

## MODEL-BASED TEAM DESIGN

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The introduction of new technology, along with cost pressures to “do more with less,” are forcing organizations to re-engineer their team structures and processes. We have developed a systematic, formal, quantitative model-based approach for designing teams. The team model specifies tasks to be accomplished, interdependencies between tasks, resources available to accomplish the tasks, and a set of goals and constraints for the team. We optimize a multi-variable objective function to develop a team design that specifies the tasks performed and the resources controlled by each team member and the authority structure and communication links for the team. We are currently designing teams in a number of military domains—Joint Task Forces, Navy shipboard command centers, Air Force Air Operations Centers, and Air Force AWACS teams. This paper will use examples from these domains to point out similarities and differences in the team-design problem across domains

### INTRODUCTION

The military’s need for effective teams has led to considerable progress in the last decade on methods for improving the performance of teams (see Serfaty, Entin, and Johnston, 1999; Brannick, Salas, & Prince, 1997; Salas, Bowers, & Cannon-Bowers, 1995; Salas, Dickinson, Converse, and Tannenbaum, 1992; Swezey & Salas 1992).

The focus of much prior team research has been on improving team performance through training to improve team competencies or through collaborative tool or decision support technologies. However, as shown in Figure 1, there is a third major facet in understanding and improving team performance—the *team structure*. Research focused on collaborative support technology or on team training and assessment usually takes the team structure as a given. Our work, in contrast, focuses on designing the best team structure for given set of goals and tasks (the team’s mission), based on the application of optimization algorithms to a model that relates the team’s structure to its performance.

### DESIGNING A TEAM STRUCTURE

The central thesis of our team-design method (described in MacMillan, Paley, Levchuk, and

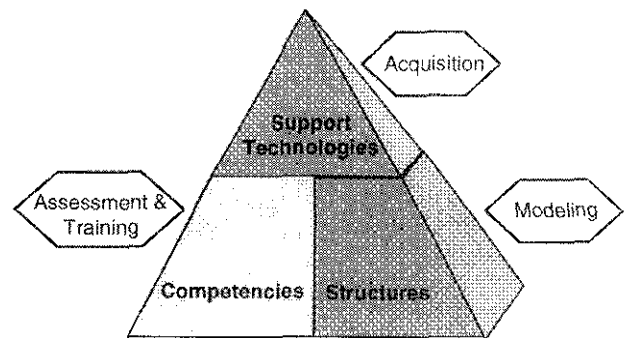


Figure 1. Three Facets of Team Performance

Serfaty, 1999) is that a set of interdependent, interrelated tasks that must be completed under time constraints has an underlying quantitative structure that can be exploited to design the “best” team for accomplishing those tasks

At the core of our method is a systems engineering approach that describes organizational performance criteria as a multi-variable objective function to be optimized (see Levchuk, Pattipati, and Kleinman, 1998 for a more detailed description of these modeling methods). This approach is based on a three part allocation model that considers: 1) the tasks that must be accomplished and their interrelationships (the “mission”); 2) the external resources needed to accomplish those tasks (e.g.,

information, raw materials, or equipment), and 3) the human decision makers who will constitute the team. The team design process is, in simplest terms, an algorithm-based allocation between these three parts.

A team structure, designed using our methods, is far more than an organizational chart or "wiring diagram" that shows who reports to whom. The questions that are answered in designing a team structure include:

- Who owns what? Who can do what? Who controls what?
- Who can see what?
- Who knows what?
- Who can talk to whom?
- Who gives orders? Who can override decisions?
- Who is responsible for what overall functions?
- Who is tasked with what?
- Who provides back-up (if anyone)?
- Who needs to talk to whom?
- Who needs to coordinate with whom?

The products of a team design include a mapping of the resources available to the team, including information; a delineation of each team member's responsibilities; back-up rules; and correlation diagrams that show the communication and coordination requirements among team members generated by the assignment of tasks to individuals.

Because the decision-making and operational capabilities of humans are limited, the distribution of *information*, *resources*, and *activities* among the team members must be designed to ensure that the decision-making and operational load of each individual remains below established thresholds. For example, when the overall information available to a team during the mission overwhelms the information processing capabilities of an individual, the team's information acquisition and decision-making must be decentralized.

While organizational design specifies the distributed nature of mission processing by assigning each team member his or her share of information, resources, and activities, a *command hierarchy* among the team members designates their

*control responsibilities* and regulates the within-team *coordination* (by assigning the responsibility for resolving decision ambiguities among coordinating team members). In addition, organizational design can specify a *communication structure* among team members (e.g., a communication net) to facilitate the distributed information processing required to complete the mission. These structures can be used to inform the design of user system interfaces as well as the physical layout of the command space.

Over the past two years, we have developed the Team Integrated Design Environment (TIDE) which can be used to optimize organizational performance within specific mission parameters and constraints as described above. TIDE is capable of creating novel, optimized organizational designs yielding teams that maximize the use of information and mission execution.

To apply the TIDE methodology, one needs to know the sequence in which tasks are performed, the resources that are used to perform each task, and the interdependencies among tasks. Given this information for a specific mission scenario, our modeling techniques can suggest ways that tasks should be grouped together (i.e., handled by the same person or the same group of people) in that scenario in order to both satisfy organizational constraints and optimize performance according to different possible criteria (e.g., maximizing mission success, minimizing likelihood of error, minimizing the need for inter-node communication, or equalizing workload across people).

TIDE is not a single tool, rather a set of methodologies that afford the flexibility to complete a variety of applications. These applications can be classified into three areas:

### **Mission and Organizational Analysis**

We use a process of decomposition to describe an organization and the operational mission it performs, then we assess the mission tasks in terms of workload, information, decisions, actions, outcomes, and the resources required to complete decisions and actions. We create quantitative mission structures that serve as the input for organizational design.

## Architecture Design

Using the quantitative mission structures, we apply optimization algorithms to create novel, optimized organizations. In the process we assign functions, tasks, and requisite resources to the decision makers, resulting in defined roles and responsibilities within the organization.

## Team Performance Improvement Approaches

The resulting structures, roles, and responsibilities can then be applied to define a series of organizational characteristics that can facilitate performance, including training, displays, physical layouts, and even applications for new technologies.

## Applications of the TIDE Method for Different Types of Teams

Figure 2 lists a series of projects—representing different types of teams—in which Aptima has employed the TIDE methodology for team design. The table indicates that certain applications of the TIDE approach have proved to be more relevant for some types of teams than for others. This is driven by two factors—the nature of the team, and the specific goals of the project.

For example, one application of TIDE is to design optimized resource allocations for the team, specifying who should control which resources in order to best accomplish the mission. This is a highly relevant issue for the Joint Task Force (JTF) teams being designed in the Adaptive Architectures for Command and Control (A2C2) program. These JTF teams control many different types of resources (e.g., tanks, aircraft, ships, infantry units, amphibious units). These resources have both a geographical location, relative to the tasks to be accomplished, and a traditional service affiliation (e.g., the Army knows how to employ tanks). The team designs produced using the model typically assign assets to decision makers based on the most effective control of those resources relative to the mission, while minimizing the need for coordination. The algorithms often suggest roles for team members that require the use of many

different types of resources (e.g., both tanks and aircraft controlled by the same individual). These team design are very different from traditional military structures, but have proved to be more effective than traditional designs provided that sufficient training is provided to the team members (Entin, 1999).

For AWACS teams, in contrast, the allocation of resources to team members is not a very relevant issue in the team design. For these teams, the major resource is information, and that can, in theory, be provided to and controlled by all of the team members. For AWACS teams, a more relevant issue is workload. The AWACS team needs to be designed so that individual members do not get overloaded with air tracks, and the design must provide back-up so that one team member can pick up tracks if the other is overloaded. A similar workload issue exists for the Anti-Air Warfare teams aboard the next generation of Navy ships.

Another pattern that can be seen in Figure 2 is that the density of checkmarks is much greater in the top two areas, mission/organizational analysis and architecture design than in the bottom area, team performance improvement approaches. This reflects the maturity of the work on mission analysis and architectures. We have identified and firmly established links between mission structure and organizational architecture design (Levchuk, et al., 1998). These links and the organizational designs we have developed using TIDE have been empirically tested as part of the Adaptive Architectures for Command and Control (A2C2) project, and architectures developed using the TIDE approach were part of the Navy's Global 1999 Wargame.

In contrast, the links between team performance enhancement approaches, team architectures, and team performance are just beginning to be explored. For example, Entin (1999) describes an experiment in which the performance of a six-person JTF team using a traditional JTF team structure was compared to the performance of a six-person and a four-person team using optimized team designs that had been prepared using the TIDE method.

Results showed that the performance of a six-person team designed using the model was higher

	Project	A2C2	DD21	AWACS	WOCT	UCAV	CODE	JFACC	DCD	Global
		Joint Task Force	Next Gen. Ship	Airborne C2 System	Ground C2 System	Auto. Combat Vehic.	Next Gen. Carrier	Air Component Command	Decision Centered Design	Large Scale Wargame
Mission/Org. Analysis	Optimized Mission Process	✓	✓	✓		✓	✓	✓		
	Workload Assessment		✓	✓	✓			✓	✓	
	Information Flow/Communication		✓	✓	✓			✓		✓
Architecture Design	Resource Allocation	✓	✓		✓			✓		
	Team Optimized Design	✓	✓	✓		✓		✓		✓
Team Perform. Improv. Approaches	Function Allocation		✓	✓		✓		✓	✓	
	Training Requirements	✓			✓					
	New Technology Insertion		✓	✓			✓	✓		✓
	Display Requirements			✓		✓	✓			
	Physical Layouts		✓				✓			

Figure 2. Team design applications for different types of teams

than for the six-person team designed using a traditional approach. Also, the performance in the model-based four- person team was almost equal to that of the six-person team using the traditional team design. However, training played a major role in team success for the innovative model-based team. Initial reluctance by operators (organizational inertia) to use counterintuitive designs (optimized teams were markedly different from current operations) needed to be overcome with training in order to obtain these results. This interaction of organizational design and team training illustrates the complexity of the links between team structure, team training, and team performance. As the TIDE approach is applied in additional areas, we should be able to expand our knowledge of these links.

**REFERENCES**

Brannick, M.T., Salas, E., & Prince, C. (Eds.) (1997). *Team Measurement and Performance: Theory, Methods, and Applications*, Mahway, NJ: Lawrence Erlbaum Associates.

Entin, E.E. (1999). Optimized command and control architectures for improved process and performance. *Proceedings of the 1999 Command & Control*

*Research & Technology Symp.*, Naval War College, Newport, RI.

Levchuk, Y., Pattipati, C., and Kleinman, D. (1998). Designing Adaptive Organizations to Process a Complex Mission: Algorithms and Applications. *Proceedings of the 1998 Command and Control Research and Technology Symposium* (11-32) Naval Postgraduate School, Monterey, CA.

MacMillan, J., Paley, M.J., Levchuk, Y., & Serfaty, D. (1999) Designing the best team for the task: A method that combines algorithms, heuristics, and expert judgment. *Proceedings of the Human Factors and Ergonomics Society*, Santa Monica, CA.

Salas, E., Bowers, C.A., & Cannon-Bowers, J.A. (1995). Military team research: 10 years of progress. *Military Psychology*, 7, 5575.

Salas, E., Dickinson, T. L., Converse, S. A. and Tannenbaum, S. I. (1992) Toward and Understanding of Team Performance and Training in *Teams: Their Training and Performance*, Eds. Robert W. Swezey and Eduardo Salas, Ablex Publishing Company, Norwood, NJ.

Serfaty, D., Entin, E. E., & Johnston, J. H. (1998). Team coordination training. In J. A. Cannon-Bowers & E. Salas (Eds.), *Making decisions under stress: Implications for individual and team training* (pp. 221-245). Washington, D. C.: American Psychological Association.

Swezey, R.W. & Salas, E. (Eds.) (1992) *Teams: Their Training and Performance*, Ablex Publishing Company, Norwood, NJ.