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A Tool for Estimating the Costs/Benefits of Teamwork in Different C2 Structures

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Introduction

Evolution of C2 towards the development of organizations which are rapidly reconfigurable, decentralized and adaptive
(Atkinson & Moffat, 2005)

Team functioning represents in itself an element of complexity
(SAS-065, 2010)

Ability to estimate the costs and benefits associated with particular team structures has become an increasingly important topic

Team Structure

No major distinction between concepts of team structure, team organization, and tean architecture

<u>Essentially involves:</u>

- task allocation

- role allocation

- information allocation

- tool allocation

Levchuk et al. (2005)

Cost/Benefit Tradeoffs in Team Design

The effectiveness of different team structures depends on the interplay between costs and benefits of teamwork

E.g., team structure based on role specialization should lead to:

benefits
…reduced information requirements
…less task switching

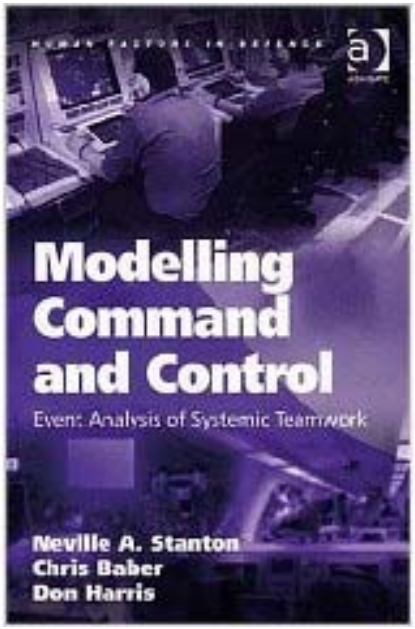
costs
…increased inter-dependence
…greater teamwork requirements

Since this interplay is not well understood, the aim of the present work is to develop a tool for estimating the effects of the organizational structure on team effectiveness

Event Analysis of Systemic Teamwork

"EAST provides an assessment of agent roles within the network, a description of the activity including the flow of information, the component tasks, communication between agents and the operational loading of each agent."

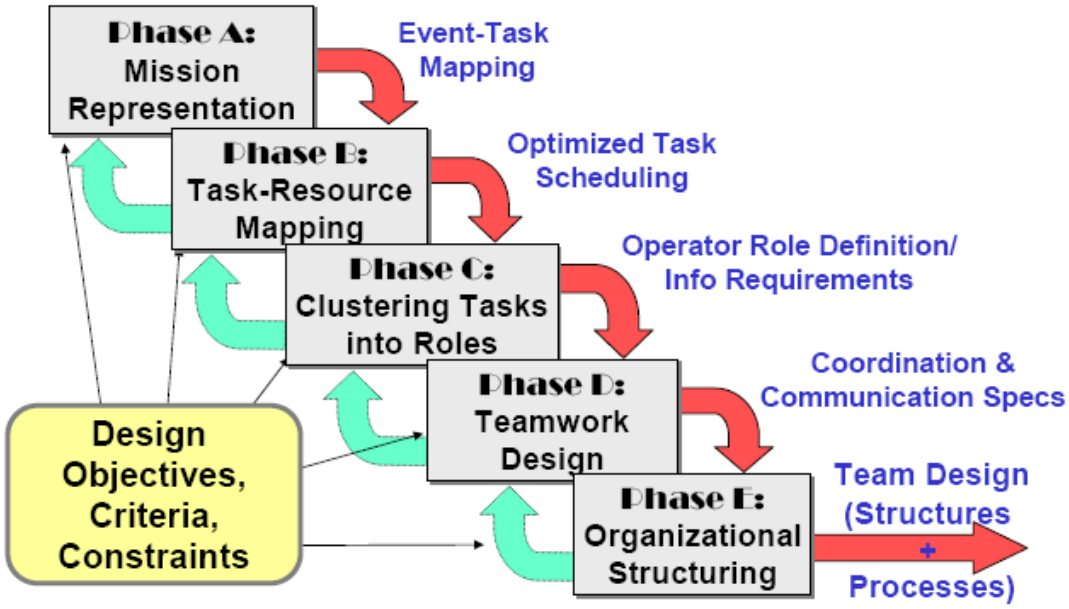
(Stanton, Baber, & Harris, 2008)



Team Optimal Design (TOD)

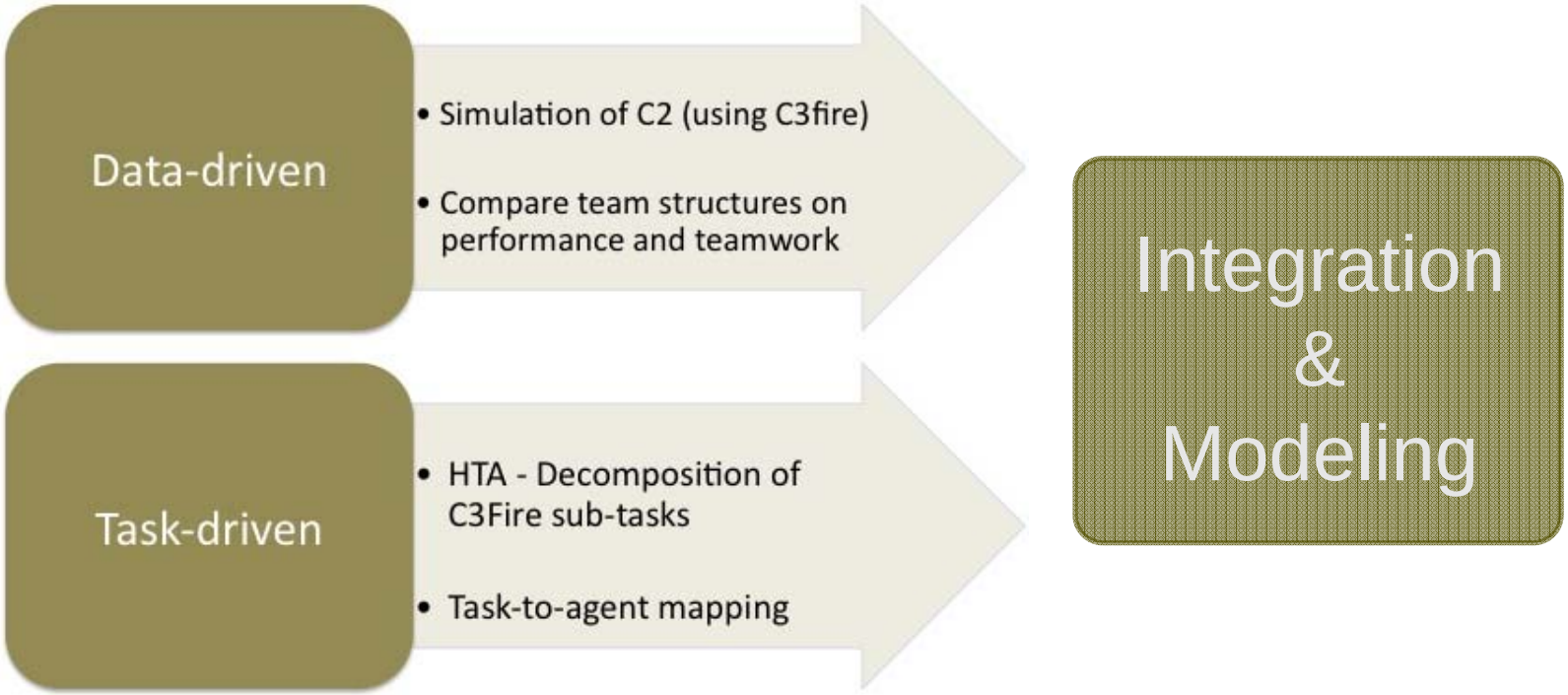
- Socio-technical approach
- Capture large range of individual and team factors
- Performance highly related to the distribution of workload
- Computational modeling and algorithm-based optimization
- Requires a model calibration based on empirical data to generate predictions

Levchuk et al. (2005)



Approach

Develop a tool that integrates results from a task analysis and laboratory experimentation to enable users to estimate the cost and benefits of teamwork in tactical C2 and identify team structures that support optimal team effectiveness

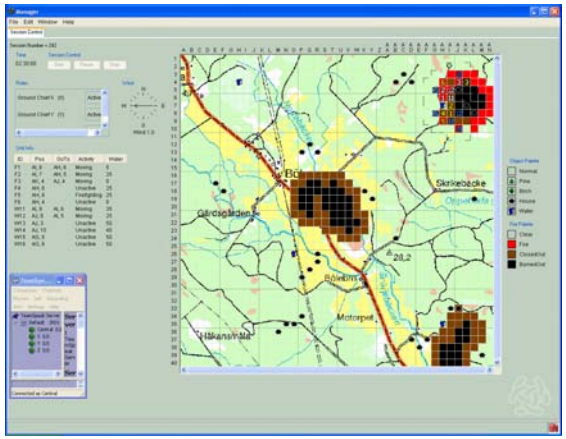


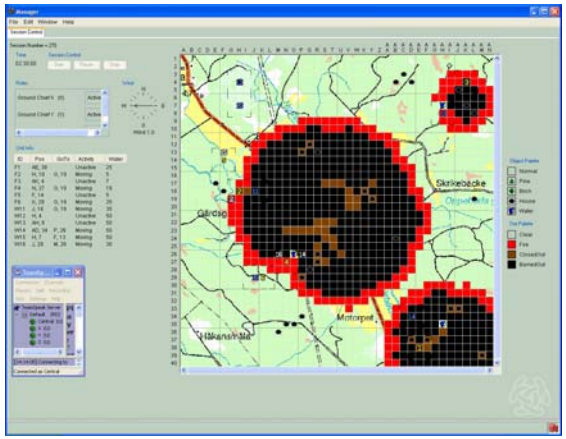
Scope

- Tactical-to-operational C2
- High tempo, uncertainty and complexity
  E.g., homeland security, crisis management
- Teamwork at the intra-team level
- Small C2 teams of 3 members
  Supervising several tactical units

C3Fire Microworld (Granlund, 1998; 2003)

- A computerized command, control and communication task environment for individuals, teams or multiteam systems
- Functional simulation of C2 under time pressure, including critical unexpected events
- Dynamic system evolving in real time both autonomously and as a consequence of the team's actions

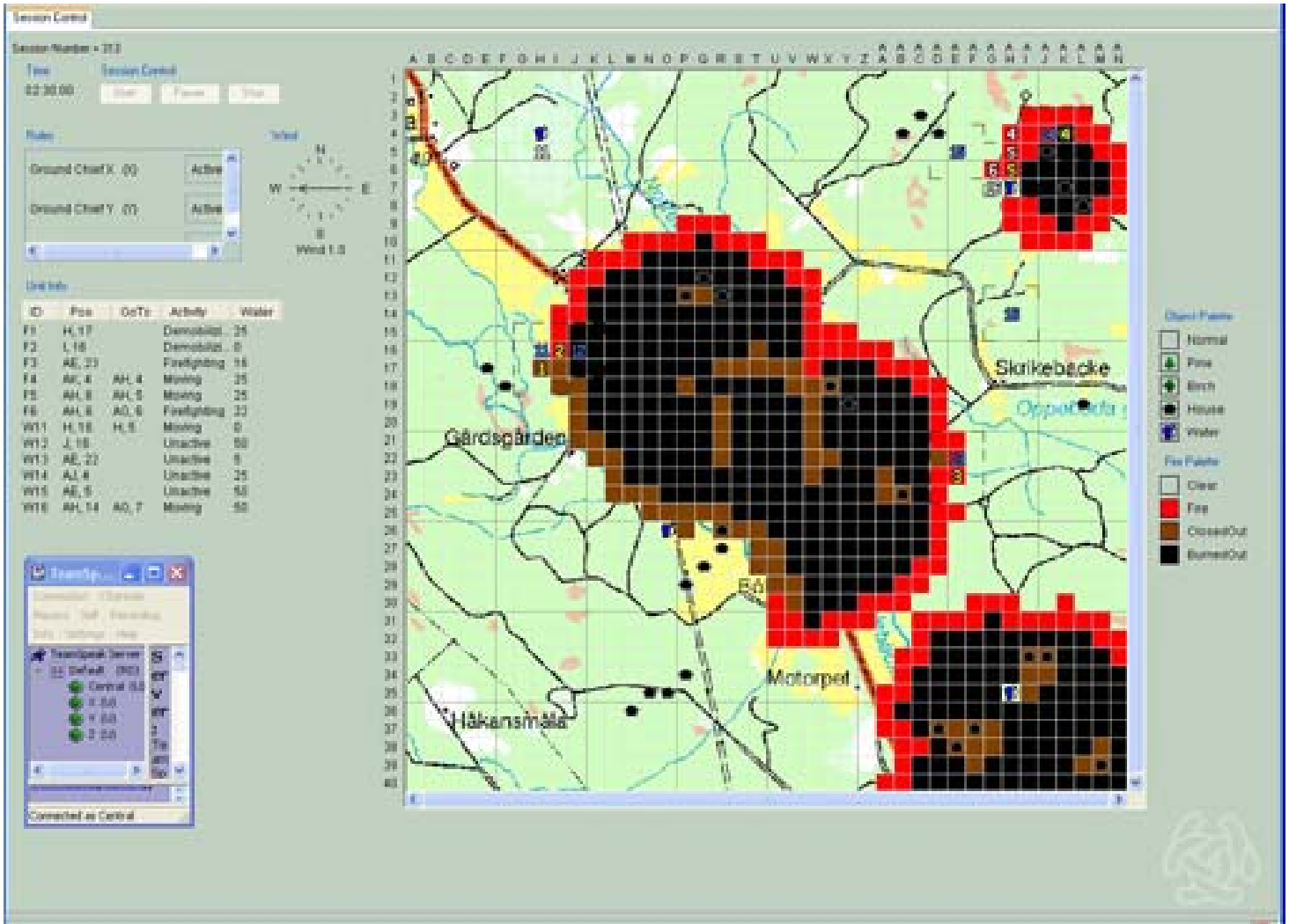




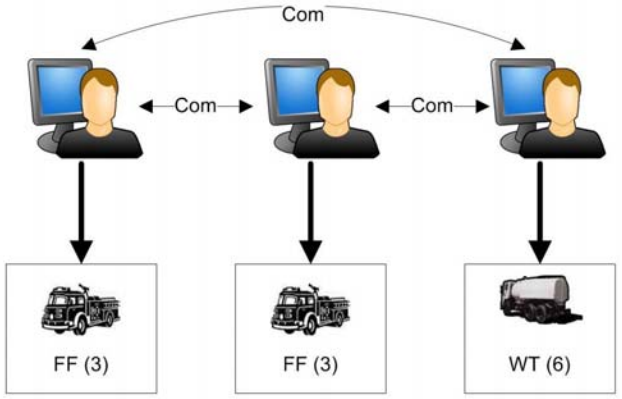
<u>Team members must manage multiple goals:</u>

Prevent houses from igniting
Limit the spread of the fire
Extinguish burning houses

C3Fire Interface

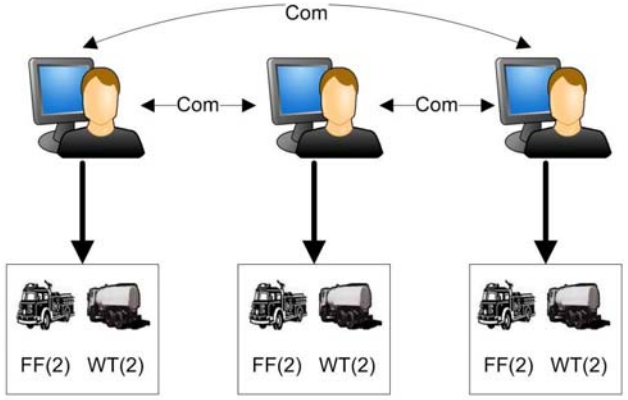


Team Structures: Functional *vs* Multifunctional



Functional team structure

Individuals have complementary roles: coordinating either firefighters (FF) or water-tankers (WT)



Multifunctional team structure

Individuals have both roles, making them self-sufficient (in terms of resource management). **Total number of units is constant**

Method

Twenty 3-person teams (randomly assigned structure)

2-hour experiment including:

- Instructions and familiarization
- 2 practice scenarios (15 min each)
- 4 test scenarios (15 min each)
- Workload questionnaire (Hart & Staveland,1988)
  Time pressure and mental load

Measure of Team Effectiveness

Defined by the team's success in managing both the *defensive* and the *offensive* aspects of the task, namely protecting the houses from the fire and putting out at many fire cells as possible.

$$\text{Effectiveness} = \text{Proportion of houses saved} \times \text{Number of cells extinguished}$$

Results and discussion

- Multifunctional teams were more effective ($p < .01$)
- Functional teams reported similar average workload ratings to those of the multifunctional teams (n.s.)
- Unequal distribution of workload. Agent X in the functional team structure (with 6 WT) reported a higher workload ($p < .01$)

Workload imbalance and interpersonal dependency may have offset the benefits of task specialization

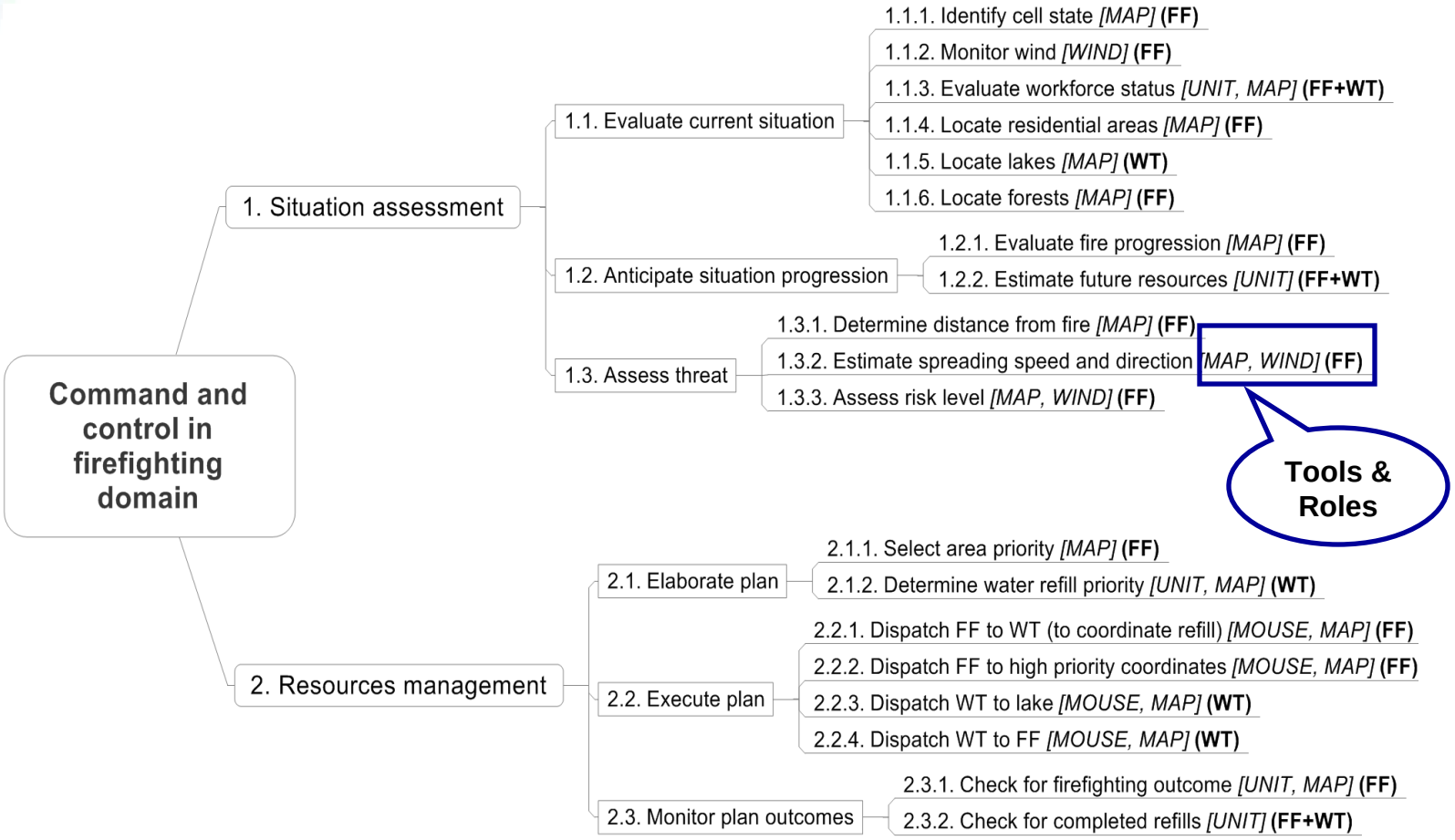
Task Structural Modeling

Two parts:

1) Hierarchical task analysis (HTA)

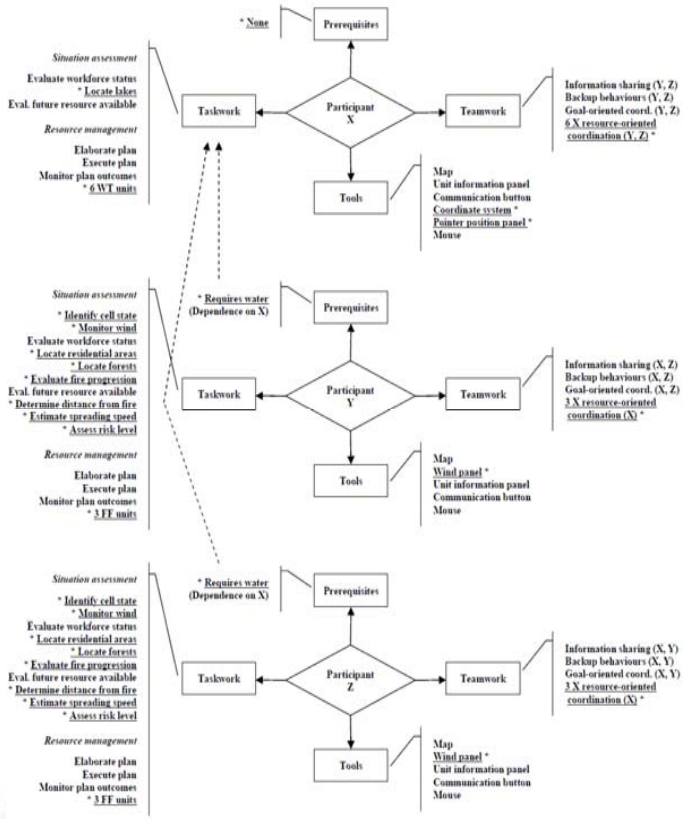
2) Task-to-agent mapping as a function of team structure

HTA

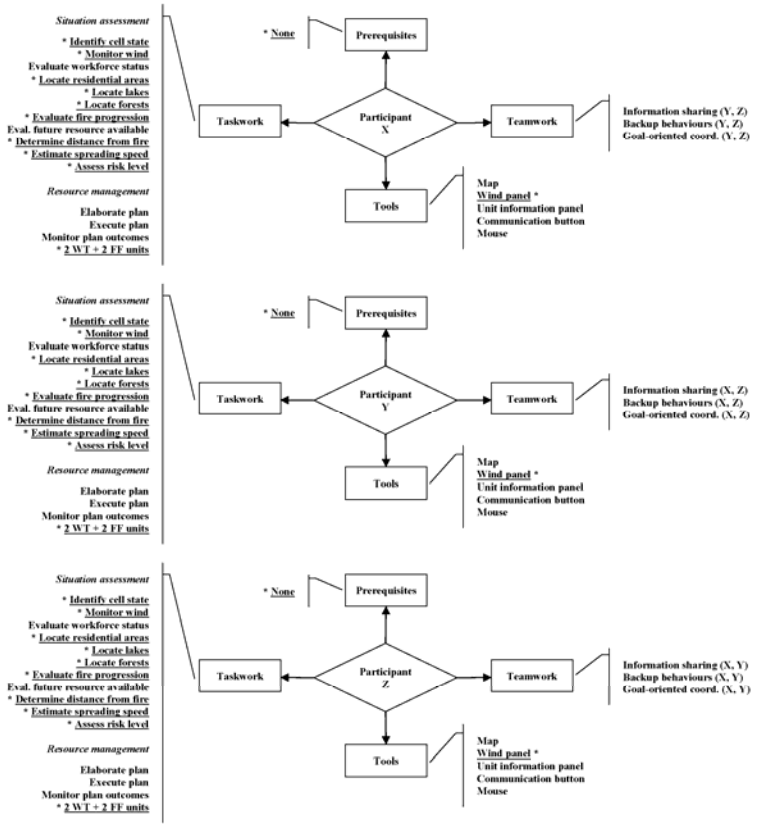


HTA representation, with tasks associated to specific roles and tools. FF = firefighting role, WT = water-provisioning role, MAP = Geospatial information display, UNIT = Unit information panel, WIND = Wind information panel, MOUSE = Computer mouse.

Task-to-Agent Mapping

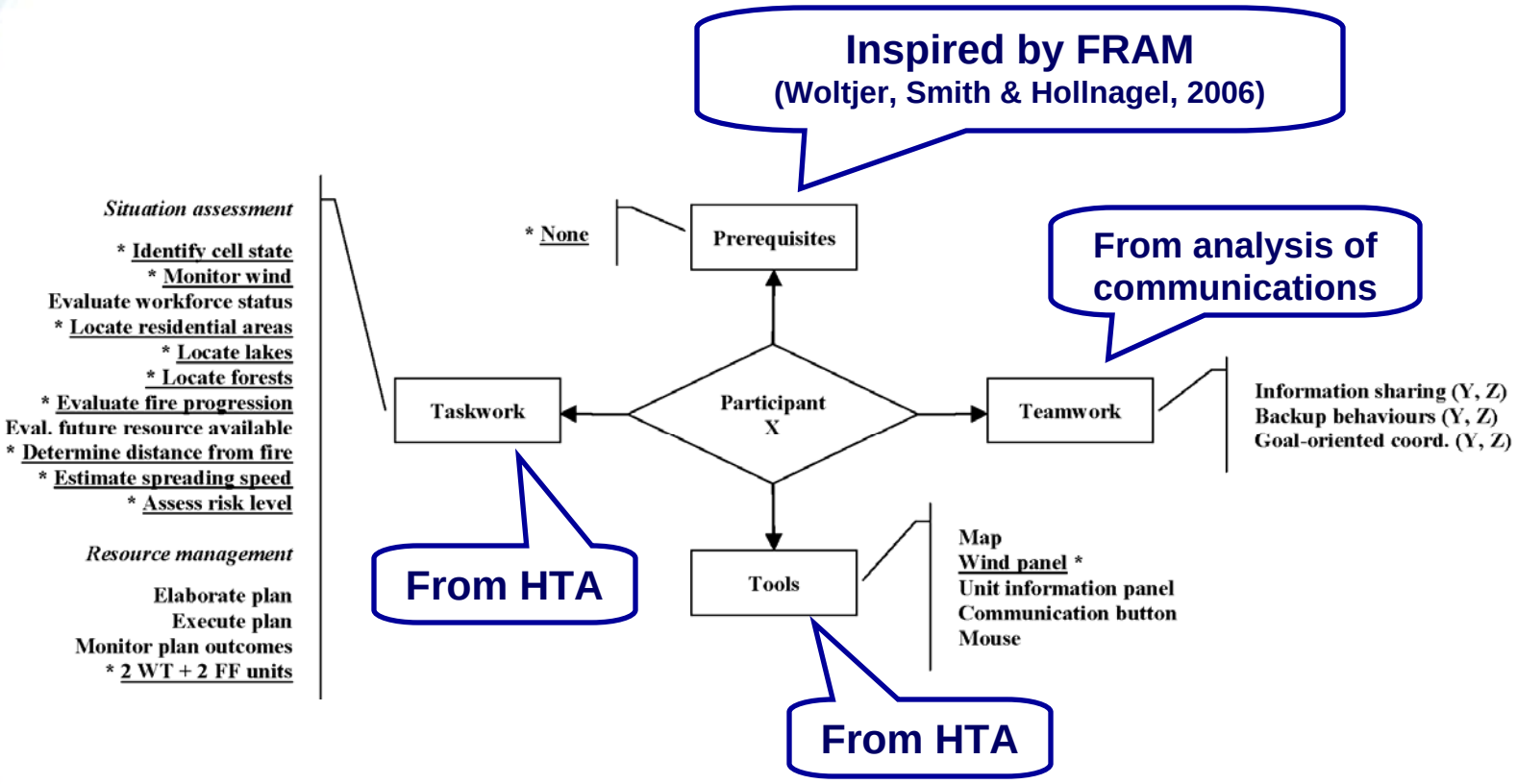


Functional



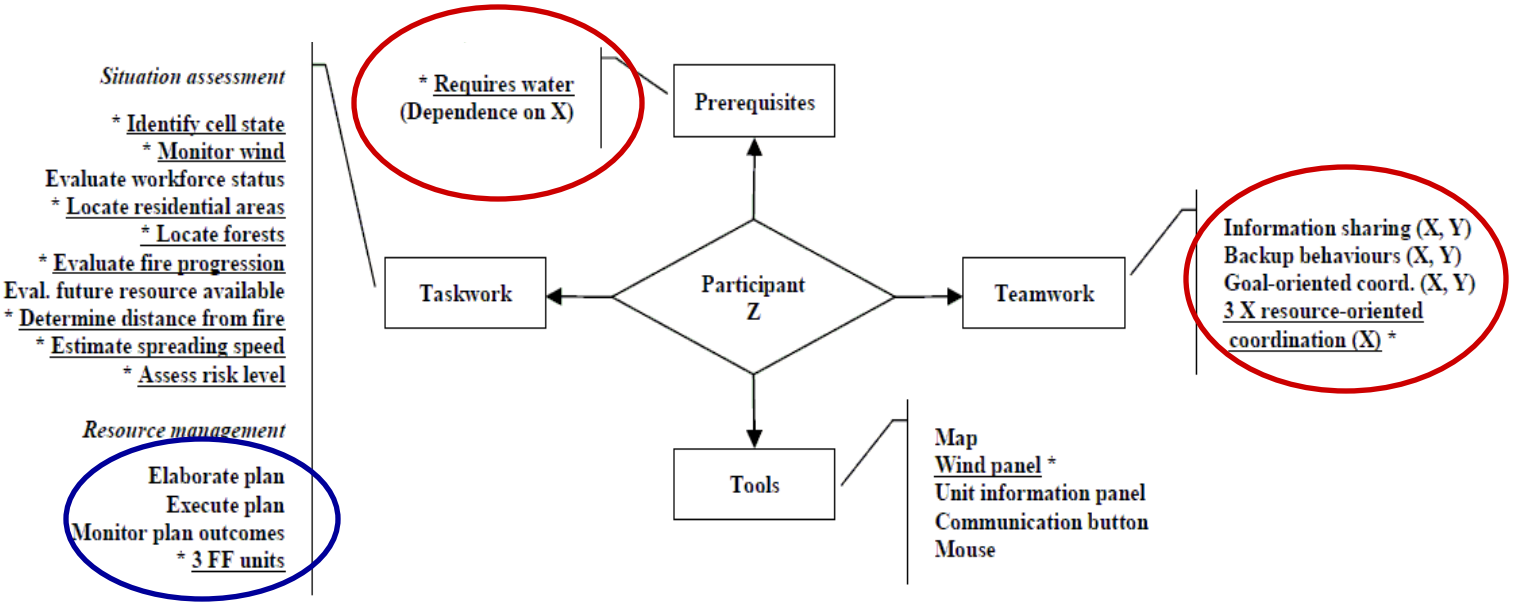
Multifunctional

Task-to-Agent Mapping



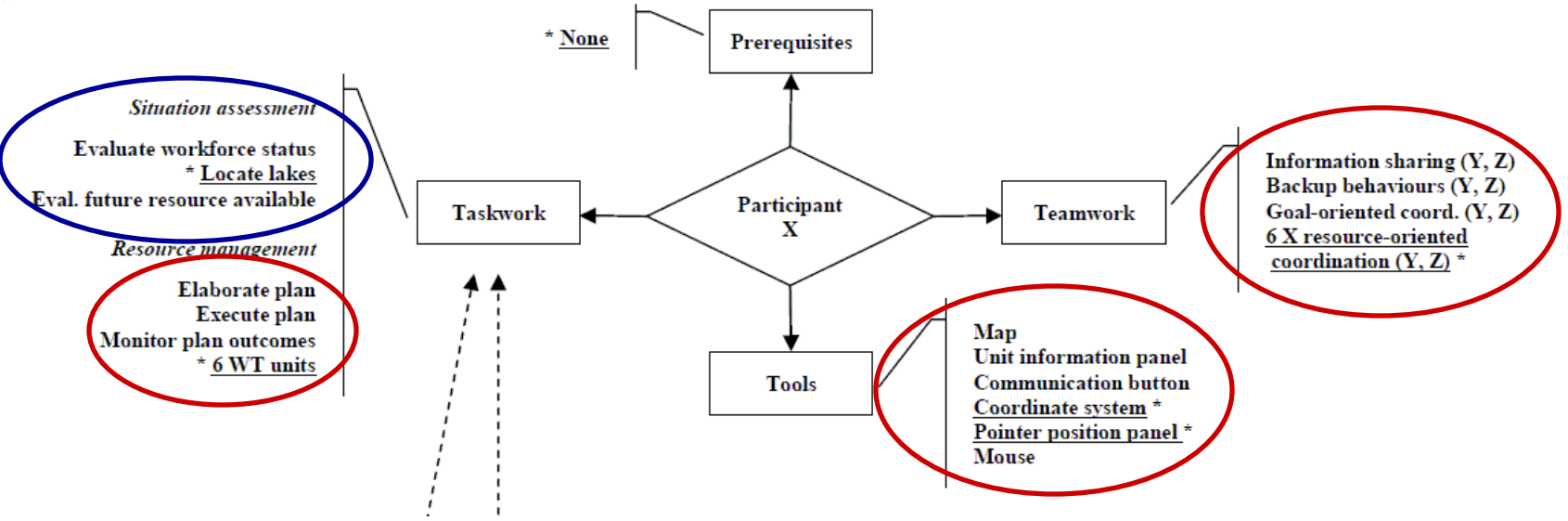
Participant X, Y or Z in the multifunctional team structure

Task-to-Agent Mapping



Participant Y or Z in the functional team structure

Task-to-Agent Mapping



Participants Y and Z depend on X for water

Participant X in the functional team structure

Architecture of the Model

Input

1. How team structure determines individual workload

2. How workload determines individual efficiency

3. How individual efficiency is constrained by inter-agent dependency and combined to account for team effectiveness

Output

From Team Structure to Workload

Table 1
Structural factors influencing workload in functional and multifunctional teams

Participant & structure	Situation assessment	Resource management	Tool interaction	Teamwork	Prerequisites
Multifunctional					
Participant X_M	11	12	5	3	-
Participant Y_M	11	12	5	3	-
Participant Z_M	11	12	5	3	-
Functional					
Participant X_F	3	18	6	9	-
Participant Y_F	10	9	5	6	Water from X
Participant Z_F	10	9	5	6	Water from X

These values are then combined to produce an estimate of individual workload:

Individual workload = *w* ((no. of SA subtasks) + (no. of management subtasks x no. of units) + (no. of teamwork subtasks) + (no. of tool interaction subtasks))

From Team Structure to Workload

Table 2
Average workload ratings reported by participants in the C3Fire study and model fits

Structure	Participant	Perceived workload	Modeled workload	Unweighted workload
Multifunctional	Participant X_M	7.73	7.74	31
	Participant Y_M	7.73	7.74	31
	Participant Z_M	7.73	7.74	31
Functional	Participant X_F	9.00	8.99	36
	Participant Y_F	7.50	7.49	30
	Participant Z_F	7.50	7.49	30

Note. Perceived workload was rated on a scale from 1 (very low) to 10 (very high). We calculated the average workload ratings of Participants $X_M/Y_M/Z_M$ in the multifunctional structure (same objective workload) and of Participants Y_F/Z_F in the functional structure (same objective workload).

From Workload to Individual Efficiency

Reverse sigmoid function

$$y = max \cdot k^n / (k^n + x^n)$$

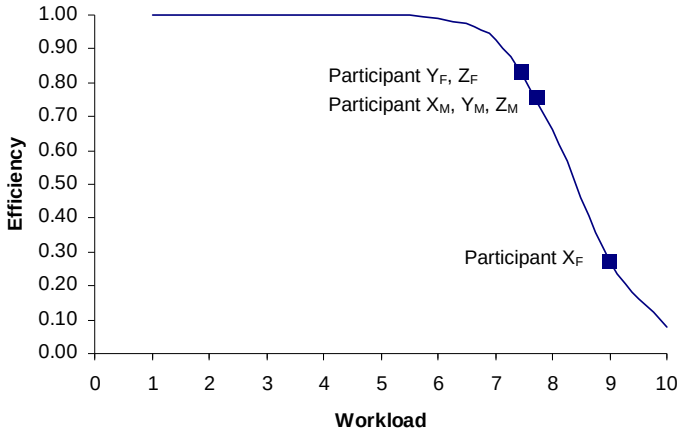
<u>1 fixed + 2 free parameters:</u>

max is set to 1

$k \approx 8.39$

$n \approx 14.20$

Estimated by least-squares minimization



$$\text{Individual efficiency} = \frac{1 \times 8.39^{14.20}}{8.39^{14.20} + \text{individual workload}}$$

Assumption that performance remains high as humans compensate for increasing difficulty and pressure, then rapidly drops past a point of overload (see Adelman, Miller, Henderson & Schoelles, 2003)

From Workload to Individual Efficiency

Table 3
Individual workload and predicted efficiency as a function of team structure

Structure	Participant	Efficiency	Workload
Multifunctional	Participant X_M	0.76	7.74
	Participant Y_M	0.76	7.74
	Participant Z_M	0.76	7.74
Functional	Participant X_F	0.27	8.99
	Participant Y_F	0.83	7.49
	Participant Z_F	0.83	7.49

So far, the model does not take into account the interpersonal dependency of participants Y_F and Z_F on participant X_F

Constrained Individual Efficiency and Team Effectiveness

Table 4
Workload and predicted effectiveness as a function of team structure

Structure	Predicted team effectiveness	Constrained efficiency	Estimated workload	Participant
Multifunctional	0.76	0.76	7.74	Participant X
		0.76	7.74	Participant Y
		0.76	7.74	Participant Z
Functional	0.24	0.27	8.99	Participant X
		0.23	7.49	Participant Y
		0.23	7.49	Participant Z

When 100 % dependent, efficiency of Participant Y_F or Z_F is multiplied by efficiency of Participant X_F

Proportion of variance explained

Table 5
Observed effectiveness and percent rank for each team in the C3Fire experiment

Team structure	Team	Observed effectiveness	Percent rank
Multifunctional	1	57.75	0.84
	2	48.30	0.63
	3	63.21	1.00
	4	45.23	0.58
	5	39.10	0.47
	6	51.44	0.68
	7	56.44	0.79
	8	53.95	0.74
	9	58.33	0.89
	10	61.84	0.95
Functional	11	32.80	0.32
	12	34.18	0.37
	13	38.89	0.42
	14	20.75	0.11
	15	23.23	0.16
	16	7.99	0.00
	17	16.53	0.05
	18	26.75	0.21
	19	29.86	0.26
	20	44.48	0.53

Predicted by model: 0.76

72 % of variance explained (R^2)

Predicted by model: 0.24

Current focus is purely on effects of team structure. Incorporating individual factors could help account for within-structure variability

Team design tool

Based on the units assigned to each team member, the tool performs a new task-to-agent mapping and recalculates workload, constrained effectiveness, and predicted team effectiveness

<u>Three candidate team structures come to mind:</u>

- An alternate form of the functional team structure

  (X = 6FF // Y = 3WT // Z = 3WT)

- A hybrid team structure (part multifunctional, part functional)

  (X = 2FF and 2WT // Y = 4WT // Z = 4FF)

- A four-person functional team structure

  (W = 3WT // X = 3WT // Y = 3FF // Z = 3FF)

Tool Demonstration

Results – Predicted Team Effectiveness

Table 6
Extension of the model as a tool for estimating the effectiveness of different team structures

Structure	Predicted team effectiveness *	Constrained efficiency	Estimated workload	Participant
Alternate functional	0.69	0.07	10.00	Participant X
		0.99	5.99	Participant Y
		0.99	5.99	Participant Z
Hybrid	0.70	0.76	7.74	Participant X
		0.93	6.99	Participant Y
		0.42	8.49	Participant Z
4-person functional	0.91	0.99	5.99	Participant W
		0.99	5.99	Participant X
		0.83	7.49	Participant Y
		0.83	7.49	Participant Z

* Effectiveness (in percent rank) relative to the effectiveness of the 20 teams in the C3Fire experiment.

Summary

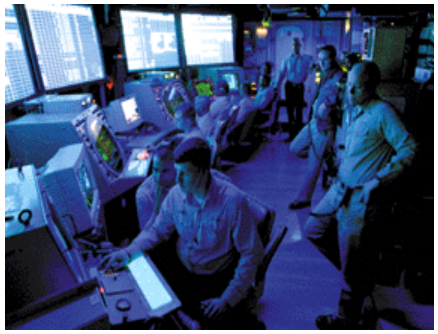
Relative ordering of team effectiveness as a function of team structure:

- 4-Person functional (91%)
- Multifunctional (76%)
- Hybrid (70%)
- Alternate functional (69%)
- Functional (24%)

Limitations and Future Directions

- Restrictions
  - The amount of units/resources must be constant
  - The model does not take into account individual factors
  - Tool is currently specific to the context of C3Fire (C2 crisis management)

- Validation, extension and generalization
  - Validate predictions on new team structures
  - Extend to larger teams and different domains
  - Integrate genetic algorithm to the team design tool



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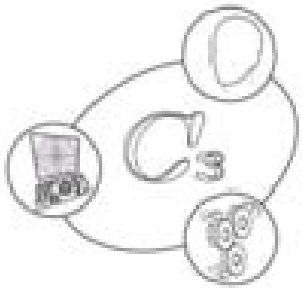

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