

Modeling, Simulation, and Experimentation for the E-10 Command and Control Aircraft

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Abstract. This paper describes a quantitative Team Optimal Design (TOD) methodology and its application to the design of optimized manning for E-10 Command and Control Aircraft. Our TOD design approach allows specification of team configuration (number and roles of operators) for efficiently operating E-10 to execute mission scenarios of various contingencies. The objective is to maximize the speed of mission execution while balancing the workload among team members, provided the decision-making, expertise, workload threshold and organization cost constraints are satisfied.

Keywords: team optimal design, organizational structure, optimal manning

1. Introduction

The wide range of potential Air Expeditionary Force employment scenarios requires the E-10 to have the maximum flexibility to support everything from autonomous operations to robust deployed force packages (Whitaker et al., 2002). Each unique mission requires detailed consideration of crew positions. Key capabilities of the E-10 will be theater-level Battle Management Command & Control and the ability to support dynamic intelligence, surveillance and reconnaissance (ISR) tasking and combat operations execution. These capabilities will encompass a combination of functionalities typically provided by the execution, intelligence, and time-critical targeting cells of the Combined Air Operations Center, the Airborne Command, Control and Communications, Airborne Warning and Control Systems, and Joint Surveillance and Target Attack Radar System platforms. Unifying this functionality into an effective airborne weapon system will be a challenge. Regardless of which systems are incorporated into the E-10 and how the aircraft is ultimately deployed, the changing capabilities will affect the way the USAF conducts airborne missions. Organizational structures must be designed and tested to optimize operational processes that will ensure that the E-10 performs as a single integrated system rather than an aircraft with a set of "stove piped" systems.

At the core of this effort is the requirement to answer the question of *how many operators* will it take to conduct a BMC2 mission given the proposed capabilities of the E-10. To answer, one must understand and represent expected mission requirements and system capabilities that support allocation of tasks to operators. As such, this effort demanded extensive coordination with both the operational and system design communities. Based on detailed structured interviews, review of system design

documents, and analysis of current command and control (C2) and ISR system, we created a comprehensive mission model and used it as a primary input to the analysis efforts. The subsequent analyses, which employed the Team Optimal Design (TOD) tool developed by Aptima, Inc., were intended as a preliminary modeling and simulation study of operator tasks and task loading for the purpose of determining an optimal team structure for the E-10 Battle Management Configuration to support a wide variety of missions. This included the definition of operational roles for E-10 operations (i.e., who does what, when, where, and how - to assure maximum efficiency and effectiveness) as a means to contribute to manpower estimates and system requirements definitions. Beginning with a set of operational concepts for the E-10, we derived a set of overall program objectives and formed the basis of an initial functional model that describes what the platform will do. The functional model, through interaction with subject matter experts and the addition of system specifications from E-10 requirements documents, is decomposed into a mission task model. The task model is the basis for the TOD analysis and results in the definition of operational roles and responsibilities.

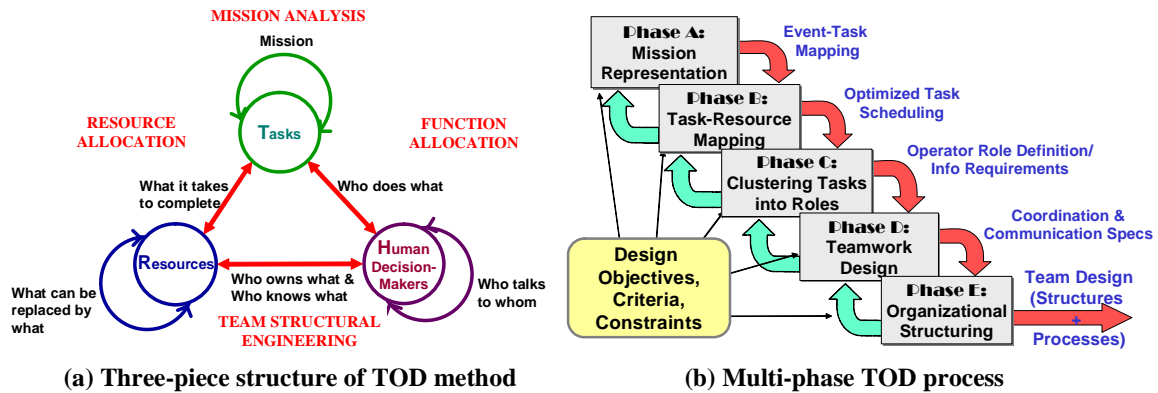


Figure 1. Team Optimal Design methodology

2. Team Optimal Design (TOD) Methodology

The central thesis of prior applications of the TOD model (MacMillan et al., 2002) was 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 structure for accomplishing those tasks. This approach is based on a multi-phase allocation model that consists of three pieces (Fig. 1a): (i) the *tasks* that must be accomplished and their interrelationships (the “mission”); (ii) the external *resources* needed to accomplish those tasks (e.g., information, raw materials, or equipment), and (iii) the human *operators* (decision makers) who will constitute the team. The team design process is, in simplest terms, an algorithm-based allocation between these three parts. The TOD process (Fig. 1b) starts with quantitative mission and organization definitions (Phase A), and proceeds to identify the optimal task-resource scheduling (Phase B), operator-resource assignment (Phase C), team coordination and communication strategy (Phase D) and the supporting structures (Phase E). The TOD method is algorithm-based, but it relies

on allocation heuristics and on the judgment of subject matter experts to frame the design problem in a meaningful way, including decomposing an overall mission (or goal) into specific tasks, specifying the relationships between tasks, resources needed to complete the tasks, duration and workload of task execution, workload thresholds of human decision makers, criteria to be optimized for the team, and task scheduling and communication rules employed by human operators modeled in TOD.

2.1. Modeling of team processes in TOD

The TOD methodology employs heuristic resource-constrained task-to-operator scheduling, which incorporates normative models of synthetic operators and teams. The model utilizes the design of priority rules to represent human preferences for task selection. Individual task execution is modeled by accounting for human workload constraints and the impact of workload, experience, and learning on task execution accuracy. Team processes are modeled using operator interactions in the form of synthetic communication, including (i) decision/action; (ii) command; (iii) information request/transfer; and (iv) task execution synchronization. The synthetic team structures (information transfer and command responsibility) serve as a medium for this communication. The TOD model employs *commander architecture* which explores interactions between the global organizational objectives and the local operator actions. The architecture consists of a hierarchy with a commander (Fig. 2a), which produces a temporal assignment of tasks to operators using global organizational objectives, and the local operator modules that select tasks for processing from their assignment set under operators' local priority rules. The operator modules can accept or reject the task assignment from a commander (Fig. 2b).

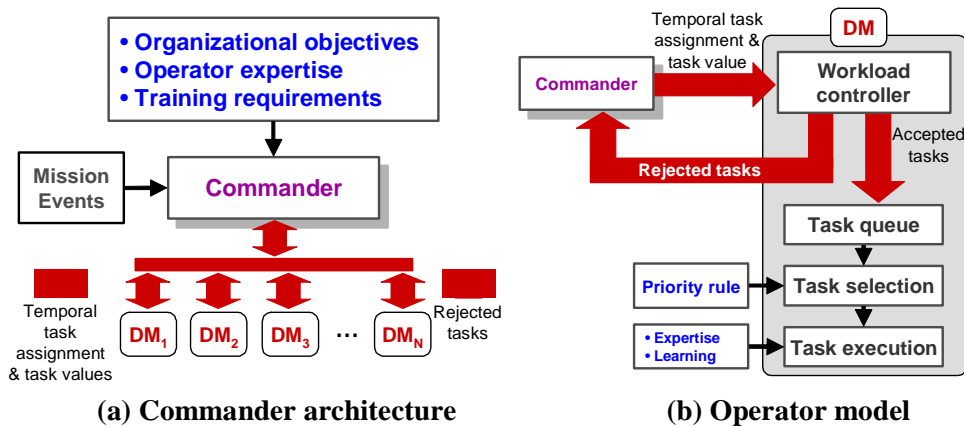


Figure 2. TOD architecture

2.2. Task prioritization and individual task processing

The TOD algorithms utilize the *Subjective Expected Value* (SEV) criterion to model optimal task selection under cognitive constraints (Pattipati *et al.*, 1980) when presented with task values by the commander, and must decide how to sequence the task execution to obtain the highest gain. The parameters that affect the sequencing are: task value, deadline, load, resource requirements, operators' current and predicted workload, accuracy versus workload function, available resources. The operator finds the expected reward

(equal to expected gain less the expected loss) from executing each task at a current time. When the rewards are calculated, the task is selected for execution using *stochastic choice* (Luce, 1977) to model the selection process. The commander can adjust task values and explore their influence on operator task selection and accrued task gain.

3. TOD Application to E-10 Design

In E-10 experimentation, we utilized TOD methodology to create the optimized team configuration (i.e., human operators and their roles) for specified scenarios. The output of the TOD model is a tentative assignment of tasks to team members that allows predicting the workload levels and dynamic operational characteristics of simulated team. Consequently, the sensitivity analysis was conducted to vary the number and type of operational roles for the configuration to obtain the team with optimized performance given constraints on resources and cost of manning.

3.1. Functions and tasks

The current E-10 model evolved over time, starting with a process model describing a *Find, Fix, Track, Target, Engage & Assess* process, followed by an activities model that addressed full integration of organic ground and air moving track indicator sensors for E-10. Independent of the model's focus, development centered on defining a set of operational tasks and linking these tasks to specific mission scenario events. Relying on subject matter experts from the operational community to describe the domain, we first identified a set of functions or high level capabilities that are decomposed into inter-related tasks. These tasks are described as a flow diagram within each function. Examples of functions included in the final model are:

- | | |
|-------------------------------|------------------------------------|
| 1. Basic surveillance routine | 6. Radar service request |
| 2. Coverage assessment | 7. Process indications and warning |
| 3. Modify sensor tasking | 8. Assess military developments |
| 4. Dynamic sensor management | 9. Perform Cross-Cueing |
| 5. Target development | 10. Jamming/Electronic Support |

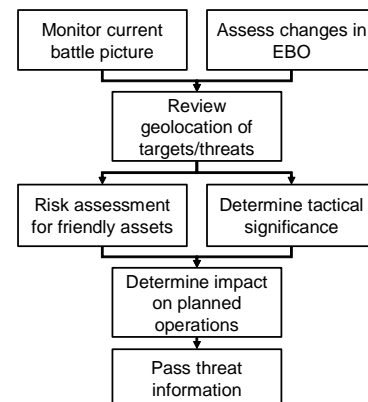


Figure 4. Example of task flow within function “Assess Active Threats”

Figure 4 illustrates an example of a task flow diagram within the function “Assess Active Threats”. Attributes were assigned to each task to help further define the model, such as information requirements, workloads and durations. The next step was to create suitable events for possible scenarios and assign functions to these events. Graphical representations of functional flows (i.e., operational requirements) within events were created and then the functions were decomposed into the tasks within the event. This step was necessary to specify what tasks must be completed given a specific environment state, remove any duplicate tasking, and connect the tasks between functions.

3.2. Organizational roles

As part of the model development effort, we conducted a set of preliminary analyses to define a set of organizational roles tailored to meet the E-10 mission requirements and not constrained by current Air Force Specialty Codes (AFSC) or “traditional” task allocations. Task cluster analysis, based on information requirements and flows within the E-10 mission model, generated a set of information-centric organizational roles. These roles represented initial operator positions and provided a baseline allocation of tasks to operators. We viewed this method as a basis for revolutionary design and one that limited bias associated with legacy positions and AFSC. An iterative method of consolidation based on task delay and workload produced the following five core operational roles:

- *Command* – mission command and leadership
- *Assessment* – interpretation of operational picture
- *Battle Management* – command and control of operations
- *Surveillance* – generation of operational picture
- *ISR Allocation* – control of ISR assets (constellation)

3.3. Mission Scenarios

In initial modeling activities, a generic set of events was used to structure model development. The list of mission events, divided into friendly and enemy activities, was developed; it provided a mechanism to construct three mission scenarios from a single data set: (1) Major Theater Warfare; (2) Contingency Operations; and (3) Air Expeditionary Force. The difference between the three was a variation in both type and frequency of events. The final E-10 model included 147 tasks, 33 functions, and 36 events. The final model was primarily execution-based, focusing on a Ground Moving Target Indicator time critical targeting mission with some Airborne Moving Target Indicator requirements associated with cruise missile defense. Technology assumptions served as a primary driver for workload estimates and determination of crew size.

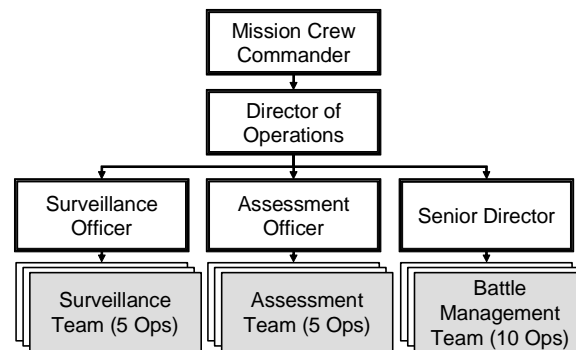


Figure 5. Mission Crew Composition (25 Operators) for Contingency Mission Scenario

3.4. Overview of results

In response to specific requests, we designed an organizational structure for an E-10 conducting a *Contingency* mission employing CDD Increment 1 end-state capabilities and automation. The Contingency mission scenario is representative of the Global Strike Task Force (GSTF) and was selected over the Major Theater War (MTW) scenario for this analysis because it provided a more representative threat environment. In total, the Contingency scenario was composed of 54 distinct mission events occurring 610 times during a 6-hour mission, requiring the E-10 crew to process 8,572 total tasks. To complete this mission, we proposed a 25 person crew as depicted in Figure 5. The selection of number and type of operators was based on sensitivity analyses focused on workload (both

