TOWARD ASSESSING TEAM TACTICAL DECISION MAKING UNDER STRESS: THE DEVELOPMENT OF A METHODOLOGY FOR STRUCTURING TEAM TRAINING SCENARIOS

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ABSTRACT

Tactical decision making teams in the modern warfare environment are faced with situations characterized by rapidly unfolding events, multiple plausible hypotheses, high information ambiguity, severe time pressure, and severe consequences for errors. Training interventions should fully exploit instructional designs that will enable teams to maintain performance under these stressful conditions. Recent research indicates that training scenarios should incorporate significant task situations (events) that present opportunities to learn and achieve desired performance requirements. In addition, the event-based approach allows for standardized, reliable, and valid measurement of team member performance. However, little guidance exists regarding how training scenarios should be designed so that they will have a significant impact on helping the team maintain performance under stressful conditions. Therefore, the purpose of this paper is threefold. First, a stress assessment methodology (SAM) will be described that guide in the creation of structured training scenarios so that they contain appropriate and relevant levels of situational stressors. The SAM is based on the idea that training scenario design should be driven by an identified standard of performance. Therefore, two evaluation instruments will be described, the Behavior Observation Booklet (BOB) and the Sequenced Actions and Latencies Index (SALI), whereby an assessment of team member performance is obtained at pre-specified, time-tagged events in the training scenario. Lastly, implications for creating event-based training scenarios are discussed.

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INTRODUCTION

Tactical decision making teams in the modern warfare environment are faced with scenarios characterized by rapidly unfolding events, multiple plausible hypotheses, high information ambiguity, severe time pressure, sustained operations, and severe consequences for errors (Cannon-Bowers, Salas, & Grossman, 1991). In order to adapt to these stressors, team members must learn to coordinate their actions so that they can gather, process, integrate, and communicate information in a timely and effective manner. Therefore, training interventions should fully exploit instructional designs that will enable teams to maintain performance under stressful conditions.

Recently, a number of team research programs have resulted in guidelines and promising strategies for team training design and evaluation. For example, Cannon-Bowers et al. (1991) have made recommendations regarding the systematic development of training for enhancing the tactical decision making of anti-air warfare (AAW) Combat Information Center (CIC) teams under stress. Hall, Driskell, Salas, and Cannon-Bowers (1992) have provided guidelines for developing stress exposure training. Prince, Oser, Salas, & Woodruff (1993) have proposed augmented guidelines for simulator scenario development used in crew resource management (CRM). Fowlkes, Lane, Salas, Oser, and Prince (1992) have described a methodology for developing measures of observable team performance during CRM. Baker and Salas (1992) have provided principles for measuring teamwork skills. Dwyer (1992) has developed an index of team performance that is based on observable indicators of effective and ineffective behaviors across several critical functions of an AAW team.

Taken together, these researchers suggest that team training requires the development of structured scenarios which provide the opportunity to perform critical team actions (Prince et al., 1993). A key factor in the design of training scenarios is determining how to structure events which elicit appropriate decision making actions. A realistic range of operational conditions and stressors should be inserted in the scenarios so that a representative sample of decision making actions can be observed and measured (Hall et al., 1992). Therefore, evaluating the efficacy of team training objectives requires that scenarios be designed so that team performance can be measured in a standardized, relevant, valid, and reliable manner. Currently, however, very little guidance exists regarding how training scenarios should be constructed so that they will have a significant impact on helping a team maintain tactical decision making performance under stressful conditions.

In response to this issue, the purpose of this paper is threefold. First, the development of a stress assessment methodology (SAM) will be described that guides in the creation of structured training scenarios so that they contain appropriate and relevant levels of situational stressors. The SAM is based on the idea that training scenario design should be driven by an identified standard of performance. Therefore, two evaluation instruments will be described, the Behavior Observation Booklet (BOB) and the Sequenced Actions and Latencies Index (SALI), whereby an assessment of team member performance is obtained at pre-specified, time-tagged events in the training scenario. Thirdly, implications for creating event-based training scenarios are discussed.

THE SAM

For purposes of illustrating the development of the SAM, the BOB, and the SALI, initial findings from a Navy research program called Tactical Decision Making Under Stress (TADMUS) will be described (Cannon-Bowers et al., 1991). TADMUS was initiated to address the problem of maintaining individual and team decision making in the CIC environment by applying recent advances in decision theory, training, and display design (Cannon-Bowers et al., 1991). A major goal of the TADMUS program is to conduct research to understand how combat-related stress affects tactical decision making of AAW CIC ship teams (e.g., tactical action officer, identification supervisor, anti-air warfare coordinator, tactical information coordinator, and electronic warfare supervisor). One of the tasks of this program has been to develop AAW research scenarios with appropriate levels of stressors, and with the capability for evaluating team performance. Development of the SAM was required to accomplish this task. Following is a description of the steps involved in the initial development of the SAM which included: (a) identification of relevant task stressors, (b) specification of significant AAW scenario events that represent task stressors, and development of an event-based scenario, and (c) documentation of specific scenario features to demonstrate different levels of task stressors. Development of the BOB and SALI will be described later in this paper.

Identification of Relevant Stressors

Fortunately, the potential for developing team training scenarios for complex simulation exercises has been advanced in recent years with the development of such process-tracing techniques as concept mapping, protocol analysis, cognitive task analysis, the critical decision method, and Cognitive Network of Tasks (COGNET) (Zachary, Zaklad, Hicinbothom, Ryder, Purcell, & Wherry, 1991). These techniques enable identification of key decision making tasks, and the associated knowledge, skills, and abilities required to perform the tasks (Klein, 1993; Redding, Cannon, Lierman, Ryder, Purcell, & Seamster, 1991; Rouse & Valusek, 1993; Woods, 1993; Zachary et al., 1991).

We utilized several of these techniques as a first step toward incorporating appropriate AAW stressors into the TADMUS scenarios. First, surveys were conducted with CIC personnel that were specifically involved in the AAW area. They indicated that large numbers of commercial and military air traffic (heavy workload), and conflicting or missing information (information ambiguity) about the air traffic were highly relevant stressors in the AAW area.

Secondly, results of work by Zachary et al. (1991), using the COGNET strategy, determined the knowledge requirements of a key member of the AAW CIC team, the AAW Coordinator (AAWC). Essentially, the two major AAW tasks involve threat response management and situation assessment. Threat response management includes evaluating the threat status of aircraft, and planning strategy and tactics (i.e. preplanned responses). Situation assessment includes understanding the geo-political and the tactical picture, the ship's resource status, and ship team relationships (e.g., the battle group, ownship, and AAW team). This analysis confirmed that effective AAW tactical decision making required the operator to process large amounts of tactical data in a short period of time, and to "deconflict" the information made available to the operator (Zachary et al., 1991).

Scenario Development

Once workload and information ambiguity had been identified as stressors, we had four Navy Subject Matter Experts (SMEs) incorporate them into a "moderately" stressful, and a "highly" stressful 30 minute AAW scenario. So that each AAW team member would experience stress, SMEs were asked to create fictional scenarios with events that were likely to require action by all the team members. The scenarios do not contain events that have actually occurred. Both scenarios involve an AAW CIC ship team located in the Northern Persian Gulf. The ship's mission is to monitor the movement of military and commercial air traffic. Both Scenarios A and B retained the same event structure (10 events each) and timing of events so that team member performance could be compared, but Scenario B had more aircraft and ambiguous events incorporated into it. Table 1 shows the basic event structure shared in Scenarios A and B. The first event occurs at the very beginning of the scenario (time zero). The last event, J, occurs at almost 28 minutes.

Table 1.
The Basic Event Structure Shared in Scenarios A and B.

EVENT	EVENT TIME MINUTES + SECONDS	EVENT DESCRIPTION
A	00+00	FRIENDLY CAP APPEARS, UNDER FRIENDLY AWACS CONTROL.
B	10+30	POSSIBLE HOSTILE F-4s, MULTIPLE BOGIES, DETECTED BY OWN SHIP, B-105, R-124NM, C-232, S-365KTs, A-9500FT, CLIMBING.
C	12+00	FRIENDLY CAP, DIRECTED BY AWACS, INITIATES INTERCEPT VECTOR TO THE NE, S-380KTS.
D	14+30	FOUR POSSIBLE HOSTILE BOGIES APPEAR TO SPLIT INTO TWO SECTIONS, SLIGHTLY DIVERGING IN COURSE, B-112,R-111NM, COURSES 230 TO 235, S-365 KTS, A-12KFT.
E	17+00	ALL BOGIES FEET WET, B-122, 104NM; FRIENDLY CAP, 40NM SW OF BOGIES, CONTINUES TO CLOSE FOR INTERCEPT.
F	19+30	APQ-120 INTERMITTENTLY DETECTED TO THE SOUTHEAST FROM THE HIGH F-4s.
G	21+42	CAP INTERCEPTS BOGIES, CONFIRMS TWO POSSIBLE HOSTILE F-4s, B-123, R-79NM, C-305, S-365KTS, ALTITUDE 10000FT.
H	23+30	TWO HI POSSIBLE HOSTILE F-4s, WITH CAP IN COMPANY TURN SOUTHEAST, B-122, R-67NM
I	24+30	UNIDENT (F-4D) TURNS TO 010 FOR APPROACH LEG TO KHARK ISLAND; APQ-120 LOST, B-053, WHEN ACFT TURNS AWAY
J	27+30	TWO POP-UP RADAR CONTACTS B-123, R-46NM, SECOND SECTION OF POSSIBLE HOSTILE BOGIES, C-305, S-365KTS, A-500FT.

The scenarios were then keyed into a simulation facility, composed of five PCs networked with a file server workstation, that had been configured to support AAW tactical decision making research (Holl & Cooke, 1989).

Documenting Stressors

The next step in the SAM process was to document the level of workload and ambiguity in both Scenarios A and B. The workload assessment matrix and the ambiguity assessment matrix were created to be used as tools to evaluate scenario stress levels, as well as to create future scenarios.

Workload Assessment Matrix. Essentially, the total number of air targets to be correctly prosecuted in a 30-minute AAW scenario is a workload indicator. However, results of the cognitive task analysis by Zachary et al. (1991) provided a way to obtain a more accurate representation of the degree to which each target creates work for the team. They found that a main goal of an AAW operator is to evaluate the threat status of air traffic. In order to do this, the operator manages workload by mentally placing the aircraft or "track" of interest into at least one of the following four activity categories: (a) unknown track, (b) interest track, (c) action track, and (d) engageable track. The findings by Zachary et al. (1991) suggested that each category requires an increasing level of operator activity in order to evaluate the aircraft. Although the degree of increased workload has not been determined, the distinction between categories enables us to, at the very least, identify task features that may hinder optimal task performance.

Following is a description of each category. An unknown track requires minimal mental activity because no actions have been taken to identify this track, and it is designated as workload level 1. If a track is designated an interest track, this means it must be monitored, because it is a potential threat, or is a friendly track that the team must be aware of for coordination in an engagement. This designation indicates a higher level of workload than an unknown track, and is labeled as workload level 2. A target is designated as an action track if it requires some action to be taken, besides monitoring (e.g., warnings, issue report, request for information). This designation indicates a higher level of workload than an interest track, and is labeled as workload level 3. A target is designated as an engageable track if it meets the rules of engagement, and indicates a higher level of workload than an action track. An engageable track is designated as workload level 4.

The workload assessment matrix was designed to evaluate scenario tracks in terms of these four categories. To illustrate, we evaluated event J from Scenarios A and B with the workload assessment matrix. Table 2 shows the workload assessment matrix with workload activity levels for air tracks during Event J of Scenario A. Five possible hostile F4s fit category 3 as action tracks. The SMEs had incorporated these tracks into the scenario for the specific purpose of creating an opportunity for the AAW team to perform a variety of the behaviors (e.g., issuing warnings, reports, and requesting information from team members). Four friendly commercial aircraft, two commercial helicopters, and three friendly military aircraft were listed as interest tracks. The Navy SMEs had added these aircraft to Scenario A to create some monitoring activities for the AAW team. The total number of action and interest tracks in event J in Scenario A were five and nine, respectively.

Table 2.
Workload assessment matrix with workload activity levels for air tracks during Event J of Scenario A.

TRACK	UNKNOWN 1	INTEREST 2	ACTION 3	ENGAGEABLE 4
Possible Hostile F4 #1			*	
Possible Hostile F4 #2			*	
Possible Hostile F4 #3			*	
Possible Hostile F4 #4			*	
Possible Hostile F4 #5			*	
Commercial Aircraft #1		*		
Commercial Aircraft #2		*		
Commercial Aircraft #3		*		
Commercial Aircraft #4		*		
Commercial Helicopter #1		*		
Commercial Helo #2		*		
Friendly AWACS		*		
Friendly Tanker		*		
Friendly CAP		*		

Table 3 shows the workload assessment matrix with examples of workload activity levels for air tracks during the same event for Scenario B. The total number of interest and actions tracks in event J for Scenario B was 12 and eight, respectively. It could be assumed that Scenario B requires more mental workload during Event J than Scenario A.

This type of evaluation could be carried out for all the events in the scenario to obtain a more complete estimate of mental workload. In addition, the workload assessment matrix could be applied to surface (ships) and subsurface (submarines) tracks.

Table 3.
Workload assessment matrix with workload activity levels for air tracks during Event J of Scenario B.

TRACK	UNKNOWN 1	INTEREST 2	ACTION 3	ENGAGEABLE 4
Possible Hostile F4 #1			*	
Possible Hostile F4 #2			*	
Possible Hostile F4 #3			*	
Possible Hostile F4 #4			*	
Possible Hostile F4 #5			*	
Possible Hostile F4 #6			*	
Possible Hostile F4 #7			*	
Possible Hostile P3C			*	
Commercial Aircraft #1		*		
Commercial Aircraft #2		*		
Commercial Aircraft #3		*		
Commercial Aircraft #4		*		
Commercial Aircraft #5		*		
Commercial Aircraft #6		*		
Commercial Helicopter #1		*		
Commercial Helo #2		*		
Friendly AWACS		*		
Friendly Tanker		*		
Friendly EP3E Aircraft		*		
Friendly CAP		*		

Ambiguity Assessment Matrix. The ambiguity assessment matrix was used to evaluate each critical event in a scenario in terms of the amount of vague, conflicting, and missing information occurring for air traffic. Ambiguous information about a target should lead to greater workload on the AAW team because they must actively pursue information about the track in order to identify it. To illustrate, we evaluated Scenarios A and B with the ambiguity assessment matrix. Table 4 shows the ambiguity assessment matrix with two examples of vague, conflicting, or missing information during Scenario A. For example, during Event B, at time 12 minutes and 30 seconds, electronic emissions from a possible hostile F4 are lost from the ship's radar. At this point, the ship's team must increase its monitoring and action activities to determine what happened to this track.

Table 4.
The ambiguity assessment matrix with examples of vague, conflicting, or missing information in Scenario A.

EVENT/ TIME	TRACK(S)	VAGUE, CONFLICTING, OR MISSING INFORMATION
B/ 12+30	1 Possible Hostile F4	Electronic Emissions Lost From Ship's Radar
C/ 10+30	1 Possible Hostile F4 Detected on Radar	Intelligence Reports Received by Ship Indicated Multiple Possible Hostile F4s Departing Shiraz

Table 5 shows the ambiguity assessment matrix with three examples of ambiguous information for Scenario B. For example, during Event I, at time 27 minutes, an internal report is received by the ship's team indicating a possible floating mine close to the ship. In this instance, the team must begin actions to validate this report. As with the workload assessment matrix, the ambiguity assessment matrix could be applied to identifying vague information regarding surface and subsurface tracks, as well.

Summary of SAM

Initial development of the workload assessment matrix and the ambiguity assessment matrix has shown evidence of their utility for evaluating stressors in AAW research scenarios. Furthermore, they can be used to specify and build new scenario features. However, in order to further validate this methodology, a measurement system that ties scenario events to team performance is required. Below is a description of a methodology for measuring event-based team performance that is being used in the TADMUS project to compare and evaluate team member responses to Scenarios A and B.

Table 5.
The ambiguity assessment matrix with examples of vague, conflicting, or missing information in Scenario B.

EVENT/ TIME	TRACK(S)	VAGUE, CONFLICTING, OR MISSING INFORMATION
A/ 3+30	1 Possible Hostile F4	Electronic Emissions Lost from Ship's Radar
I/ 27+00	Internal Report	Possible Floating Mine Close to Ship
J/ 30+30	1 Unidentified Possible Hostile F4s joins with a Section of 2 other Unidentified Possible Hostile F4s, and are headed toward ownship	Unclear Determination of Aircraft Intent

A METHODOLOGY FOR MEASURING EVENT-BASED TEAM PERFORMANCE

The accurate diagnosis of performance shortfalls and the tailoring of subsequent training toward correcting these shortfalls for teams and team members is contingent upon systematic performance assessment (Fowlkes et al., 1992). One of the benefits of employing the SAM approach is that it allows for an event-based scenario structure which can serve as the basis for performance measurement. The AAW scenarios created for TADMUS can be described as a set of critical events that serve as a basis for developing tactical decision making performance objectives. Consequently, the Navy SMEs that helped create Scenarios A and B were also enlisted to develop performance standards for each of five AAW team members: tactical action officer, identification supervisor, anti-air warfare coordinator, tactical information coordinator, and electronic warfare supervisor. They identified critical observable behaviors for each team member that should occur at specified events in Scenario A.

Behavior Observation Booklet

Next, the BOB was developed for each AAW team member position. Figure 1 is an example of a page from the BOB for AAWC actions during Event J of Scenario A. Seven actions were identified that the AAWC can be expected to take for event J. Upon observing the AAWC's performance in response to a pop-up radar contact on two aircraft, trained observers rate the individual's overall performance quality on a five-point scale, ranging from 1 (poor) to 5 (very good). Space is made available to add actions. This evaluation is carried out for each event, and for each team member participating in the scenario. For each team member, the BOB scores are averaged across all of the events in the scenario to derive an overall BOB score for that individual.

CIC TEAM POSITION: ANTI-AIR WARFARE COORDINATOR
EVENT J: POP-UP RADAR CONTACT, SECOND SECTION
TIME: 27 MINUTES AND 30 SECONDS

STEP 1
1. Looking for Aircraft profile
2. Issue external report
3. Issue new track number
4. ____________________

STEP 2
1. Ensure Tactical Action Coordinator issues trip wire warning calls
2. Recommend enhanced alert posture/equipment
3. Configure ship's position to TAO
4. Direct/modify that team configure equipment accordingly
5. ______________________________

OVERALL PERFORMANCE QUALITY FOR EVENT J

1	2	3	4	5
VERY POOR	POOR	AVERAGE	GOOD	VERY GOOD

OVERALL SEQUENCING QUALITY FOR EVENT J

1	2	3	4	5
VERY POOR	POOR	AVERAGE	GOOD	VERY GOOD

Figure 1 Example of page from BOB (Performance Quality) and SALI (Sequencing Quality) for AAWC actions during Event J of Scenario A.

Sequenced Actions and Latencies Index

Also, Figure 1 shows an example of the two-step sequence in which an AAWC is supposed to perform the seven actions. The SALI is an overall quality determination of whether the AAWC performed the actions in or out of the sequence shown. Upon observing the AAWC's performance in response to a pop-up radar contact on two aircraft, trained observers rate the individual's overall sequence quality on a five-point scale, ranging from 1 (poor) to 5 (very good). For each team member, the SALI scores are averaged across all of the events in the scenario to derive an overall SALI score for that individual.

Summary of the BOB and SALI

The advantage of the BOB and SALI is that they can be used as a diagnostic tool for observing and evaluating team member performance over the course of a scenario run. A major advantage to this measurement system is that immediate feedback to team members can be provided to improve performance. Results of team member performance can be charted against other team members on a timeline to determine areas of performance that require improvement. The key to the BOB and SALI is that they document observable team member actions. While the development and use of these measures may be somewhat labor intensive, the complexity of team performance requires observation (Baker & Salas, 1992). The technology for enabling observers to capture information about team behaviors needs improvement.

IMPLICATIONS FOR CREATING EVENT-BASED TRAINING SCENARIOS

Ultimately, the main objective of scenario development is to provide an opportunity for team members to perform critical behaviors (Fowlkes et al., 1992). The SAM is based on the idea that training scenario design should be driven by an identified standard of performance. Once performance objectives have been defined, training scenarios should be built so that they present opportunities to learn and achieve the desired performance requirements. SAM addresses the issue of identifying, assessing, and manipulating appropriate levels of situational stressors to create a productive learning context, and to enable effective assessment of performance objectives using the BOB and SALI. One of the main lessons learned in the initial development of the SAM is that scenario development and identification of performance standards is an iterative process. Navy SMEs provided input about changes in Scenario A and B events that were necessary to ensure behaviors were elicited from all the AAW team members.

This is the first step in providing guidelines for designing scenarios for team training. Future work in this area will include refinement and validation of the SAM, the BOB, and the SALI, use of the SAM to produce scenarios with different levels of stressors, and application of SAM, BOB, and SALI to other training situations. This same methodology could be transferred to other types of stressors and task situations (e.g., army battleforces, air traffic control, and nuclear power plant operations). In conclusion, the following are recommendations that are offered as a point-of-departure in the design of training scenarios and the measurement of team performance.

* To identify stressors, employ process tracing techniques that will enable detection of key complex decision making tasks, and the knowledge, skills, and abilities to perform the tasks.

* Use the workload assessment matrix and the ambiguity assessment matrix to assemble scenario events. In this way, different levels and types of task features can be systematically incorporated into a series of training scenarios.

* Utilize SMEs to help incorporate stress events into scenarios that will elicit key observable decision making actions.

* To create a BOB and SALI, utilize SMEs to identify key team member actions and action sequences that should occur at each significant event in the training scenario.

* Keep in mind that development of training scenarios and performance

measurement instruments should be closely tied together, and changes in performance objectives should influence training design.

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