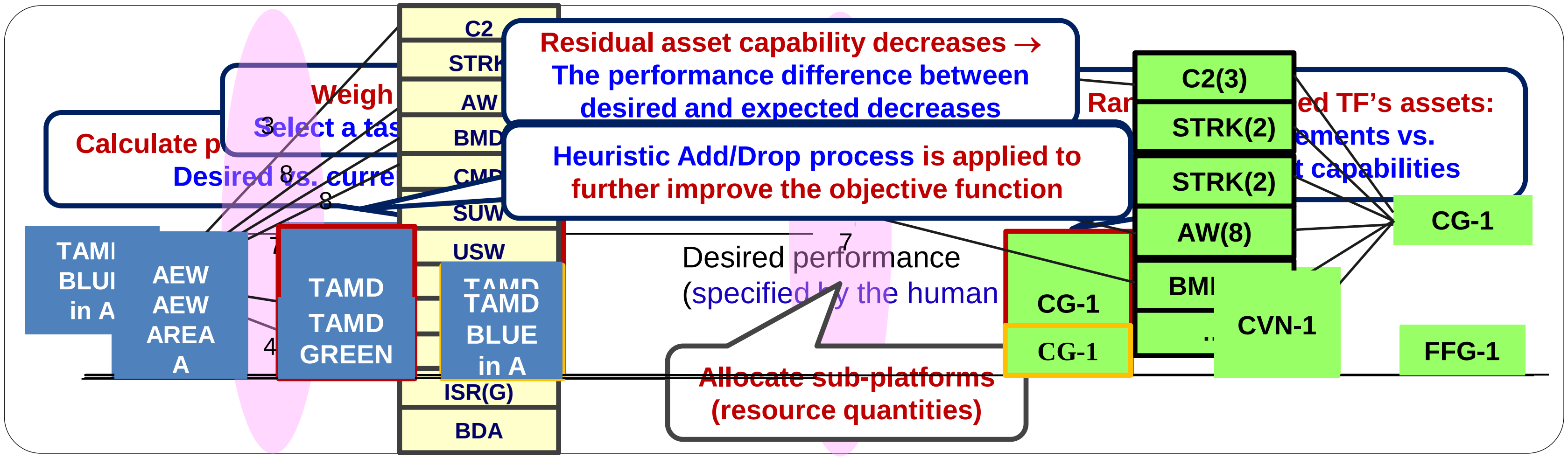
$\cdots$ geographic constraint ;

$$x_{ikl} \in (0,1), z_{iklmp} \in (0,1), y_{iklm} \in (0,1)$$

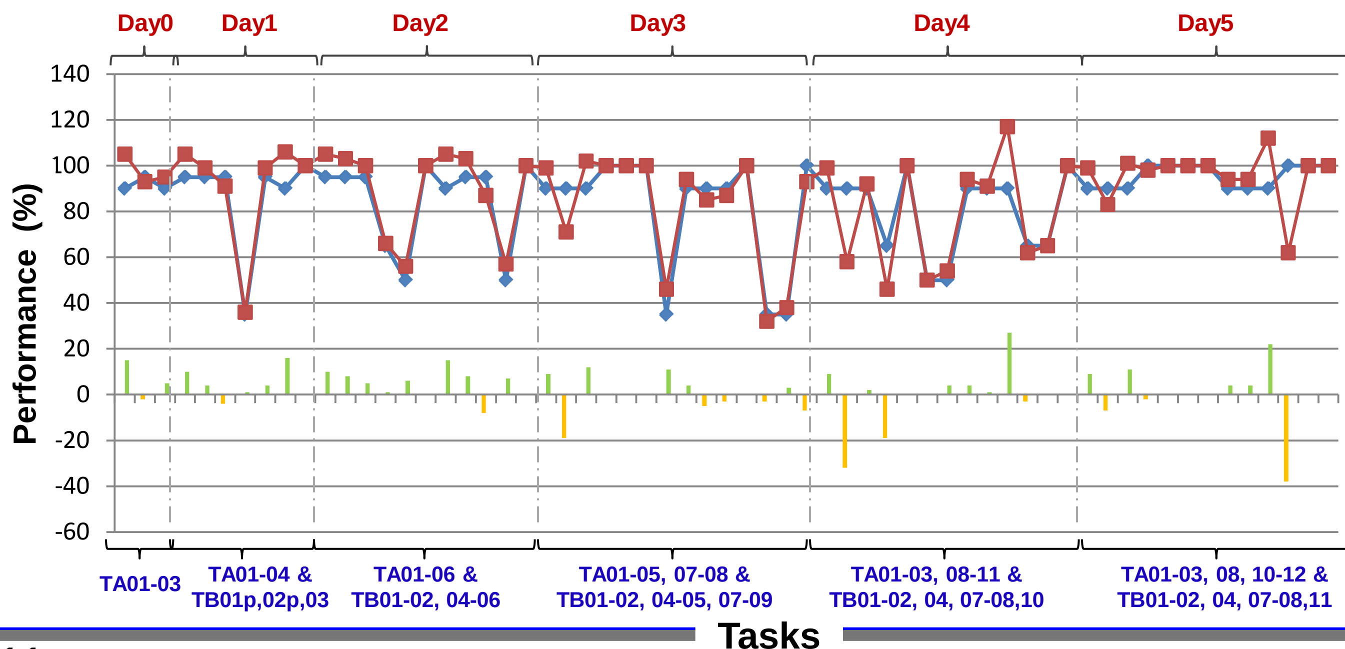
- ❖**Five Dimensional Assignment Array =>2000 decision variables per day**
- ❖**Complex constraints => 3000 constraints per day**
- ❖**Large scale Linear Integer Programming (LIP) Problem**
  => No polynomial run time solution

Solution and Results

■ Dynamic List Planning Method



■ Desired vs. Expected Performance (Accuracy or % Completion)



- 61 tasks over 6 days: <15/day
- Average deviation from desired: 6.61%
- Consistent primary TF allocation for the continuing tasks
- Run time: < 10 sec / day vs. > 40 days by exhaustive search

Summary and Future work

- Summary: optimization-based multi-level asset allocation model
  - Developed an interactive human-in-the-loop planning tool for operational level planning among different team structures
    - Mixed initiative human plus agent environment for laboratory research
  - The tool accommodates the real world challenges – information transfer, dynamic updates from the battlefield
  - Dynamic list planning method used to solve the multi-level asset allocation problem
- Future research
  - Integrate uncertainty factors in operational level planning
    - Weather impacts on planning included in MOC-2011 experiment
    - Uncertainty due to Logistics, ISR and weapon capabilities
  - Incorporate more realistic constraints
    - Temporal constraints: asset maintenance and refueling
    - Multi-level mission representations
  - Improve agent's capabilities
    - Develop operational level agents to optimize Task Force Assignment
    - Scheduling agents to determine optimized mission progress per day