14TH INTERNATIONAL COMMAND AND CONTROL RESEARCH AND TECHNOLOGY SYMPOSIUM

C2 AND AGILITY

RESULTS OF AN EXPERIMENTAL EXPLORATION OF ADVANCED AUTOMATED GEOSPATIAL TOOLS: AGILITY IN COMPLEX PLANNING

Primary Topic:
Track 5 – Experimentation and Analysis

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Abstract

Typically, the development of tools and systems for the military is requirement driven; systems are developed to meet specified requirements and evaluated on compliance with those requirements. The real question we should ask about tools and systems in development is, "what benefit does the system provide to the warfighter?" The U.S. Army Topographic Engineering Center (TEC) is sponsoring a series of rigorous experiments designed to answer this question and thereby help to focus its research and development efforts. The first experiment in this series, which was presented at the 12th ICCRTS, demonstrated the value of a Geospatial Decision Support Systems (GDSS), Battlespace Terrain Reasoning and Awareness – Battle Command (BTRA-BC), in a strictly terrain analysis scenario. This second experiment in the series, building upon the results of the first experiment, evaluated the value of BTRA-BC in a realistic planning environment with a scenario that requires more complex decision-making. This paper discusses the experimental design (presented at the 13th ICCRTS) and the preliminary results of this experiment.

1. Background

As researchers and developers strive to provide advanced tools to process faster and more accurate data, it necessitates the assessment of each innovation so that key resources can be allocated to areas that yield the most "bang for the buck." The Joint Geospatial Enterprise Services (JGES) program of the U.S. Army Engineer Research and Development Center (ERDC) is designed to meet this need by evaluating the value-added to military decision-making through the use of Geospatial Decision Support Systems (GDSSs). We define a GDSS as a Decision Support System that performs automated analyses of geospatial data, and then displays that geospatial data and the results of automated analyses, i.e., geospatial information. A GDSS can consist of one or more Geospatial Decision Support Products (GDSPs) which calculate and display geospatial data or geospatial information. BTRA-BC consists of a collection of GDSPs called Tactical Spatial Objects (TSOs) that can be embedded as modules of a GDSS. TSOs are computationally lightweight objects that provide geospatial information services specific to the context for which they are developed. The context for which our TSOs are developed is that of military ground operations. In that context, the potentially superior situation awareness afforded by BTRA-BC TSOs opens up new possibilities for the conduct of military operations. Translating these possibilities into practical decision support requires a build-test-build cycle that channels technology in spiral development to ensure results that best support the warfighter. This paper reports on the second in a series of experiments designed to assess the value of Geospatial information to the decision-maker, and to provide results that inform the spiral development cycle. In the case of military GDSSs, the ultimate decision maker is the military commander, and the ultimate goal is to support command decisions in the most effective way.

The first experiment in the series assessed the value of the Battlespace Terrain Reasoning and Awareness – Battle Command (BTRA-BC) GDSS to the terrain analyst performing the Intelligence Preparation of the Battlefield (IPB) planning task using the Army's Digital Topographic Support System (DTSS). Army and Marine Corps enlisted terrain analysts attending the Advanced Terrain Analyst Course (ATAC) were given planning tasks to complete with and without BTRA-BC functionality. The experimental design was very similar to that of our current experiment (described in section 4 below). The results of the experiment demonstrated that using BTRA-BC functionality (1) dramatically decreased the time to perform the terrain analysis tasks, (2) improved the quality of the terrain analysis output, (3) maintained or improved the participants' knowledge of the impact of terrain on planning, (4) maintained or reduced the variability in both time to completion and plan quality, and (5) improved the participants' perception of the quality of their plans.

The goal of the current experiment is to continue to assess the benefits of BTRA-BC information and knowledge products. Based on what was learned from the first experiment, this experiment explored the benefits of GDSSs for planners who perform more complex military decision-making tasks. Because BTRA-BC provides geospatial decision support, the automated analysis functionality is of primary interest. Our current experiment was specifically designed to assess these capabilities. The BTRA-BC capabilities evaluated in this study include all the factors involved in the previous experiment as well as the ability of BTRA-BC to identify battle positions, engagement areas, and assist the planner in determining optimum ambush sites and Named Areas of interest.

The paper is organized as follows. Section 2 describes the overall scope of our research program and the scope of this experiment. Section 3 discusses the primary and secondary hypotheses to be examined. Section 4 lays out the design of the experiment and the reasoning that led to this design. Section 5 discusses the computing environment to be used in the experiment. Section 6 describes the metrics to be used to quantify the results of each trial. So far, the experiment has been conducted with only half the planned number of participants (8) that we anticipate will be needed to generate statistically significant results for most of the hypotheses. Section 7 and 8 discusses the preliminary results and our tentative conclusions.

2. Scope of Experiment

Our ultimate objective was to evaluate the benefit, to commanders at the brigade level and below, of combining a fully developed GDSS with currently available Command and Control planning tools. The first experiment, presented at 12th ICCRTS (Laskey, et.al., 2007), was limited in scope to the terrain analysis portion of Intelligence Preparation of the Battlefield (IPB) process. Our current experiment builds on the first experiment by expanding the scope to include the more complex decision-making required to develop a Course of Action (COA). In this experiment, the general scenario asked military planners, working individually, to plan a battalion movement to seize an objective in the presence of enemy units. Follow-on experiments will further address different kinds of planning problems, at various levels of command, and involving collaboration among members of staffs as well as individual decision makers.

3. Hypotheses

As we discovered while planning the first experiment, in order to evaluate the military value of GDSPs in general and specifically BTRA-BC, we needed a clear definition of military value, along with quantifiable metrics of value. Our determination of what constitutes value in this experiment is based on discussions with several experienced military planners. These planners believe that the value of GDSSs lie in their ability to:

(1) Reduce the time spent generating a given tactical decision product. Since the timeframe available to military decision makers is limited, GDSSs that reduce the time required to produce the desired output can free up time for a more thorough analysis of the large amount of data available. This more complete analysis is expected to result in a higher quality output that will be of more value to the decision maker.

(2) Automate many of the routine planning tasks. Many of the terrain evaluation tasks traditionally performed by military planners with paper maps and acetate overlays are sufficiently rote in nature that a GDSS, given digital information and the appropriate parameters, can perform these low-level terrain analysis functions more quickly and with less error than a human.

(3) Provide standardized outputs. A well-designed GDSS should provide a more flexible, precise, and easily understood display of the information required. It should display data and the results of analyses in a more readily understandable format than idiosyncratic manual notation.

A danger of automation is that exclusive reliance on a tool for analysis of data might reduce analyst familiarity with the terrain and its impact on military planning. In response to this concern, our experts believe that the automated analyses conducted by the GDSS are procedural and that using the output of the GDSS will not compromise the level of understanding by the analyst. The experiment is designed to test this belief.

It follows from the discussion above that, in comparison with decision-makers using tools without BTRA-BC functionality, we hypothesize that trained and experienced military planners who use BTRA-BC would:

1. *Produce a COA more quickly*. Rationale: The automation and analysis functions in BTRA-BC should allow the participants to complete the repetitive and rote tasks more quickly allowing more time for the generation of more options for the COA and a subsequently higher quality product.

2. *Produce a higher quality output.* Rationale: The automaton in BTRA-BC should minimize errors of omission and calculation. Furthermore, the standardized graphical representation of important terrain features and TSOs will display information more succinctly.

3. *Display as good an understanding of the impact of the given terrain on military decision-making.* Rationale: The judgment required to complete the required tasks will still be required when using BTRA-BC.

As the determination of military value and the design of the experiment evolved, we identified several secondary hypotheses. The automation of previously manual tasks, which adds value to using a GDSS, would likely reduce the variation in the output. As this reduction in variation does not necessarily add value, this was not considered a primary hypothesis. The structure of the experiments requires the repetition of various tasks and there was concern that a learning effect my might skew the results of the experiment. The secondary hypotheses investigated include:

4. *The output generated with BTRA-BC would be more uniform i.e. have less variance in the first two of the three categories above (speed and quality), than output generated without the use of BTRA-BC.* Rationale: Less variation in the output when using BTRA-BC is expected due to the level of automation incorporated in BTRA-BC.

5. *There would not be a learning effect due to experimental design.* Rationale: The participants have previous training and extensive experience using C2 planning tools and the tasks the participants are asked to perform are those that they have performed in the normal course of their duties.

6. *Participants would consider using BTRA-BC superior with respect to speed, quality, usability, terrain understanding, and overall.* Rationale: The participants should consider BTRA-BC's automated tools of benefit in the planning process.

4. Study Design

The study design employed a factorial design with three independent variables: System (with and without BTRA-BC functionality), System Order (whether the first scenario was worked with or without BTRA-BC functionality), and Scenario Order (whether scenario 1 or 2 was worked first). System was a within-subjects variable because each participant worked one planning scenario with BTRA-BC and one scenario without BTRA-BC. A within-subjects design was particularly valuable when the number of available participants is limited, as in the current case. Results from the sets of tasks were compared for each participant, thus eliminating participant-specific effects that might add variability to the results. System Order and Scenario Order were between-subjects variables because any given participant can only be in one ordered sequence for these variables.

The participants performed the same tasks on two similar military planning scenarios, using the same underlying planning system, the Commander's Support Environment (CSE). One of the tasks was performed with BTRA-BC functions added to the basic CSE functions; and the other task was performed with the basic CSE alone. The two trials were essentially identical except for the use of BTRA-BC functions. The order of the tasks was randomly selected so that half of the participants performed each of the tasks first. Randomizing the order of the tasks enabled the analysis to control for learning effects.

The instructions, tasks, requested outputs, and evaluation of these outputs were the same in both scenarios with the exception of geographic references necessitated by the requirement to have different geographic areas for each trial. Different geographic areas prevented participants from repeating their responses from the first scenario when they formed responses for the second scenario. The two areas were carefully selected for their geographic similarity such that the tasks performed by the participants and the expected results will be as nearly identical as possible. Randomization was used to control for differences between scenarios.

The participants were Army officers who have been previously trained in military planning and have operational experience at the battalion (Bn) or brigade (Bde) level.

Four of the eight were active duty majors and four were retired lieutenant colonels and colonels. The more junior of the participants were very conversant with computer-assisted decision-making whereas the two of the more senior were not so conversant. Based on the results of questionnaires detailing the participants' training and experience, the participants were split into two groups that are evenly balanced with respect to ability and knowledge. Group I performed the set of tasks first without BTRA-BC and then with BTRA-BC. Group II performed the tasks in reverse order. The groups were further divided into two subgroups while maintaining the balance of ability and knowledge. Each subgroup performed the same tasks for the same two scenarios, but the two subgroups saw the two scenarios in the opposite order. This design allowed us to control for differences due to the order of system use and the scenario order.

The tasks consisted of that portion of the military planning process beginning with analyzing the specific terrain given a Combined Obstacle Overlay (COO) up to the point of generating a potential COA. Specific tasks included (1) identifying Mobility Corridors (MC), (2) categorizing MCs by size, (3) grouping MCs to form potential Avenues of Approach (AA), (4) evaluating enemy COAs, (5) planning routes for 3 vehicle types, (6) identifying choke points on potential AAs, (7) calculating transit times, (8) recommending subordinate Areas of responsibility, in this case recommending company battalion boundaries, (9) planning company movement from a line of departure (LD) to an objective (OBJ), (10) recommending Named Areas of Interest (NAI), (11) identifying ambush sites, (12) identifying battle positions, and (13) generating a formatted Operations Order (OPORD).

The participants produced a graphic overlay depicting the results of the above tasks as well as a written OPORD that explains the reasoning behind their decisions. In order to gather data for the metrics below, the participants also responded to questionnaires: one that assessed their understanding of the effects of terrain on the military planning process and one that assessed their subjective experience with and without BTRA-BC functionality.

Prior to beginning the tasks, both groups of participants received standardized training on the use of BTRA-BC and CSE. The training was sufficient to allow the participants to perform the required tasks and included training on the modes and features unique to BTRA-BC and CSE. The last phase of the training required the participants to perform tasks based on the training and similar to those that the participants encountered during the trials, but of lesser complexity.

5. Environment

The evaluation was conducted using the Commanders Support Environment (CSE) as the Command and Control (C2) planning system. CSE is a robust C2 planning and execution based system developed for experimentation. CSE has been enhanced to incorporate the BTRA-BC GDSPs. CSE provided the capability to develop one or more COAs through a graphically oriented interface to represent the units, control measures, and their tasks. CSE was originally developed for Defense Advanced Research Projects Agency (DARPA)/Army Multi-Cell and Dismount C2 Program (M&D C2) which was continued from the Future Combat System Command & Control (FCS C2) program. CSE is primarily written in C++ code for the Microsoft Windows environment. It is built upon the Viecore FSD Decision Support System (VDSS), and the Data Analysis and Visualization Infrastructure for C4i (Davinci) Toolkit. The VDSS architecture enables rapid addition of modules for communication between CSE and other systems and components. The CSE's GIS components are built upon the Commercial Joint Mapping Toolkit(C/JMTK) which includes ESRI's ArcGIS Desktop licensed at the ArcEditor level.

The CSE provided two main GDSPs: BTRA-BC Movement Projection engine and optimized Line of Sight (LOS) analysis in addition to displaying BTRA-BC TSOs. The BTRA-BC Movement Projection engine provided movement and route analysis. This tool allowed the planners to generate various types of routes for his maneuver planning. These routes were incorporated into tasks that became part of the plan. The LOS GDSP displays a real-time analysis based on the relevant digital elevation data. CSE can also invoke and display various BTRA-BC TSOs. To keep things simple for this experiment, we utilized some pre-generated TSOs.

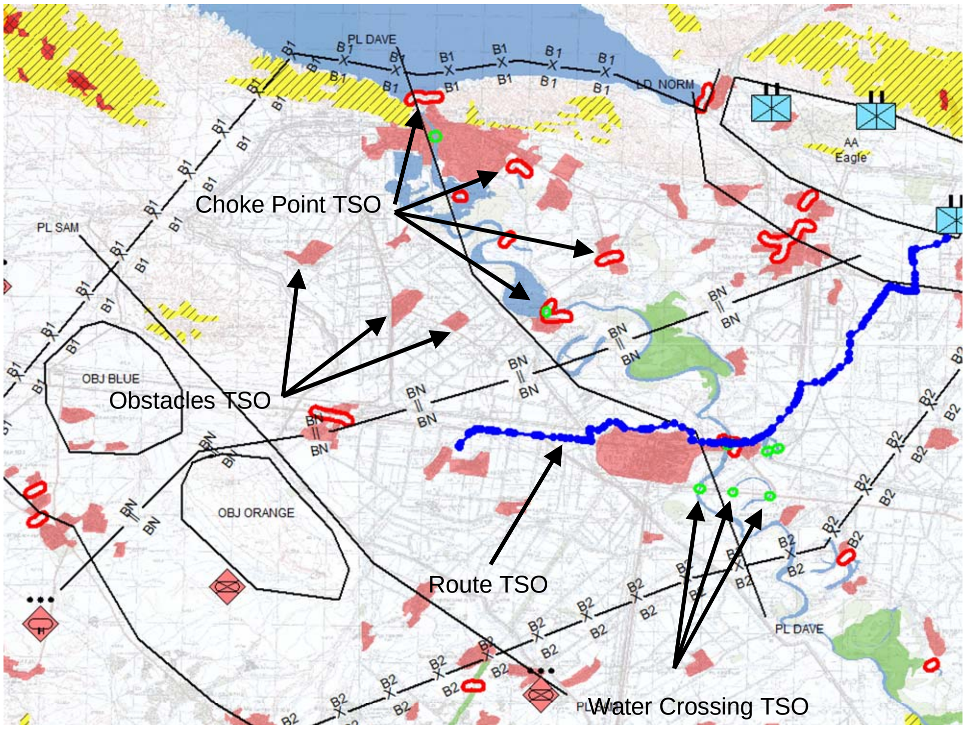

Figure 1: Geospatial Product Including BTRA-BC TSOs

Figure 1 is an example of a geospatial product consisting of several layers including BTRA-BC TSOs. The background is an image of a map geo-referenced to the digital data on which the graphics are based. The second layer consists of operational boundary and unit graphics. Additional layers consist of TSOs. The TSOs generate the information from the underlying digital geospatial data. In Figure 1, a route generated by the Route TSO is indicated by the blue line. Water crossings are outlined in green; choke points for Bn-sized units are outlined in red; and natural obstacles are in solid red. Figures 2 and 3 below depict the same geographical region with BTRA-BC TSOs and without BTRA-BC TSOs, respectively.

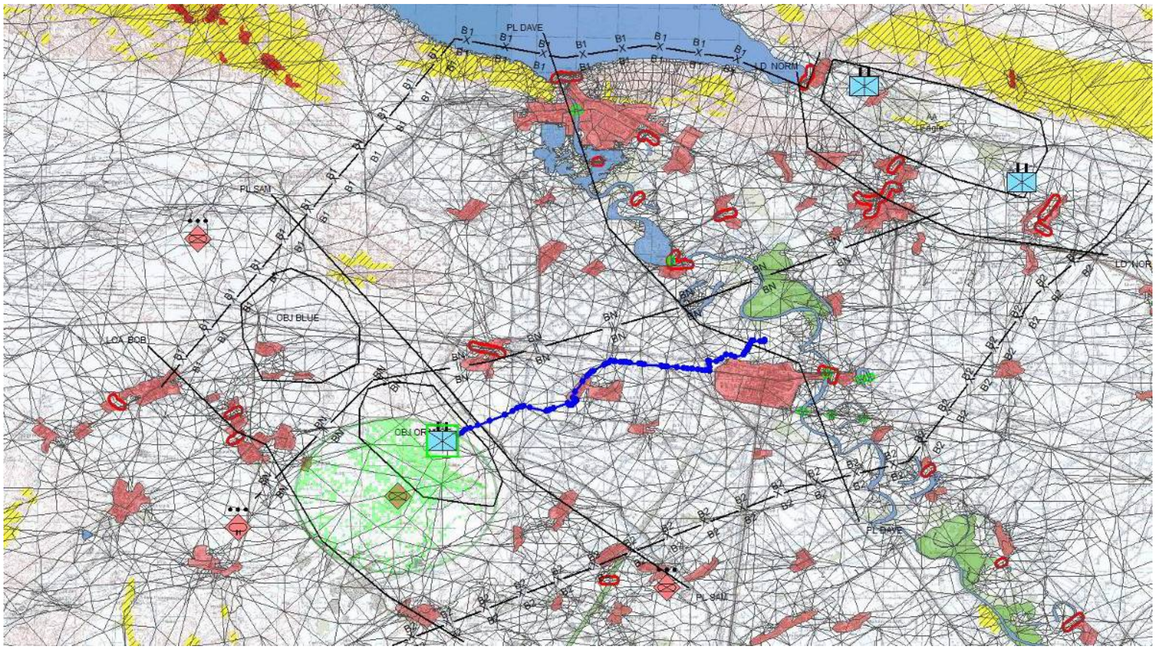

Figure 2: With BTRA-BC TSOs

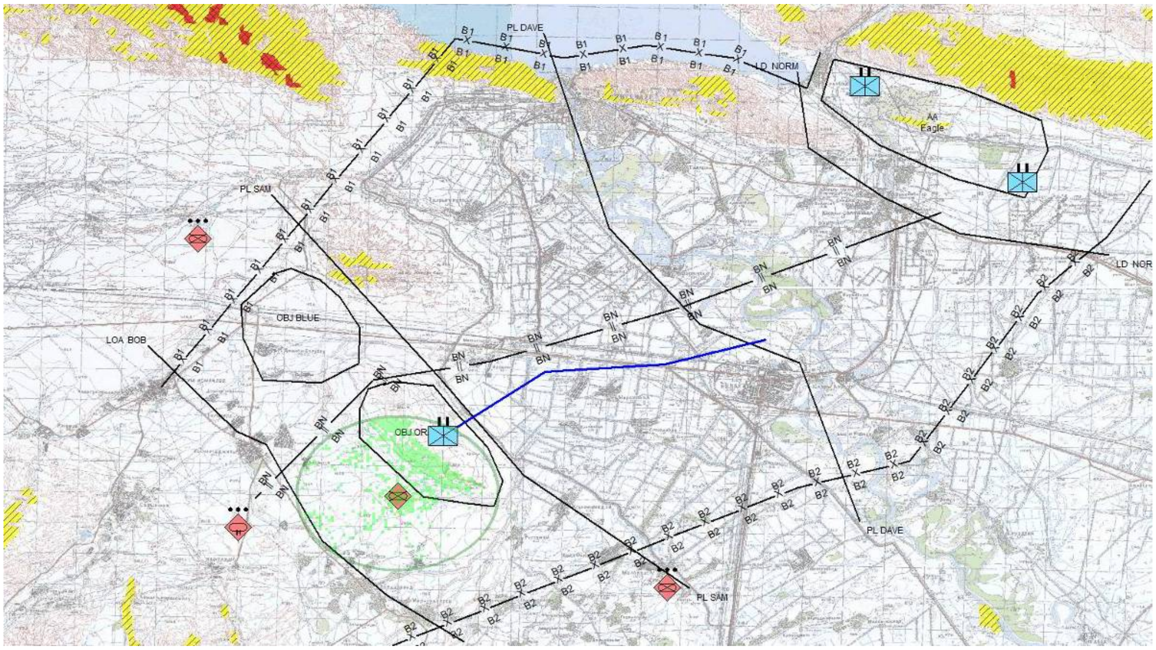

Figure 3: Without BTRA-BC TSOs

6. Metrics

Due to the differences in the graphical representation between CSE alone and CSE with BTRA-BC, blind scoring was not feasible. BTRA-BC's graphics were not easily replicated manually in CSE and, although the evaluators were not told which of the products were produced using BTRA-BC, given the number of products they graded, they were able to determine which were produced with BTRA-BC. Although the outputs are distinguishable as to their source, the evaluators were Subject Matter Experts (SMEs) who had no connection to the development of BTRA-BC, and we assumed the subjective evaluations are unbiased.

The criteria for evaluation of the BTRA-BC tools were: (1) a comparison of the rapidity with which the requested outputs can be produced, (2) the quality of those outputs, (3) the level of understanding of the participants of the impact of the terrain on the military decision making, and (4) the perception of the participants regarding the merits of the additional BTRA-BC functionality.

Time to Completion. The evaluation of how quickly the desired outputs are produced was measured objectively and independently of the experimental condition by logging the amount of time it takes participants to complete the tasks. The maximum duration of each trial was 3.5 hours. The actual time was calculated by taking the difference between the start and stop times and subtracting any break time.

Quality. We considered two factors that contribute to the quality of a participant's output: (1) the information presented and (2) how the information was presented. The method of scoring quality was subjective scoring; scores for each participant's output were assigned by independent Subject Matter Experts (SMEs). The SMEs judged the quality of the output with respect to the usefulness to the commander and based their evaluations on criteria developed beforehand. The focus of the subjective evaluation was relatively broad but focused on the BTRA-BC TSOs being evaluated. The participants' outputs were scored in fifteen categories with a total of 29 sub-categories that encompassed both the graphic and written portions of each output. The scoring was done on a 5-point Likert scale.

Terrain Knowledge. We administered a questionnaire to evaluate the participants' knowledge of the terrain and understanding of the impact of the specific terrain on military decision-making. The answers to the questions were not outputs of CSE or BTRA-BC. Answering the questionnaire required judgment and reasoning about the terrain and its effect on the military decision making, and not just regurgitating data presented by the system (CSE with or without BTRA-BC). Like the subjective evaluation, the SMEs evaluated the participants' answers on a 5-point Likert scale. The questions addressed reasoning about the general geography of the area, vehicle routing considerations, the selection of battle positions, engagement areas, and ambush sites.

7. Results.

We are presenting the preliminary results for the first run of the experiment, which was conducted in April of 2008 with eight participants. Given eight similar participants, the results discussed below that are statistically significant with only eight participants are likely to remain significant, and results that are not statistically significant may become significant with an additional eight participants. The qualifications set for future participants should result in participants with similar characteristics to the first eight. We conducted simulations (discussed below) to estimate the quality of our conclusions

OVERALL

System	$\overline{x}$	s
CSE w/o BTRA-BC	143.0	17.509
CSE w/ BTRA-BC	147.5	19.936

Table 1: Time to Completion Data (min)

Hypothesis 1: Time to Completion. There was no evidence that participants completed the tasks more quickly when using CSE w/ BTRA-BC than when using CSE w/o BTRA-BC. A repeated measures ANOVA provided no evidence ($p = 0.573$) that there was, on average, any difference between the Time to Completion for the two systems (Table 1).

Hypothesis 2: Quality. The analysis of the Quality data provided informative results. A repeated measures ANOVA analyzing the participants' mean scores for all thirteen criteria of Quality suggests that participants using CSE w/ BTRA-BC produced higher quality outputs

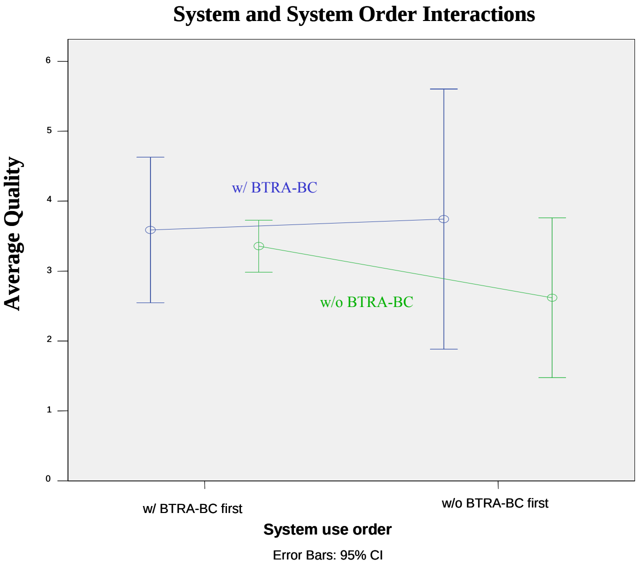

Figure 4: Plan Quality and System Order

than when using CSE alone, but the p-value of 0.08 does not reach the traditional level for statistical significance. All thirteen criteria of Quality were developed in conjunction with SMEs, but of those thirteen criteria, seven are criteria of general plan quality and six are specifically related to the TSOs being evaluated. A second repeated measures ANOVA on the latter six criteria indicated that with respect to these TSOs there was strong statistical evidence (P = 0.012) that the participants' plan quality was superior using CSE w/ BTRA-BC. As the goal of this experiment was to determine the benefits of geospatial technology, specifically the TSOs, this result is encouraging.

Hypothesis 3: Terrain Understanding. As expected, the analysis of Terrain Understanding data is consistent with Hypothesis 3, that Terrain Understanding when using CSE w/ BTRA-BC will not be less than when using CSE alone. A repeated measures ANOVA result shows no evidence (p = 0.271) that, on average, the Terrain Understanding differs; we cannot reject the hypothesis that there will be no difference.

Hypothesis 4: Uniformity. Equal variance tests indicated that overall there was no evidence (p = 0.357), on average, of a difference in the variance of Time to Completion. However, there was some statistical evidence (p = 0.096) that, on average, the variance of time to completion was less with the first systems used (Table 2).

CSE w/ BTRA-BC	$\bar{x}$	s
Used First	163.0	8.832
Used Second	132.0	14.445

CSE w/o BTRA-BC	$\bar{x}$	s
Used First	147.5	7.594
Used Second	138.5	24.570

Table 2: Time to Completion Variance

Hypothesis 5: Learning Effect. The analyses of Time to Completion and Quality metrics showed evidence of a possible learning effect. First, for Time to Completion there was significant evidence (p = 0.05) that the participants, on average, completed the tasks more quickly on the second system used.

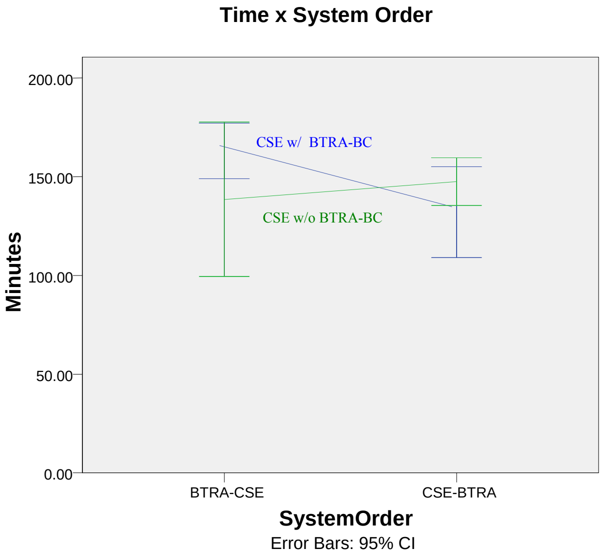

Figure 5: Time and System Order

Figure 5 graphically show this learning effect. Second, for CSE w/ BTRA-BC, there was no evidence of a learning effect, the evidence suggests ($p = 0.09$) that when using CSE w/o BTRA-BC second, participants' plan quality was improved (Figure 4). This effect may have been due to the participants having seen the information provided by the BTRA-BC TSOs on their first trial, and were trying to replicate manually the information they provided in their first trial.

Hypothesis 6: Perception. Paired T-Tests of participant responses demonstrated that, on average, there was strong evidence ($p < 0.001$ and $p = 0.013$ respectively) that participants believed CSE w/ BTRA-BC aided them in producing better quality outputs and that they thought CSE w/ BTRA-BC was superior overall (Figure 6). Additionally, there was evidence ($p = 0.06$) that participants thought CSE w/ BTRA-BC made completing the tasks easier

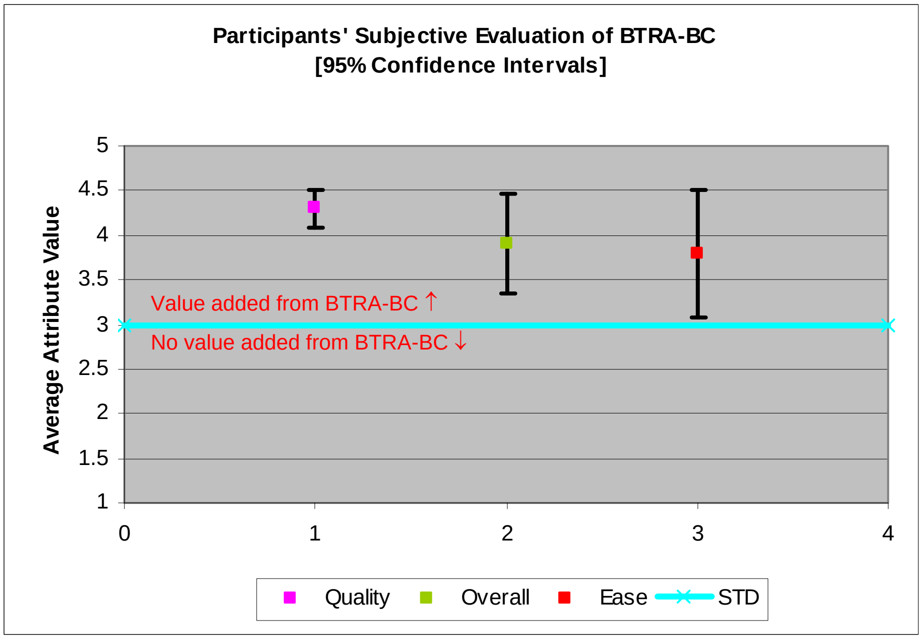

Figure 6: Subjective Perception

As shown in Table 3, paired T-Tests of the participants beliefs indicated, on average, that there was evidence ($p \leq 0.057$) that CSE w/ BTRA-BC was more useful for four of the eight tasks and overall (green at right), and there was weak evidence ($p \leq 0.111$) that for three of the eight tasks that CSE w/ BTRA was more useful (blue at right).

TASK	SIGNIFICANCE
Identifying Potential Avenues of Approach	0.092
Identifying Choke Points	0.100
Determining Hostile Force Engagement Areas	0.015
Determining Battle Positions	0.025
Determining Assault/Hide Positions	0.057
Determining Ambush Sites	0.111
Ability to Answer Commander's Questions	0.026
Overall	0.049

Table 3: Perception by Task

Predicting significance levels with 16 subjects. In order to determine whether the distributions of the responses from the eight participants could be treated as normal, an analysis of residuals was conducted on the Time to Solution, Quality, and Terrain Understanding data. The residual P-P and Q-Q plots for BTRA-BC Time to Solution and BTRA-BC quality appeared roughly normal. There was enough deviation in all the plots that a Kolmogorov-Smirnov (K-S) test was conducted of the hypothesis that the residuals were drawn from a normal distribution. The K-S test did not reject the hypothesis that the residuals were drawn from a normal distribution. Note that the K-S test results must be viewed with caution, because the underlying assumption of independent observations is not met in this case.

We conducted a simulation to determine what the potential significance of the analyses would be if we had an additional eight participants with the same characteristics i.e. with responses in the same statistical distributions. Our simulation generated ten sets of eight additional data points for both the BTRA-BC and CSE conditions for Time to Completion, Quality, and Terrain Understanding. Each set of points was generated randomly from the normal distribution specific to each

ANOVA Trial	Time to Completion	Quality	Terrain Understanding
1	0.628	**0.014**	0.177
2	0.960	**0.015**	0.325
3	0.788	**0.000**	0.122
4	0.480	**0.000**	0.669
5	0.291	0.108	0.366
6	0.095	**0.025**	0.213
7	0.602	0.337	0.669
8	0.391	**0.021**	0.934
9	0.344	**0.025**	0.189
10	0.546	**0.013**	0.132

Table 4: Simulation Results

condition and type of data. With 10 data sets from a total of sixteen participants (eight real and eight simulated), we repeated the ANOVA analyses described in the results section above. Table 4 contains the results of the simulation runs. For Quality, eight of ten p-values are less than the traditional 0.05 indicating that if we continued the experiment with eight additional subjects we would likely achieve statistically significant results confirming that participants using BTRA-BC produced higher quality products (hypothesis 2). Our simulation results suggest that adding eight additional subjects is unlikely to yield strong statistical evidence regarding Hypothesis 1 (time to completion) or Hypothesis 3 (terrain understanding).

8. Conclusions

The first run of the experiment was conducted in April of 2008. Although only eight of the estimated sixteen required participants were available, the results are encouraging. The statistically significant results from our preliminary analysis are:

1. Participants using CSE w/ BTRA-BC produce better quality plans. Statistical evidence supports this and there is also strong evidence that the produced better plans with respect to the areas supported by the TSOs.
2. Participants demonstrated no loss of Terrain Understanding due to system automation. The participants' Terrain understanding using CSE w/ BTRA-BC was equal to or better when than their terrain understanding when using CSE alone.
3. There is evidence that there were two learning effects. On average, participants finished the tasks in less time on the second trial. This indicates that they continued to learn about analyzing the problem throughout the trials, but this effect is not related to the systems used. There was also an inverse learning effect in that participants who used CSE w/ BTRA-BC first took longer when using CSE alone.
4. The participants believed that using CSE w/ BTRA-BC improved the quality of their plans, made their planning easier and that overall CSE w/ BTRA-BC was superior to CSE alone.

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