Supporting Courses of Action Planning with Intelligent Management of Battle Assets

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Abstract

A battle space contains information that is dynamic, unstructured, uncertain, and temporal. The commander must use this information to plan, analyze, and decide on the "best" strategy to defeat the enemy. Such information must be context-specific and content-sensitive to changes in the battle space. Typically, the commander must integrate information from various sources (terrain, weather, resources, equipment, personnel, and mission definition) to develop courses of action and executable operation order. A typical collection asset decision aid will be useful to the commander in planning for resource management, courses of action (COA) analysis, logistics, and sample profiles on the order of battle operation. This paper describes an analytical decision aid for supporting the commander's courses of action planning and analysis based on battle asset information. The METT-T (Mission, Enemy, Troops, Terrain, and Time) paradigm is the main knowledge that drives the Alternative Courses of Action Display (ACAD) software. Usability test of the ACAD shows its utility to expert and novice battle planners have favorable impression and acceptable trust metric scores

Introduction

Because of technology, the amount of information that military commanders and staffs must process has increased tremendously since World War II and the amount of time available for decision-making has decreased dramatically. What remains unchanged is the cognitive capacity of the human decision- maker. According to Wohl (1981), the growing complexity of battlefield decision-making, when combined with increased data input of new sensor technology and reduced decision time can benefit from computerized decision-making aids. Such aids can structure, generate, and help the commander to assess the different hypotheses and options needed to conduct an effective tactical maneuver. Decision aids are, ubiquitously used today to support the commander in military decision-making process (MDPS). The Alternative Courses of Action Display (ACAD) software is one of such aids

To the commander and the battle staff, information is required for modeling the MDMP. These tasks include, among other things, planning, analyzing, selecting, and executing alternative courses of action (DOD, 1997a, 1997b).

A typical MDMP consists of four essential steps:

1. Mission analysis. This requires the commander to create a prototype of the battle situation, conduct scenario analysis, and define the goal and objectives to be accomplished.
2. Course of action (COA) development. At this stage, the commander identifies various opportunistic strategies that may or may not result in a mission achievement. These opportunistic strategies are either accepted or rejected based upon the mission objectives and the potential risks associated with the strategy.
3. Courses of action analysis. Here the commander with his staff, provide an integrated view of the battle strategy including resource requirements, avenues of approach (AA), and risks associated with a particular strategy. Usually, a COA

analysis compares the friendly and enemy information and uses it to conduct trade-off studies in terms of risk and mission objectives.

4. Decision. At the decision stage, the commander selects the COA he/she believes to be the most advantageous.

In general, courses of action modeling constitute the primary task of the commander and his/her staff at the strategic planning stage of MDMP. A course of action is a multi-attribute, multi-criteria decision-making problem because of the many variables required in the modeling process.

Within the framework of a course of action (COA) model, the commander must estimate the necessary information about his/her force, as well as estimating equal or more information on the enemy force. The results derived from such efforts determine, in part, how the battle is to be fought as detailed in a production order issued to field commanders. The approval of derived operation plans and operation orders (OPLAN and OPORD) by the higher level commander results in a mission execution (DOD, 1995).

Motivation for Developing ACAD

A key difference between attrition warfare - the wearing down of an enemy - and maneuver warfare - high tempo warfare - is the method of engaging the enemy. Attrition warfare is the application of friendly strength against an enemy's strength. It is typically a "linear" or two-dimensional style of fighting that is frequently indecisive and inherently costly in terms of personnel, resources, and time. The concept of attrition warfare is especially suitable for constructive modeling and simulation as human and equipment resources can be aggregated at the atomic level of granularity to derive a single measure of performance.

Courses of action planning with "attrition" criterion have been of interest to military planners. The current practice is to use computer modeling and simulation to support such objective. However, most of the existing COA decision support systems lack the inclusion of "intangibles" and representation of the commander's intent in their attrition models.

At the planning phase of the battle, estimating attrition for both the enemy and friendly forces is a rather complex and difficult task because of information density to be analyzed. For the most part, information may be incomplete, excessive, subjective, and multi-dimensionally heterogeneous. This poses a significant problem to the commander and the battle staffs who are tasked to use the available information to determine the "best" course of action to defeat the enemy. Defeating the enemy, generically, translates to combining the "best" available friendly resources to fight against the enemy resources. In the ACAD model, we attrite the enemy through systematic and interactive instantiation of the commander's intent, asset combination, as well as intangibles that reflect the battle environment and personnel morale. The commander's intent is particularly important in cases where the situation that gives rise to orders changed. The ACAD model can simulate such an unexpected scenario by allowing the user to reconfigure the necessary battle assets to match the new situation.

Related Work on Military Decision Aiding Tools

There many battle planning decision aids available (Ntuen and Park, 2003). The following decision aids have historical relationships to ACAD development. They are:

FOX-GA: This is a COA generation tool developed at UIUC by Schlabach and Hayes (1998), an Army Intel officer. A genetic algorithm model developed drives FOX-GA to mimic the state-space mappings (enumerative search) predetermined friendly force strength to that of the enemy. The GA uses a niching strategy to ensure the quality of a selected COA. The major input variables to FOX-GA are avenues of approach, tactical assembly areas, terrain objectives, the forward edge of the battlefield (FEBA), and lines of defensive terrain.

CORAVEN: This is a model developed for Intelligence Collection Management (ICM) and analysis (Jones, Wilkins, Bargar, Sniezek, and Asaro, 2000). The sub-functions of CORAVEN include Requirements Management, Mission Management, Asset Management, and Dissemination. CORAVEN runs in a multimedia system to support intelligence analyst. It uses Bayesian belief network as a modeling tool. It also has an embedded prototype sonification data streams to enhance situation awareness by supporting alarms and warnings about false events.

OWL: This is a decision-analytic COA wargaming tool developed by Rockwell Science center (Uckun, Tuvi, Winterbottom, and Donohue, 1999) for predicting alternative outcomes of a battle based on uncertain information available about friendly and enemy forces. The information used consists of mission, weather, and terrain. OWL is designed as a post-processor for FOX-GA. OWL executes the same wargame scenario in several iterations each with randomly generated inputs derived from a defined probability distribution function. The input to OWL is modified combined obstacles overlay (MCOO) represented by a graph structure, a set of possible friendly courses of action (FCOAs), and a set of enemy courses of action (ECOAs).

Description of The ACAD Model

The ACAD model is designed to implement analytical and behavioral models of a battle scenario. The key outputs of ACAD include (1) determining the predictive battle state based on the RFR calculation, and (2) graphical and textual portrayal of expected attrition index on hourly basis during a selected battle mission time, and the calculation of potential vulnerability for the friendly troops. The ACAD model calculations consider the following: (a) mobility factors (b) personnel attrition, (c) attrition of weapons, (d) resupply policies, (e) troop advance rate, (f) equipment type, and (g) troop composition for combined campaign.

In the context of ACAD design, the decision support display (DSD) modeling represents the process of portraying the available courses of action information on a visual space so as to enable the commander's ability to visualize enfolding decision events, actions, or goals in real-time. The ACAD database has command and control (C2) behavioral variables such as explicit intangibles as leadership styles, level of morale, communication, and shoreline vulnerability. Most of its intelligence activities are derived from Table of Organizations and Equipment (TOE), which break down a combat force into its constituent units, personnel, and weapons

The ACAD has three major sub modules: VIE, CADIV and RDM. First, VIE (Visualizing Intent Environment) is a constructive, event-based simulation model for predicting and updating battle states based on the input from a specific COA. The VIE model uses a finite state automaton to model the Markovian dynamics of the battle events. The VIE's knowledge base is based on heuristic models of modified Lanchester (Taylor and Parry, 1975) and Dupuy's (1985) equations. The classical Dupuy [7] equations use long time spans and cannot update relative force ratio and effectiveness. In our model, the ACAD can calculate COA objective function values in time increments of one hour up to 120 hours (or 5 days) of continuous battle.

The second component of the ACAD is the Collective Asset Display and Intent Visualization (CADIV) model. The CADIV model has three decision support displays in one screen. These are cognitive display of the commander's intent, courses of action display, and performance metrics display. The CADIV model portrays the animated version of possible avenues of approach on a terrain map with overlays. The cognitive display of the commander's intent portrays the space-time dimension of the battle objective as perceived by the commander. Changes in the user's input are written into an Excel database and displayed graphically based on the simulated state of events: "delay operations", "defend", and "counter-attack". An avenue of approach with military symbologies is used to capture the mental model of the commander's intent as he/she conceptualizes a combat strategy designed to defeat the enemy.

The third component, Resource Decision Model (RDM) is used to portray the status of resources and their impact on the effectiveness of meeting system level objectives. The resource management display is designed using a configural display concept (Barnes, 1995). Changes in the emergent features of the object (e.g., shapes, patterns and proportions) are directly related to various system states. All display modules are linked to each other through data templates stored in a common database.

The ACAD Methodology

The ACAD software considers mobility and maneuver issues as aggregate parameters in its knowledge base. The course of action analysis is based on "Force-on-Force Strength Matching (FOFSM)". Under the FOFSM algorithm, a predefined enemy force structure is played against the commander's (friendly) selected force structure. A selection of a force structure defines a COA with battle asset configuration. Each COA outcome is determined by the FOFSM algorithm which computes several measures of performance, including effectiveness, attrition (for personnel and weapons), event posture residency time, and posture risk and probabilities.

The ACAD has a built-in set of Tables of Organization and Equipment (TOE) for the friendly and enemy forces for each level of the unit or troop composition. Each TOE defines the number and types of combat units to be involved in a battle. Selecting a resource block in the ACAD's graphical user interface (GUI) automatically references the TOE for use in the analytical models. The ACAD analytical models use the METT-T input information to wargame highly abstracted combats situations.

The ACAD domain provides the use some options to select the desired resource combinations, force strength multipliers, number of friendly course of action (FCOA), predefined enemy course of action (ECOA), planning time (maximum of 120 hours), reserve policy, and the level of surprise. At the end of a wargame, the ACAD displays the relevant measures of effectiveness in a graphical format. The user can visualize this information and use it to determine the best course of action. The ACAD displays the relevant measures of effectiveness in a graphical format. The user can visualize this information and uses it to determine the best course of action. If desired, the ACAD model allows the user to override the computer model's recommendation. Exhibit 1 shows sample user input screen in ACAD.

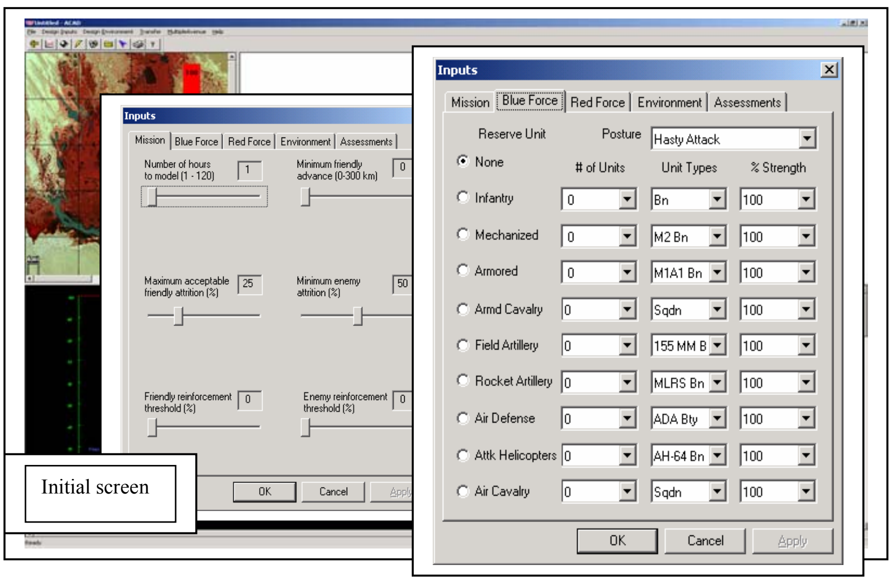

Exhibit 1. Sample ACAD input screen.

The illustration in Exhibit 1 shows a sample input data screen. The Editing Tools allow the user to describe, correct and use widgets, radio buttons and icons. There is a Guidance facilitates the help menu and provides assistance to the user. The User Model is selected from the "Calibrate" button. The first window to the left allows the user to set simulation parameters. Upon the selection of the either the "Blue Force" or "Red Force", the second screen on the right hand side appears. This screen allows the user to define the asset configurations based on a defined RFR desired. The marked "X" in red on the map area defined the terrain target to be captured. The ACAD's user interface supports direct manipulation through widgets, windows and menus (WWM). The WWM design is based on an intelligent object (IO) metaphor (Ntuen and Hanspal, 1999).

The first feature in the ACAD model is the subjective information of the military experts. The second feature is the heuristic knowledge base developed from the Colonel Dupuy's (1985) combat models of war. Dupuy's model was chosen because of two reasons. First, the knowledge base contains the salient characteristics of a general battlefield. Second, previous validation studies by Dupuy indicated a 90 percent correlation between theoretical and actual outcomes

The Dupuy's combat model was reviewed and found to fall short of addressing modern information-centric warfare environments. Therefore, the VIE model was developed in ACAD (Ntuen and Park, 2003, in this volume) to recalibrate Dupuy's combat parameters to modern digital weapons. The VIE's algorithm converts Dupuy's operational lethality index (OLI) to values in Battalion equivalents (BEs). OLI is a measure of the killing power of weapons ranging from the sword to the nuclear bomb. Dupuy provides tables of values as well as formulas for calculating OLIs of unlisted weapons for which certain characteristics are available. The OLI terminology is unfamiliar to many commanders who are more accustomed to the battalion equivalent (BE) concept. DOD (1997a) and DOD (1977b) have information for both American and Russian units in terms of BEs.

Sample ACAD Application

The ACAD model is implemented on an NT Personal Computer using C++ object program language, EXCEL™ spreadsheet, and Microsoft VISUAL BASIC 6.0. Once the user is in the ACAD domain (Exhibit 1), the user follows the instructions for interaction and user input. There is an on-line "HELP" utility.

To demonstrate the application of the ACAD, consider the simple case: The 1st BDE of the 52nd IN Division (MECH) is currently in a defensive posture planning for future offensive operations. While the OPTEMPO is high, enemy contact has been sparse for the last 48 hours and ability to conduct unimpeded planning operations has given the TOC a less than hectic pace, although tempers and patience are on edge as 24 hour operations have taken their tolls on the staff officers and fatigue and stress have compounded the difficulty for efficient TOC operations. New estimate has indicated a potential of achieving 3:1 relative force ratio (RFR) because of new supply. The current scheme of maneuver that is in the BDE commander's head is to capture terrain "X" by moving from south flank northwards. The problem is to reconfigure the equipment, assess the troop moral, and the new terrain, and, determine expected attritions for friendly and enemy troops.

In this problem, we can start the simulation by selecting 120 hours, which is.5 days of continuous battle operation. Exhibit 2 shows the original input data (right side) and the maneuver animation with military symbols showing the units selected for both friendly force (blue) and enemy force (red). The number in the avenue of approach arrow indicates the composite troop strength at the end of the simulation. In this case, the friendly force has 84% strength and the enemy has 44%. The graph below indicates time phase plot of the troop strength. The user can recalibrate the input and run ACAD for different asset combinations. Each run is considered to be equivalent to a single COA. All output data under each COA can be saved in a separate file under "MultipleAvenue" selection bottom. Specific scenario profiles can be saved and used for a re-run, printed, or imported to another system for use. For example, ACAD attrition data is used by Charles Analytic's FOX model as a front-end input data.

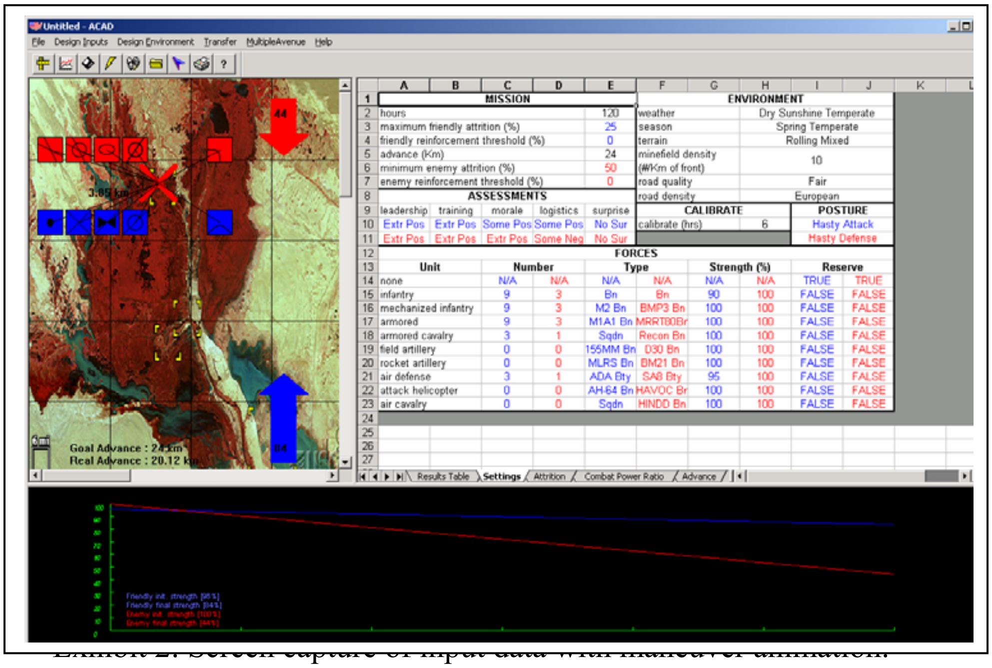

Exhibit 2. Screen capture of input data with maneuver animation.

Exhibit 2 shows the graphical plot of attrition factors.

Experimental Evaluation of ACAD

The objective of the study was to determine the level of usability and trust experienced commanders have on the ACAD as a battle plan assistant.

Subjects: We were concerned that task experience with problem familiarity could affect participant's trust on the ACAD software. Such influence of prior knowledge of task and use of decision aids has been illustrated previously by several studies between experts and novices (Benbasat & Taylor, 1978: Vessey, 1985). To control for level of expertise, participants with no command experience and knowledge of COA were eliminated. Six experienced military commanders qualified to participate in the study. The subjects' composition was 5 males and one female officer. The female had a Lt. Colonel rank in the U.S. Air Force and was a commander of ROTC Air Force Regiment at North Carolina A&T State University (NCA&T). For the male officers, four had the ranks of Lt. Colonel and two with Major ranks in the U.S. Army. Three of the male participants were retired (2 Lt. Col, 1 Major); the Major was a commander of a reserve army unit in Guilford County, North Carolina. Two male officers were active duty officers (1 Lt. Col was the commander of ROTC Regiment at NCA&T, and 1 Major was an instructor at NCA&T's ROTC Regiment. The two majors had unit command experience during Korean and Desert Storm wars. The female officer had command experience in Kosovo, and all the male participants with the rank of Lt. Colonel had experience commanding either field artillery or infantry battalions. All participants had a combined military experience of 113 man-years.

Procedure: Each officer participated individually in the study during the months of June to September 2000. The researcher explained the general procedure of the study and then participants read and signed a consent form. The researcher briefed the participants on the

ACAD and the types of input-output of the software. On the average, all participants were trained for 45 minutes on the use of the ACAD software, including help menus and guidelines.

Before the experiment, the participants were given a Decision Aid Expectation Form (DAEF) to complete. This was used to assess individual expectations computer-based decision aids. The DAEF had subjective rated values from 0 to 100, with "0" indicating absolutely not important, and "100" indicating absolute important. The participant must select their scores so that the total over the attributes equal to 100. The aprior expectations were later used as weight assignments. Table 1 shows the contents of DAEF.

Table 1. Sample Decision Aid Expectation Form

Attribute	**Level of important (0-100)**
Information content/ management	
Reliability of decision	
Personal dependency of decision aids	
Robustness of decision aid	
Confidence on decision aids	
Total score	**100**

The problem to be solved was given in the "Sample ACAD Application" section of this paper. In addition, S2 (an intelligent scout) has determined the following information about the enemy surprise strategy: (a) based on similar encounter, the probability of enemy surprise and posture is completely known; (b) the probability of surprise and location is 50% known; (c) there is information on the enemy surprise strategies. These conditions are known as "Low", "Medium", and "High" scenarios, respectively.

In the first experiment, the officers were told to manually (pen-and paper approach) develop their COA for each of the three scenarios using the given asset information. The developed solutions were collected from the officers by the experimenter. In the second experiment, the officers were told to develop their COA solutions using the ACAD software for each of the three scenarios. Each participant was given sufficient time as needed to complete the task. Each participant performed five trials of each scenario randomly on different dates. The times taken to complete a COA under each method were recorded for the three scenarios. At the end of a scenario, each officer was asked to write down all experiences with the ACAD software, then compete the rating of the software using the DAEF questionnaire (See Table 2). At the end of the experiment, each participant was given a computer print out of all the six scenarios—three for paper and pen (manual) and three with automated ACAD support (Low uncertainty, Medium uncertainty, and High uncertainty).

Table 2. Sample Decision Aid Rating

Attribute	**Rate your perception of the ACAD software (0-100)**
Information content/ management	
Reliability of decision	
Personal dependency of decision aids	
Robustness of decision aid	
Confidence on decision aids	

RESULTS

1. COA Completion Time: Data was summarized on the average time taken by the officers to derive acceptable COA. This is shown on Table 3. Figure 1 shows the histogram plot of the distribution of time in Table 3.

Table 3. Means and standard deviation of COA times (in minutes)

Experience level	Low uncertainty COA	Medium uncertainty COA	High uncertainty COA
Experts (Lt.Col.)	2.18 (std=0.26)	3.51 (std=0.62)	3.937 (std = 0.51)
Novices (Majors)	3.94 (std =1.03)	5.76 (std = 0.93)	8.43 (std = 1.27)

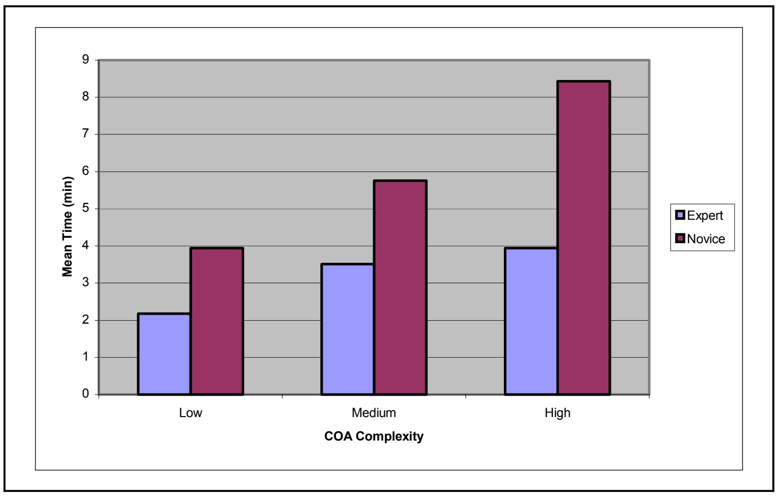

Figure 1. Mean time distribution for COA development

A 2 (expertise level) X 3 (COA complexity) within-subjects analysis of variance (ANOVA) was conducted on the completion times. The data showed that there were significant differences between novices and experts in COA completion times, F (1,24 = 249), p = 0.018. The levels of COA uncertainty was significant, F (2,24) = 19.45, p =0.003. There was no interaction between the levels of expertise and COA complexity, F (2,24) = 19.45, p = 0.237. Thus, in terms of COA problem solving, there were differences between novices and experts, as well as the effects of surprise uncertainties on the COA development.

To test the effect of manual and decision aid on COA development, A 2 (expertise level) X 3 (COA complexity) x 2 (manual vs. ACAD) within-subjects analysis of variance (ANOVA) was conducted on the completion times. The data showed that there were significant differences between the use of the ACAD software and manual approach to COA development times, F (1,60 = 252.), p = 0.0003. However, when the manual and the ACAD development times were analyzed by COA complexity, there was no statistical significant.

2. Perception of the ACAD software as a COA decision aid: Data on the subjective rating factors and the officers' trust on the ACAD tool were analyzed. Table 4 gives the average values for each factor. Each score was computed by multiplying the percentage equivalent of a prior weights derived from Table1 by the percentage rating values derived from Table 2. Trust values were computed by taking the average of all composite scores for all observations. There was a noticeable significant difference on the officers' perception of the ACAD software as a COA decision aiding tool, ($t_{calulated} = 3.98 > t_{(10, 0.025)} = 2.2281$), p = 0009. Table 3 shows the average trust scores for a COA with "Low" uncertainty.

Table 4 Mean perception score of ACAD

Attribute	Expert Score	Novice Score
Information content/ management	0.72	0.93
Reliability of decision	0.56	0.87
Personal dependency of decision aids	0.40	0.58
Robustness of decision aid	0.675	0.90
Confidence on decision aids	0.82	0.85
Trust score	0.913	0.966

3. Expertise and COA complexity: At the 5% level of significance, the hypothesis that there is some strength of association between commanders experience and COA tasks could not be rejected ($\chi^2_{(calculated)} = 3.21 < \chi^2_{(2,0.95)} = 5.99$), with p = 0.0034. Additionally, the student T-statistics (with repeated measures) indicate that the commanders (Majors and Lt. Colonel) used in the study did show some differences in ACAD trust in dealing with uncertainties ($t_{calulated} = 2.93 > t_{(5,0.05)} = 2.571$, p = 0.0237. Figure 2 shows the graph of average trust scores by COA scenario

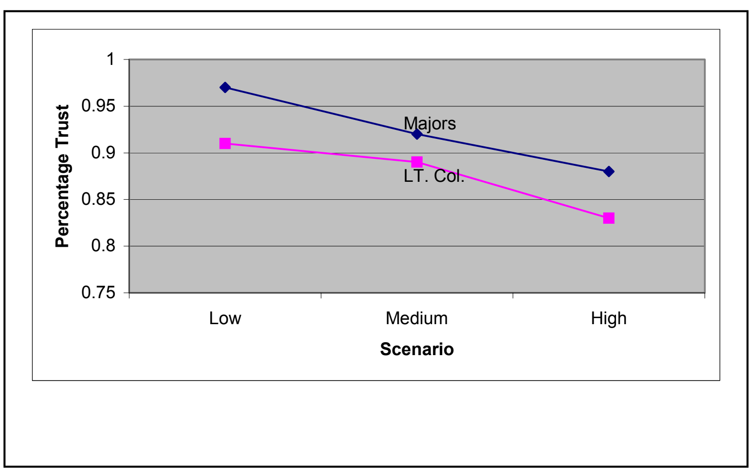

Figure 2. Sample plot of average trust scores by the commanders

Discussions, Conclusions, and Lessons Learned

This study presents the development of the ACAD software as the commander's assistance. Particularly, the commander's perception of the ACAD was analyzed. In terms of COA development time, the experts consistently outperformed novices either with the use of the ACAD software or using paper and pencil (manual). The same result was true for the times to develop the COA based on their complexities as defined by uncertainty of enemy surprises. Also, the experts show some differences in dealing with uncertainties. The expert group was able to discern and generate low risk COAs than the majors. In terms of the officers' perception of the ACAD, there was a significant difference between the experts and novices. The experts were more conservative in rating the ACAD software. However, they showed high confidence in the ACAD (82%) and agreed that the ACAD has a good database for COA planning (72%). The reliability and robustness scores were low (average of 56% and 67.5%). For the novice group, trust in the ACAD was rated highly (average score of 96.6%). All other factors receive high ratings (Table 4) except their perception of potential dependency on the decision aid in making tactical COA decisions.

Experimental validation of the ACAD with military subjects show that expert military commanders with more years of combat experience show conservative trust on the ACAD as a planning tool. Commanders with less experience tend to show more trust and dependency on the ACAD. The reason for this is obvious. Experts who use decision aiding systems need information that matches their mental models as well as situations that pose novel solutions (Adelman, 1991). In the ACAD domain, the interface design and the database contain information already familiar to the expert commanders. The challenge and novel part of the ACAD software is that it allows the commanders to configure military assets to counter a given relative force ratio; and they can war game the scenario to determine the attrition factors they are willing to accept. For the novice, the obvious is that they are looking for any solution that is better than their own (Benbasat & Taylor, 1978). Therefore, one advantage of the ACAD software is that it can be used to train novices in COA development exercises. The major drawback in the ACAD is that the intangible variables are mostly guesses. This is not true in the real battlefield scenarios

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