A Novel Congruent Organizational Design Methodology Using Group Technology and a Nested Genetic Algorithm

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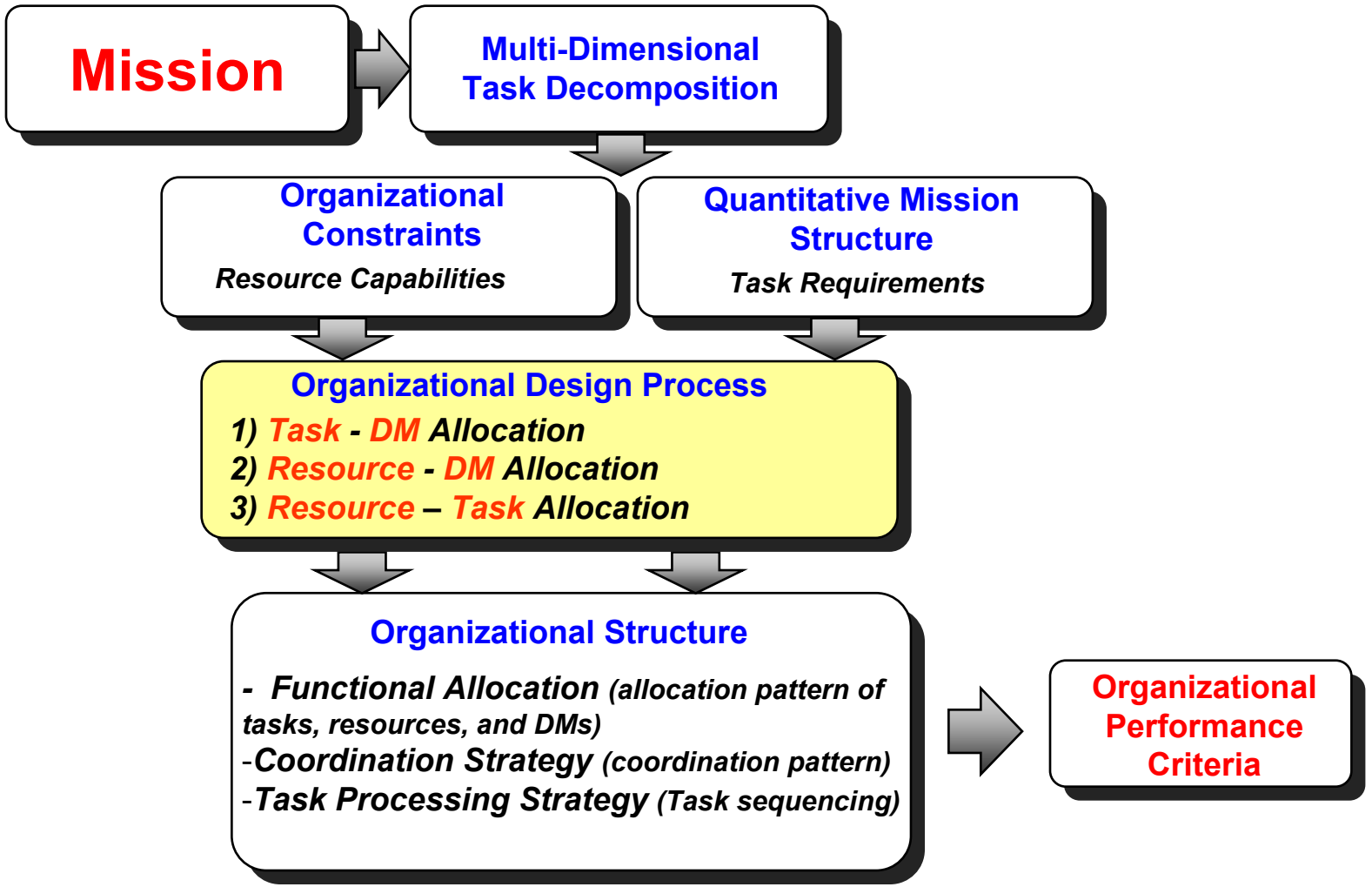
Track 1: ***Modeling and Simulation***

Overview

- Motivation
- Problem Formulation
- Solution Approach—Group Technology and Nested GA
- Performance Measures
- Numerical Simulation
- Conclusion

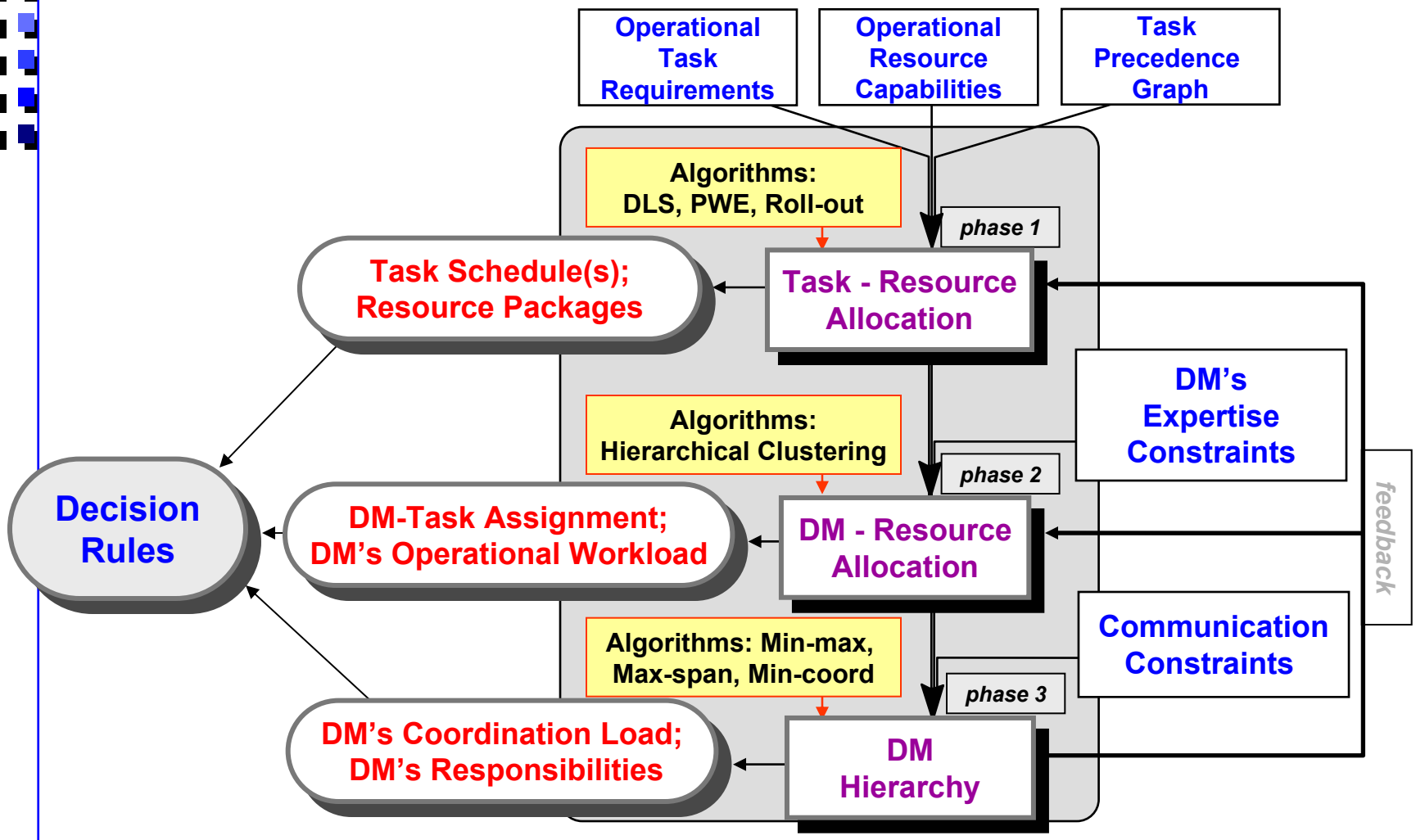
Motivation - 1

Design Process for Command Organizations



Motivation - 2

Current Three-phase Design Methodology



Motivation - 3

Drawbacks of 3-Phase Design Methodology

- The organizational design problem has been decomposed into several sub-problems to overcome computational complexity
- Phase *I* does not account for the workload of inter-DM coordination, which may cause high degree of sub-optimality in phases *II* and *III*
- The 3-phase design process does not take into account the task execution accuracy; it assumes that all the task requirements can be fully satisfied, which is not true in practice

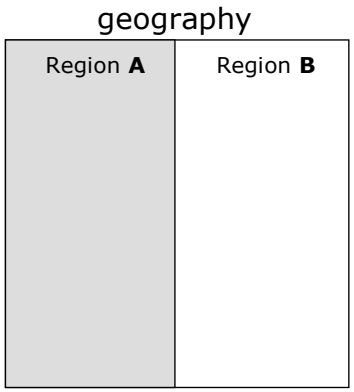
Motivation - 4

Mission responsibility assignment ⇒ task allocation:

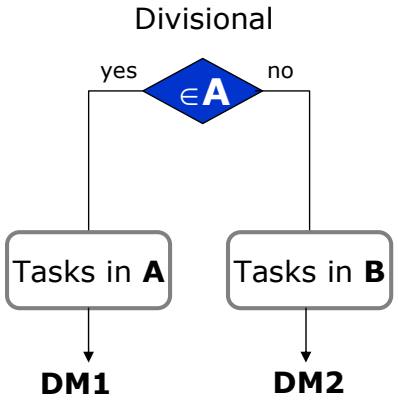
- Functional organization:
  - Assets/resources of the same type
  - Mission responsibility by functional area
- Divisional organization:
  - Assets/resources of different types
  - Mission responsibility by geographical area
- What organization lies between functional and divisional? Hybrid responsibility rules?

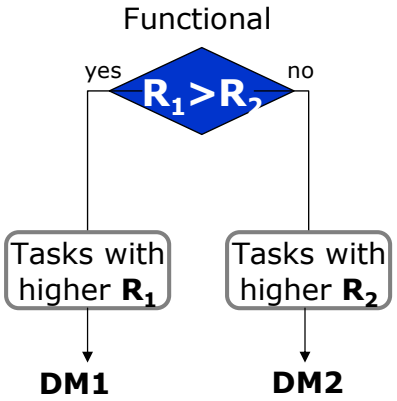
Motivation - 5

Example of hybrid assignment by *decision trees*:



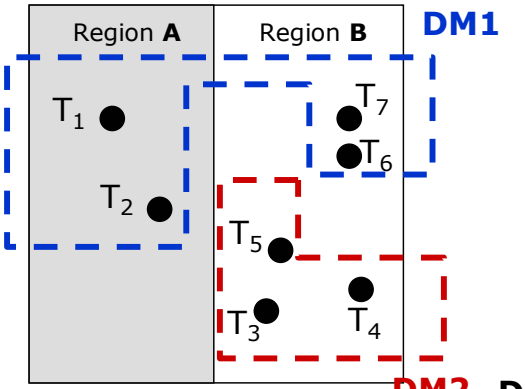
Resources: $R_1(=strike), R_2(=AAW)$

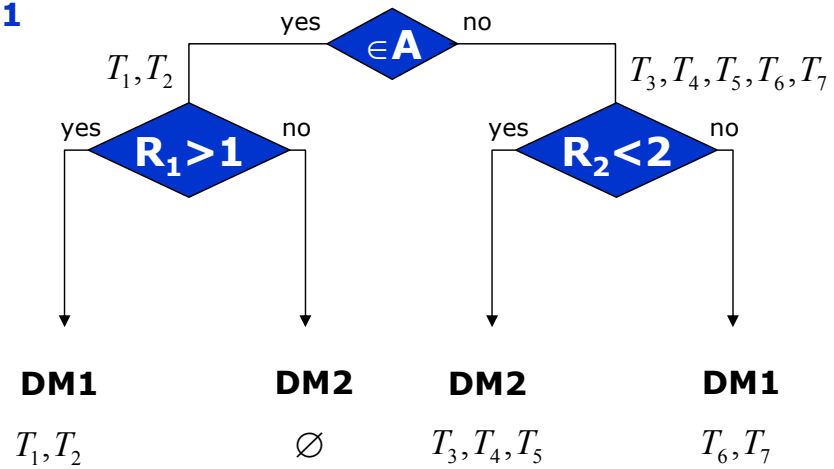




resources

	R_1	R_2	
T_1	2	4	DM_1
T_2	3	3	
T_3	4	1	DM_2
T_4	4	0	
T_5	2	1	
T_6	0	3	DM_1
T_7	4	3	





Problem Formulation - 1

The objective is to minimize the aggregated **workload** of each DM, which takes into account both the intra-DM and the inter-DM coordination workloads. In order to balance the workloads among DMs, we seek to minimize the root mean-square value of the aggregated workload, which is given by:

Minimize:

$$WRMS = \sqrt{\frac{1}{M}\sum_{m=1}^{M} W^2(m)}$$

where $W(m) = \alpha W_{Intra}(m) + (1-\alpha) W_{Inter}(m)$

$W_{Intra}(m)$ **is the intra-DM workload of DM *m***

$W_{Inter}(m)$ **is the inter-DM workload**

α **is the weight assigned to the intra-DM workload**

Subject to:

1. **Each Platform can only be assigned to one DM**
2. **Each DM should be assigned at least one Task**

Problem Formulation - 2

The objective function (1) can be separated into 2 sub-problems:

1. Minimize the intra-DM workload

$$W_{Intra}(m) = \sum_{T_i \in \underline{T}_m} \frac{t(m,i)}{TAS_i} = \sum_{T_i \in \underline{T}_m} \frac{t(m,i)}{[A_{Intra}(m,i)]^{\rho_1}} \qquad (2)$$

where $t(m,i)$ **is the overall platform transfer time when processing task T_i in DM *m***

$A_{Intra}(m,i)$ **is processing accuracy of task T_i in DM *m***

ρ_1 **is the intra-DM task accuracy significance index**

2. Minimize the inter-DM workload

$$W_{Inter} = \sum_{m=1}^{M} W_{Inter}(m) = \sum_{T_i \in \hat{\underline{T}}} \frac{\hat{t}(i)}{[\hat{A}_{Inter}(i)]^{\rho_2}} \qquad (3)$$

where $t(i)$ **is the inter-DM platform transfer time when processing coordination task T_i**

$A_{Inter}(i)$ **is task accuracy of coordination task T_i**

ρ_2 **is the inter-DM task accuracy significance index**

Solution: Group Technology - 1

What is Group Technology (GT) ?

- Group technology (***GT***) recognizes and exploits similarities in three distinct ways:
  - by performing similar operations together
  - by standardizing similar tasks
  - by efficiently storing and retrieving information about recurring problems

- ***GT*** can be carried out by dividing a C^2 system into several manageable subsystems or cells, responsible for managing tasks, assets (platforms), and information flow

Solution: Group Technology - 2

- The advantages of introducing ***GT*** into C^2 systems are:
  - Improved speed of command
  - Reduced task latencies (execution delays)
  - Reduced resource requirements
  - Reduced mission inefficiencies
  - Reduced synchronization delays
  - Reduced response time
  - Improved flexibility
  - **Deconfliction - identifying responsibility areas**

- ***GT*** algorithms:
  - Matrix-based Clustering
  - Hierarchical Clustering
  - Graph-Theoretic Clustering
  - ***AI*** based Clustering
  - Evolutionary Clustering
  - Decision-tree Clustering

Example (1)

Example

Task resources requirement data:

Task ID	Task Name	AAW	ASUW	ASW	GASLT	FIRE	ARM	MINE	DES	Locations		Pro. Times
1	CVBG	5	3	10	0	0	8	0	6	70	15	30
2	ARG	5	3	10	0	0	8	0	6	64	75	30
3	Resupply Port North	0	3	0	0	0	0	0	0	15	40	10
4	Resupplu Port South	0	3	0	0	0	0	0	0	30	95	10
5	Encounters North&South	0	3	0	0	0	0	10	0	28	73	10
6	HILL	0	0	0	10	14	12	0	0	24	60	10
7	NORTH BEACH	0	0	0	10	14	12	0	0	28	73	10
8	SOUTH BEACH	0	0	0	10	14	12	0	0	28	83	10
9	Defend N. Beach	5	0	0	0	0	5	0	0	28	73	10
10	Defend S. Beach	5	0	0	0	0	5	0	0	28	83	10
11	S/P Road	0	0	0	0	0	10	5	0	25	45	10
12	A/P Road	0	0	0	0	0	10	5	0	5	95	10
13	SAM SeaPort	0	0	0	0	0	8	0	6	25	45	20
14	SAM AirPort	0	0	0	0	0	8	0	6	5	95	20
15	SEAPORT	0	0	0	20	10	4	0	0	25	45	15
16	AIRPORT	0	0	0	20	10	4	0	0	5	95	15
17	GTL	0	0	0	0	0	8	0	4	5	60	10
18	Blow Bridge	0	0	0	8	6	0	4	10	5	60	20

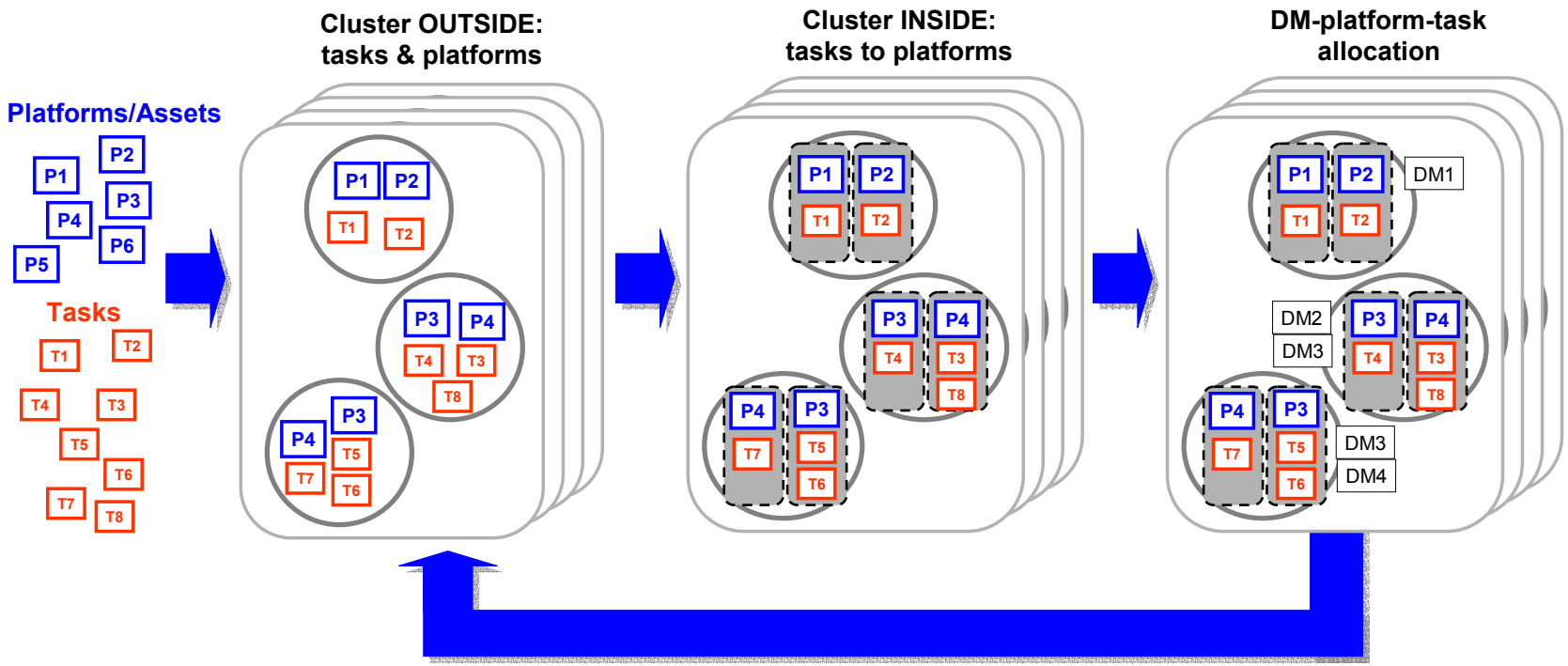
Platform capability data:

Platform ID	Platform Name	AAW	ASUW	ASW	GASLT	FIRE	ARM	MINE	DES	Velocity
1	DDG	10	10	1	0	9	5	0	0	2
2	FFG	1	4	10	0	4	3	0	0	2
3	CG	10	10	1	0	9	2	0	0	2
4	ENG	0	0	0	2	0	0	5	0	4
5	INFA	1	0	0	10	2	2	1	0	1.35
6	SD	5	0	0	0	0	0	0	0	4
7	AHI	3	4	0	0	6	10	1	0	4
8	CAS1	1	3	0	0	10	8	1	0	4
9	CAS2	1	3	0	0	10	8	1	0	4
10	CAS3	1	3	0	0	10	8	1	0	4
11	VF1	6	1	0	0	1	1	0	0	4.5
12	VF2	6	1	0	0	1	1	0	0	4.5
13	VF3	6	1	0	0	1	1	0	0	4.5
14	SMC	0	0	0	0	0	0	10	0	2
15	TARP	0	0	0	0	0	0	0	6	5
16	SAT	0	0	0	0	0	0	0	6	7
17	SOF	0	0	0	6	6	0	1	10	2.5
18	INF(AAAV-1)	1	0	0	10	2	2	1	0	1.35
19	INF(AAAV-2)	1	0	0	10	2	2	1	0	1.35
20	INF(MV22-1)	1	0	0	10	2	2	1	0	1.35

- 8 requirements/capabilities are modeled: AAW (Anti-Air Warfare), ASUW (Anti-Surface Warfare), ASW (Anti-Submarine Warfare), GASLT (Ground Assault), FIRE (Artillery), ARM (Armor), MINE (Mine Clearing), DES (Designation)

Example (2)

Nested Grouping Process



Example (3)

Tasks

Platforms

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	0	0	0	0	1	1	1	1	0	0	1	1	0	0	1	1	0	1
5	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	0	0	1	1	0	0	1	1	0	0	0	0	0	0	0	0
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	1
15	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	1
16	1	1	0	0	1	1	1	1	0	0	1	1	1	1	1	1	1	1
17	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
18	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
19	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
20	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Tasks-platform relationship before clustering

Clustering (NGA)

Tasks

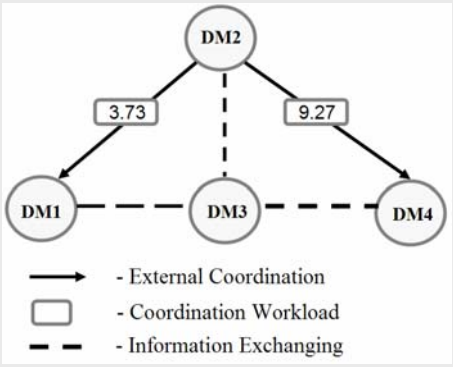
Platforms

	3	15	16	18	6	11	12	13	14	17	1	2	4	5	7	8	9	10
1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0
17	0	0	0	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0
20	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1

Tasks-platform grouping after clustering

DM1	Ground Assault
DM2	Attack
DM3	Defend
DM4	Marine Operations

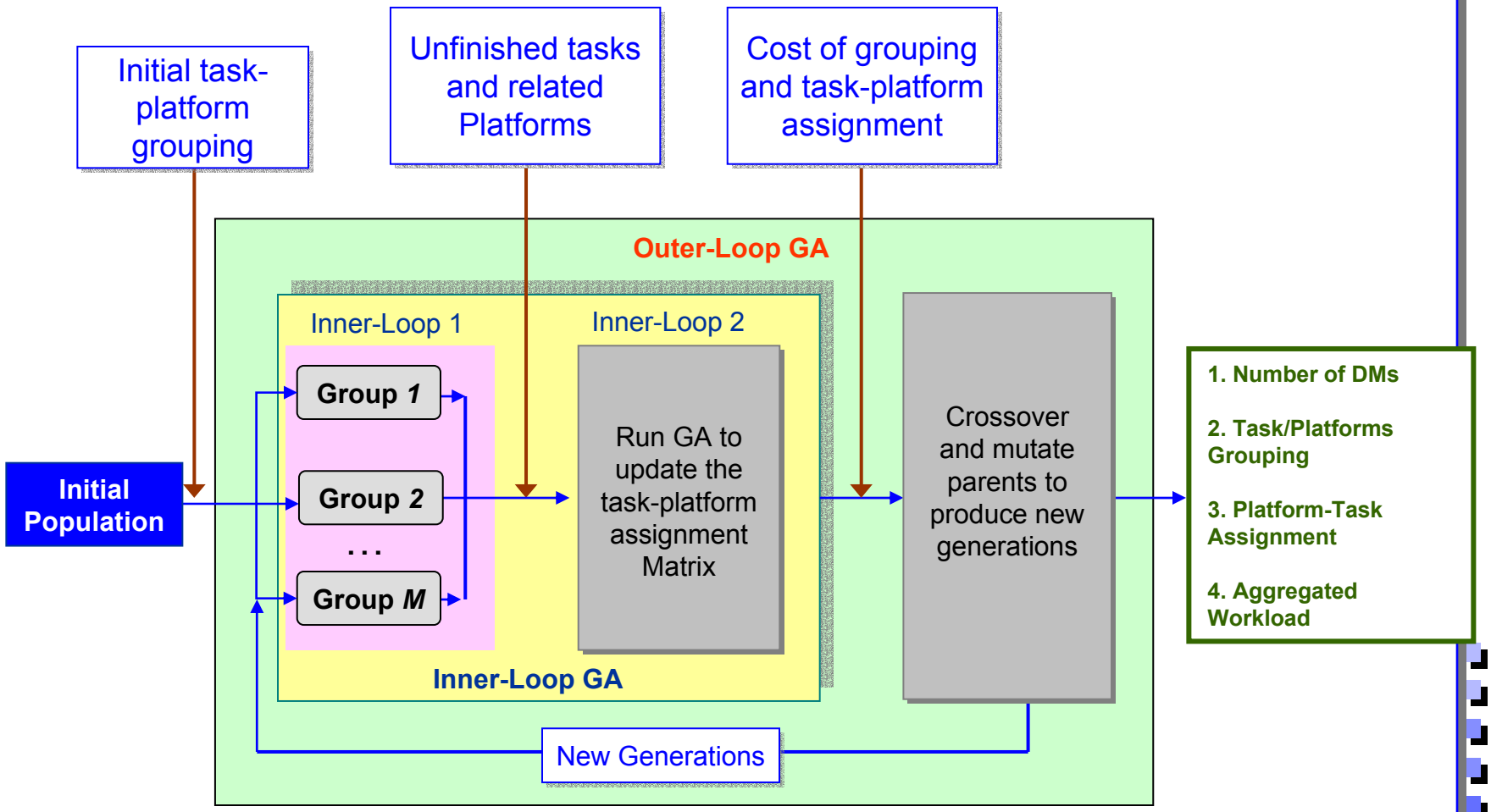
DM Functionality



DM-DM Coordination Structure

Nested GA Procedure

The Nested GA is comprised of two loops: Outer-loop and Inner-loop
There are two stages for the Inner-loop: Inner-loop1 and Inner-loop2



Performance Measures

A. Average Platform Transfer Time

Total intra-DM and inter-DM transfer time of platforms divided by number of platforms

B. Clustering Efficiency

Ratio of task-platform assignment in groups to the total task-platform assignment

C. Average Task Accuracy

Sum of each task accuracy over number of tasks. Average Task Accuracy measures how good the overall tasks have been processed

D. Average Platform Utilization

Sum of utilization of each platform over number of platforms. The utilization of each platform is the percentage of resource capability of platform being used for task execution

Conclusion

- Introduced Group Technology *(GT)* concept into organizational design
- Proposed a two-layer algorithm framework for solving organizational design problem
- Applied Nested GA (NGA) as a solution approach
- Defined performance measures
- Numerical simulation shows that this solution approach is capable of designing a congruent organization in terms of resource and task allocation structure

- Next step: Implement decision-tree clustering