**AFCEA-George Mason University Symposium**

**Critical Issues in $C^4I$**

# EVALUATION OF HIGH RESOLUTION IMAGERY AND ELEVATION DATA

Suggested Topics:
Capabilities embedded in C2 systems:
Battlefield representation and visualization
Geospatial capabilities

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# Abstract

How does the underlying data affect the ability of warfighters to derive useful information and make decisions? The Army Topographic Engineering Center (TEC) and GMU endeavor to shed light on this question with the third in TEC's series of value experiments. The fundamental objective of the series is to improve TEC's support of military personnel in the field through better geospatial products. The third experiment in the series goes in a different direction from the previous two experiments. Whereas previous experiments assessed the value of cutting-edge geospatial tools while keeping the data constant, the present experiment evaluated the effect of higher resolution imagery and elevation data while keeping the tools constant. The high resolution data under evaluation was generated from TEC's Buckeye system, an operational airborne surveillance system. This paper discusses the scope of the third experiment, its hypotheses, its experimental design, and initial results.

## I. Introduction

As researchers and developers provide increasingly advanced tools to process data more quickly and accurately, it is necessary to assess each innovation so that key resources can be allocated to areas that yield the most "bang for the buck." To meet this need, the U.S. Army Engineer Research and Development Center (ERDC) initiated the Joint Geospatial Enterprise Services (JGES) program. The objective of JGES is to evaluate the value-added to military decision-making through the use of Geospatial Decision Support Products (GDSPs). GDSPs are computer-based tools that allow users to access, display, and reason with geospatial data. GDSPs have the potential to provide superior situation awareness through the use of tools that can open up new possibilities for the conduct of military operations. Implementing Geospatial technology to most effectively support the warfighter requires a spiral-build-test-build development cycle that focuses technological efforts in directions that provide the most value to the warfighter. This paper reports on the third in a series of experiments designed to assess the value of geospatial information to the warfighter. The experimental results concerning high-resolution data from the Buckeye system will be use to guide its further development and ultimately to support command decisions most effectively.

## II. Background

Overhead imagery obtained from aircraft was used extensively for military purposes in World Wars I and II. Reconnaissance aircraft remained the primary source for overhead imagery until the advent of low earth orbit (LEO) surveillance satellites. As early as 1963, satellites generated non-digital imagery with a 9 - 25 foot resolution, and by 1967 the resolution had improved to 6 feet, or approximately 2 meters. Although this resolution was significantly less than the 2.5 foot (< 1 meter) resolution available from the U-2 reconnaissance aircraft, the area covered by the imagery from a single satellite pass dwarfed the total imagery collected by surveillance aircraft. Consequently, satellite imagery became the standard source for reconnaissance imagery (Richelson 2003). The development of digital image technology provided the military, and later the public, with access to digital imagery in the 1-meter resolution range. The military standard 1-meter resolution imagery is designated Controlled Image Base 1 (CIB1). Google Earth™ is an example of 1-meter resolution digital imagery available to the public. While 1-meter resolution imagery was adequate for surveillance and military planning for conflicts involving large units, the situation is different for asymmetric warfare. Asymmetric warfare involves small groups of combatants, and requires the ability to recognize objects with dimensions of less than one meter. The Buckeye system was initially developed to provide higher resolution imagery (< 1 meter) than was currently available to facilitate the asymmetric battle through the automated change detection in digital imagery (TEC 2005).

Until relatively recently, elevation data has historically been generated by manual survey. The completion of the space shuttle radar survey generated Digital Terrain Elevation Data level 2 (DTED2) for the Earth between 60N latitude to 57S latitude (Rabus et al. 2003). DTED2 data has an accuracy of +/- 30 meters with data points every 30 meters (Pike 2008). DTED2 data is "bare earth" data; it has been processed to eliminate elevation data due to man-made structures (buildings, bridges, other structures) and flora (trees and ground cover). DTED2 data is what is included in most paper and digital topographic maps.

The Buckeye system consists of two components: a high-resolution digital camera to generate imagery, and a Light Detection and Ranging (LIDAR) system to generate elevation data. Buckeye can be mounted on a helicopter or an Unmanned Aerial Vehicle (UAV). Buckeye provides digital color imagery with a 4 to 6-inch resolution that is orthorectified (synchronized with known geospatial reference systems). This imagery is of higher resolution than other previously available, unclassified aerial reconnaissance imagery. The elevation data generated by Buckeye is comparable to Digital Terrain Elevation Data level 5 (DTED5) with an accuracy of +/- 1 meter @ 1 meter spacing. Buckeye LIDAR data is not "bare earth." It accurately depicts the elevation data associated with man-made structures. Buckeye data has been collected for most of the urban areas and major transport arteries in Iraq. Buckeye data is unclassified due to its unclassified source, but is treated as For Official Use Only (FOUO) and is available on the military SIPRNET and NIPRNET (with PKI) from TEC.

As a vivid depiction of the combat utility of Buckeye imagery, consider the images shown in Figures 1 and 2. Figure 1 shows CIB1 imagery of a complex whose purpose cannot be determined from the image. A Buckeye image of the same complex is shown in Figure 2. The image clearly shows sports facilities and bleachers, strongly suggesting that the compound is not a military target.

The goal of the current experiment is to assess the benefits of Buckeye/LIDAR data to the warfighter. Specifically, we seek to assess the effects of higher resolution data on military decision-making. We investigated two aspects of how experienced military personnel learn from imagery and elevation data: (1) the derivation of information from data and (2) the evaluation of the data with respect to a specific mission. Both these aspects are tasks that military planners routinely undertake when evaluating imagery/elevation data and both aspects are well-defined cognitive processes involved in decision-making theory. In his revised hierarchy of cognitive processes, Bloom describes the derivation of information from the available data as the fourth level - analysis; and the evaluation of information and data as the fifth of his six levels (Anderson et al. 2001). The evaluation of imagery and elevation data in a mission specific context requires a series of decisions and judgments based on written policy and experience. This experiment captured the impact of higher resolution data on decision-making in a military planning context. This was achieved by quantifying and measuring the participants' ability to derive information from and evaluate data.

The paper is organized as follows. Section 2 describes the overall 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. Section 7 discusses the results and the impact of the experiment.

## III. Scope of Experiment

Our ultimate objective is to evaluate the benefit, to the warfighter, of integrating higher resolution imagery and elevation data with currently available Command and Control planning tools. This third experiment sponsored by the U.S. Army Topographic Engineering Center (TEC) for the Joint Geospatial Enterprise Services (J-GES) program takes a different approach from the first two experiments. The previous two experiments evaluated the benefits of Geospatial Decision Support Systems (GDSSs). GDSS are a subset of Geospatial Decision Support Products (GDSPs) that perform automated analyses of geospatial data and generate geospatial information, in addition to displaying data and information. Those experiments varied the tool set while keeping the resolution of the data constant. In contrast, the current experiment evaluates the impact of higher resolution data while keeping the tool set constant.

Discussions with Subject Matter Experts (SMEs) indicated that planners for Battalion sized units or larger (the unit size of previous experiments) were unlikely to benefit from Buckeye/LIDAR data. Planners for large units are interested in large, operationally significant features such as forests, roads, urban areas, and rivers and bridges. Planners for small units are interested in finer-grained, tactically significant features such as trees and shrubs, alleys and paths, building heights and walls, and streams and fords. Therefore, small unit planners would probably benefit more from the higher resolution of Buckeye/LIDAR data than would large unit planners. In this experiment, the general scenario asked experienced military operators, working individually and acting as small unit planners, to evaluate multiple potential sites for a Vehicle Control Point (VCP). Follow-on experiments will address additional kinds of planning problems, at various levels of command, and involving collaboration among members of staffs as well as individual decision makers.

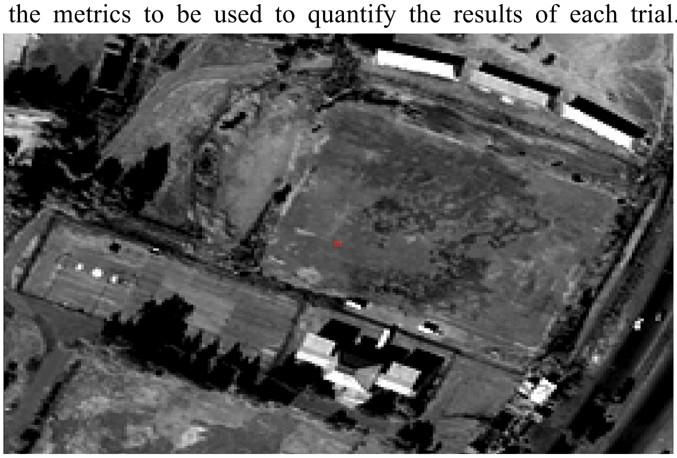


**Figure 1: CIB1 Image of Complex**

**Figure 2: Buckeye Image of a School**

## IV. Hypotheses

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

(1) *Reduce the time spent evaluating an area*. Because the higher resolution of Buckeye/LIDAR data should reduce uncertainty about the terrain, participants should be able to spend less time subjectively estimating the impact of the uncertainty on the mission than when using CIB1/DTED2. Less uncertain data should also allow the participants to form their overall evaluations more rapidly.

(2) *Improve the operator's ability to extract meaningful information.* As the resolution of imagery and elevation data improves, the data becomes more faithful to reality, and the associated uncertainty decreases. However, as the resolution improves, the volume of the data is increased by orders of magnitude and GDSSs must be used to extract meaningful information. Using a GDSS with Buckeye/LIDAR data should allow the operators to extract more meaningful (less uncertain) information than using a GDSS with CIB1/DTED2 data.

(3) *Improve the operator's ability to evaluate each site*. As the higher resolution Buckeye/LIDAR data has less uncertainty, evaluators using it should be able to better evaluate a site's value as a VCP site. The Buckeye imagery should provide evaluators with better visual data on the structures and the condition of the structures present at the site. The LIDAR data should provide the evaluators with better information on the topography of the site including the heights of buildings and obstacles that would obstruct fields of view.

(4) *Increase the uniformity of participants' responses.* Since the participants' judgments are based on higher-resolution, less uncertain information, their assessment of the factors contributing to the quality of potential VCP sites should be more accurate. This is expected to reduce the variability in their responses, because the responses should cluster around an accurate assessment of the value of the site.

It follows from the criteria above that, in comparison with decision-makers using higher resolution data, we hypothesize that trained, experienced, military planners who use Buckeye/LIDAR data, in comparison with those using CIB1/DTED2, would:

H1. *Evaluate the data more quickly.* Rationale: Higher resolution data reduces the uncertainty associated with the information upon which the participant's evaluations are based and thus their evaluations should require less time.

H2. *Require less additional information to establish a VCP.* Rationale: The higher resolution data should provide more information for the participant's evaluation and thus they should assess that less additional information is required from external sources.

H3. *Be able to more accurately derive information.* Rationale: When using the higher resolution Buckeye/LIDAR elevation data, the participants should be better able to use the available GDSS to answer questions about the sites more accurately.

H4. *Be more uniform in their evaluations, i.e. have less variance, in two of the four categories above (better information and better evaluation).* Rationale: Using higher quality information derived from less uncertain data should cause the participants evaluations (each criterion and overall) to agree more closely.

As the determination of military value and the design of the experiment evolved, we identified two secondary hypotheses. First, the structure of the experiments requires the repetition of evaluations and there was concern that a learning effect might skew the results of the experiment. Second, although not a concrete benefit, the perception of the participants as to the specific utility of the Buckeye/LIDAR data will assist in the integration of Buckeye data into deployable systems. The secondary hypotheses investigated include:

H5. *There would not be a learning effect due to experimental design.* Rationale: The participants have previous training and experience using C2 planning tools and the tasks the participants are asked to perform are similar to those that they have performed in the normal course of their duties.

H6. *Participants would consider using Buckeye superior with respect to speed, ease of use, usefulness of information, and overall.* Rationale: The participants should consider the high-resolution Buckeye/LIDAR data of benefit in the planning process.

## V. Study Design

The experiment employed a factorial design with three independent variables: Data Source (Buckeye or CIB1), Data Order (whether the first scenario is worked with Buckeye data or CIB1 data), and Scenario order (whether scenario 1 or 2 is worked first). Data Source was a within-subject variable because each participant worked one independent planning scenario with CIB1/DTED2 and one independent scenario with Buckeye/LIDAR data. A within-subject design is particularly valuable when the number of available participants is limited, as in the current case. Results from the sets of tasks can be compared for each participant, thus eliminating participant-specific effects that might add variability to the results. Data Order and Scenario order were between-subjects variables because any given participant can only experience one ordered sequence for these variables without repeated exposure to both data sources.

The participants evaluated sets of three potential VCP sites. A VCP is a checkpoint on a road where vehicles are stopped and searched. The participants evaluated all sites using the same underlying C2 system, the Commander's Support Environment (discussed in section 5). One set of three sites was evaluated using Buckeye/LIDAR data, and a second set of three sites was evaluated using CIB1/DTED2 data. A third evaluation re-evaluated the sites originally evaluated with CIB1/DTED2, this time using Buckeye/LIDAR data. This third evaluation provided a vehicle for directly comparing the participants' evaluations on the same site, but with different imagery and elevation data. Because the judgments may have been biased by having seen the sites previously, this direct comparison was not our primary comparison. Nevertheless, the direct comparison provides information about whether participants' evaluations of the sites improved when CIB1/DTED2 data was replaced by Buckeye/LIDAR data. All the trials are essentially identical except for the source of the imagery and elevation data. The Data Source for the evaluations was randomly selected so that half of the participants used Buckeye and LIDAR first. Randomizing the order of the tasks enabled the analysis to control for and evaluate learning effects.

The instructions, sites, evaluation criteria, and tools 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 are required to prevent participants from repeating their responses from the first scenario when they form responses for the second scenario. Having the participants evaluate three sites in each trial was advantageous in two ways: (1) we were able to analyze the participants' evaluations by individual site and directly compare their evaluations; and (2) by averaging each participant's responses, the impact of variations in each site could be minimized. The trios of sites have been carefully selected for their geographic similarity such that the evaluations performed by the participants and the expected results were as nearly identical as possible. Randomization was used to control for differences between scenarios.

The participants were Army enlisted personnel and officers who have previous experience establishing VCPs in Iraq or Afghanistan. They were split into two groups that were as evenly balanced with respect to ability rank/time in service as possible. Of the fifteen U.S. Army subjects, eleven were stationed at Ft. Lewis, WA, and four were stationed at Ft. Benning, GA. Five participants were majors and ten were enlisted (six Staff Sergeants, three sergeants, one specialist). Fourteen were active duty and one was retired. Further evaluation of the relative ability/experience of the participants was not possible due to the inability to contact the participants prior to conducting the trials. Group I performed the evaluations first with Buckeye/ LIDAR and then with CIB1/DTED2. Group II performed the evaluations in the reverse order. The group was further divided into two subgroups while maintaining the balance of ability and knowledge. Each subgroup performed the same evaluations 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.

Each trial consisted of evaluating one of two sets of three similar potential VCP sites (a scenario) on the same criteria. There were 28 evaluation criteria divided into six categories. The questions were derived from a U.S. Marine Corps battalion Standard Operating Procedure (SOP). In each evaluation, the participants evaluated each site on the 28 criteria with respect to the amount of additional information that would be required to actually establish a VCP at each site. For each site, the participants also answered four questions that only required that they derive information using the tools inherent in CSE. After completing the evaluation of all three sites in a scenario, the participants ranked the sites relative to one another on the overall quality of the site for a VCP and estimated their confidence in their ranking.

After completing all three trials, the participants weighted the relative importance of the categories and criteria. Because participants may weigh the various criteria differently, these rankings may help in exploring which criteria are most important in their evaluations and help us to compare the differences in the rankings of each site. Finally, the participants completed a questionnaire comparing the relative benefits of Buckeye/LIDAR and CIB1/DTED2 in the areas of speed, ease of use, utility of the information, and overall.

Prior to beginning the tasks, both groups of participants received standardized training on the use of CSE. The training was sufficient to allow the participants to perform the required evaluations and included training on the tools and features unique to CSE. The last phase of the training required the participants to perform the complete evaluations of two training sites similar to those that the participants encountered during the trials.

## VI. Environment

The computers used for the experiments were not homogeneous: four Dell desktops, four Dell XPS laptops, two Prostar laptops, and two other Dell laptops were available. The laptops were configured such that the monitor resolution and area displayed were near to, but not less than, that of the desktops. All the computers were dual core with greater than 2.0 GHz processors and USB 2.0 capability. Because input/output operations (I/O) are approximately 1000 times slower than accessing data from RAM, the limiting factor in the display of the imagery and elevation data was the time required to access the data from the external hard drive. Ensuring that all the computers were using USB 2.0

minimized variation in the response time due using heterogeneous computers. The laptops were provided with mice so that participants would not be required to use touch pads. To control for any remaining variation due to the participants using specific computers, the participants used a randomly assigned computer for each trail.

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 system developed for experimentation. The CSE was originally developed for Defense Advanced Research Projects Agency (DARPA)/Army Multi-Cell and Dismount C2 Program (M&D C2). M&D C2 is a continuation of the Future Combat System Command and Control (FCS C2) program, and hosted a series of experiments designed to test out network centric warfare concepts. The 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 the quick 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.

In addition to its ability to display imagery and elevation data, the CSE provides one primary GDSS, an optimized Line of Sight (LOS) analysis tool. The LOS tool performs real-time line-of-sight analysis based on the relevant digital elevation data, and displays the results as either a $360^{o}$ fan or an elevation cross section out to 5 km from the cursor.

## VII. Metrics

The criteria for evaluation were: (1) the speed with which evaluations were conducted; (2) the need for additional information; (3) the accuracy of the derived information; and (4) the perception of the participants regarding the relative merit of the Buckeye/LIDAR and CIB1/DTED2 data. The participants either recorded their evaluations of each of the 28 criteria on a 5-point Likert scale or provided short answers to questions. To ensure anonymity, participants were assigned participant numbers and evaluation designators, and data were recorded by these designators.

### A. *Time to Completion (H1, H4, H5).*

The evaluation of how quickly the participants completed their evaluations was measured objectively by logging the amount of time it takes participants to complete the tasks. The maximum duration of each trial was 1.5 hours. The actual time was calculated by taking the difference between the start and stop times and subtracting any break time.

### B. *Additional Information (H2, H4, H5,).*

In military parlance, a commander would issue a Request For Information (RFI) to higher authority for this information. Depending on the amount of information, the detail requested and the source required, a response to an RFI can consume man-hours of effort by numerous people in multiple external agencies, and thus may significantly delay the mission. The participants evaluated each site on the 28 criteria on a 5-point Likert scale where a 1 is "significant additional information required" and 5 is "no additional information needed." This metric is a subjective judgment based on the participants' analysis of the amount of information contained in the data.

### C. *Accuracy of derived information (H3).*

We asked the participants to answer four questions about each site to determine how higher resolution data affected the participants ability to derive accurate information from the data. Two of the questions require that the information be derived from an examination of the imagery and two require that the participants use the LOS GDSP (acting on the elevation data) to derive the information. Unlike the RFI evaluation, these questions are objective in that there is a right answer and little or no subjective analysis is required on the part of the subjects. Deriving this information is typical of the many individual tasks that are required to make the overall evaluations. The information generated by the subjects was compared to "ground truth" answers derived using all the available data.

### D. *Perception of Merits (H6).*

We administered a questionnaire to evaluate the participants' subjective judgment of the benefits of Buckeye/LIDAR data as compared to CIB1/DTED2 data. The participants evaluated which data are more beneficial as to speed, ease, and value of information with respect to the imagery and the elevation for nine tasks and overall. Like the evaluation criteria, the participants evaluated the participants' answers on a 5-point Likert scale. The results of these questions and information gathered in a debriefing session conducted at the conclusion of the experiment will be particularly valuable in guiding the future integration of Buckeye/LIDAR data with deployed systems.

### E. *Area Characteristic Ratings*.

One additional metric that had potential to help understand the benefits of high-resolution data was an Area Characteristic score. The participants would rate each site on the same 28 criteria as they did the RFI metric, but instead rate how "good" the site was with respect to the criteria and mission. In order to control for the difference in terrain at each site, the participants' scores would have to be compared to a "ground truth" score for each criterion for each site. There is no objectively correct "ground truth" for these ratings, and therefore there is no way to evaluate objectively whether Buckeye enabled participants to produce better area characteristic ratings. As a surrogate for "ground truth," three SMEs were tasked with evaluating each site individually and arriving at consensus scores.

This approach proved infeasible due to the lack of agreement on the part of the SMEs as to what constituted "good" for each criterion. The SMEs consisted of a Captain, a retired Staff Sergeant, and a Corporal. Their experience with VCPs ranged from Commander, platoon sergeant to fire team leader. The attitude in Iraq during their deployments ranged from attempting to incite a response from insurgents to actively avoiding disrupting the day-to-day life of the populace. Their wide range of experiences contributed to widely varying judgments as to what constituted a good VCP. The average correlation among the SMEs was 0.4. This low correlation diminishes confidence in their consensus score. As a consequence, this metric is not considered in the analyses reported below.

## VIII. Analyses of Results.

### A. *Hypothesis 1: Time to Completion.*

The statistical analysis of the time to completion yielded important insights. A repeated-measures ANOVA indicated strong statistical evidence ($p = 0.01$) that the average time to completion differs for the two data resolutions (

). Contrary to our hypothesis 1, on average, participants

| | $\bar{x}$ | s |
|---|---|---|
| CIB1/DTED2 | 47.40 | 6.080 |
| Buckeye/LIDAR | 51.67 | 9.499 |

took more time to complete the evaluations when using Buckeye/LIDAR than when using CIB1/DTED2. Discussions with the participants after completion of the trials indicated that the higher-resolution data of Buckeye/LIDAR allowed a more detailed analysis of each site. Consequently, the evaluations with this higher resolution data took additional time. Although significant statistically, the overall average difference was only four minutes for each trial, less than 10% of the total time per trial.

### B. *Hypothesis 2: Additional Information (RFI).*

A repeated measure ANOVA conducted on the averages of the 81 data points for each participant for each trial (27 criteria x 3 sites) resulted in strong evidence ($p < 0.001$) that, on average, participants required less additional information when using Buckeye/LIDAR data than when using CIB1/DTED2 data. The RFI metric is a proxy for the value of the information contained in the data. The relationship between RFI data and the value of information is an inverse one; that the participants required less additional information with Buckeye/LIDAR data implies that the participants acquired more information from this data than from CIB1/DTED2 data. As the data for both Buckeye/LIDAR and CIB1/DTED2 covers the same geographic area and features, the finer-grained Buckeye/LIDAR data provided more information and was consequently more valuable than the CIB1/DTED2 data.

**Table 1: Time to Completion (Minutes)**


| | $\bar{x}$ | s |
|---|---|---|
| CIB1/DTED2 | 47.40 | 6.080 |
| Buckeye/LIDAR | 51.67 | 9.499 |


### C. *Hypothesis 3: Derived formation.*

| | Percentage of Correct Responses | | | |
|---|---|---|---|---|
| | **Buckeye** | **LIDAR** | **CIB1** | **DTED2** |
| **Overall** | **72.80%** | | **15.60%** | |
| **Elevation** | | **74.40%** | | **23.40%** |
| **Q1** | | 62.20% | | 13.40% |
| **Q2** | | 86.60% | | 33.40% |
| **Imagery** | **71.20%** | | **7.80%** | |
| **Q3** | 75.60% | | 11.20% | |
| **Q4** | 66.60% | | 4.40% | |

In support of our hypothesis, analyses indicated that participants were able to derive information more accurately using Buckeye/LIDAR. Table 3 shows the percentage of correct responses over all four questions (Overall), for overall Elevation and Imagery data, and by question. Pearson Chi-Squared tests were conducted that compared the number of correct and incorrect answers to the questions that were designed to tests the accuracy of information derived from the digital data. There is strong statistical evidence ($p < 0.001$) that, for both imagery and elevation data from all sites, participants were able to more accurately derive information from the Buckeye/LIDAR data than from CIB1/DTED2 data. Overall, the participants using Buckeye/LIDAR data generated correct responses approximately 73% of the time, as compared to just under 16% when using CIB1/DTED2. This was as expected, as the empirical evidence from post trial debriefs with the participants indicated enthusiasm for the Buckeye imagery and LIDAR data.

### D. *Hypothesis 4: Uniformity.*

There was no statistical evidence to support our hypothesis that using higher-resolution data would result in less variable evaluations.

### E. *Hypothesis 5: Learning Effect.*

There was strong statistical evidence ($p = 0.01$) of a Data and Data Order interaction. The average time to completion when using both data resolutions was longer for the first data set used, indicating that the participants were learning about the problem during the trials (Table 2). This effect is probably due to the evaluation tasks being similar but not identical to the tasks participants performed when actually setting up VCPs. In the field, the final evaluations of VCP sites are

**Time to Completion: Data Order**
**Table 2: Time to Completion Interactions**
**CIB1/DTED2**

| | $\bar{x}$ | s |
|---|---|---|
| CIB1/DTED2 First | 49.71 | 6.237 |
| Buckeye/LIDAR First | 45.38 | 5.528 |

**Time to Completion: Data Order**

**Buckeye/LIDAR**

| | $\bar{x}$ | s |
|---|---|---|
| Buckeye/LIDAR First | 54.50 | 10.184 |
| CIB1/DTED2 First | 48.43 | 8.162 |

typically done on site and the evaluator would have first hand information in addition to digital geospatial data. Although the participants were trained on sites similar to those evaluated, and pilot testing indicated that the training was sufficient, these results indicate that participants continued to learn how to evaluate the available geospatial information throughout the experiment.

Figure 3 summarizes the analyses we conducted. The two points for the Buckeye-CIB1 Data Order (left side of Figure 3) indicate a definite difference between the average times for trials when the data order was Buckeye/LIDAR first and CIB1/DTED2 second. This difference in the average times is due to the compound effect of the longer time required when using Buckeye and during a first trial, as compared to the shorter time required both when using CIB1/DTED2 and during a second trial.

Conversely, the two points for CIB1-Buckeye Data Order (right side of Figure 3) shows little difference for the two trials. The longer time required for a Buckeye/LIDAR trail seems to have been offset by the shorter time required on a second trail.

*F. Hypothesis 6: Perception.*

From the questionnaire data, there is evidence that the participants of the experiment considered Buckeye/LIDAR superior to CIB1/DTED2 in that they believed it allowed them to compete the tasks faster, that it made the tasks easier, that the information was more useful, and that it was superior overall. Figure 4 graphically depicts this. In post trial debriefs most participants indicated that they were genuinely impressed with the level of detail of Buckeye/LIDAR data.

## IX. Conclusions.

This experiment provided significant insight into the benefits of high-resolution imagery and elevation data. The primary benefits noted were:

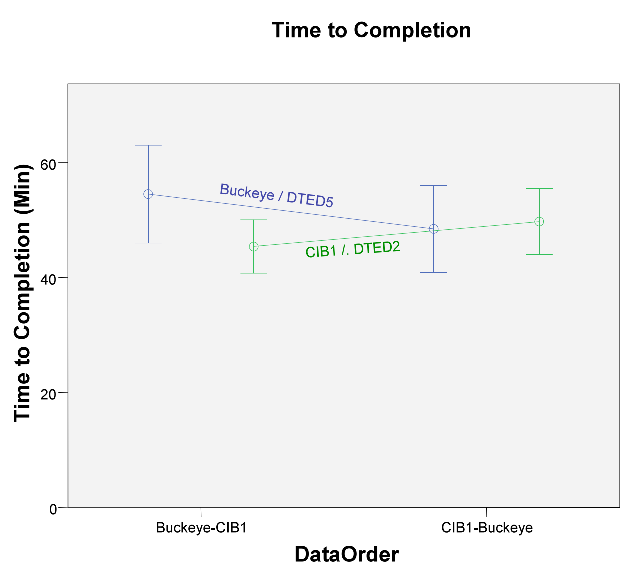
1. High-resolution imagery and elevation data provided more information. In all cases, the participants indicated they would require less additional information if they were to actually complete the mission.
2. High-resolution imagery and elevation data allowed the participants to derive more accurate information. In all cases, participants using the higher resolution data answered questions about sites more accurately.
3. The participants believe that using high-resolution data allows them to complete their evaluations more quickly, made the evaluations easier, contained more useful information, and was superior overall.

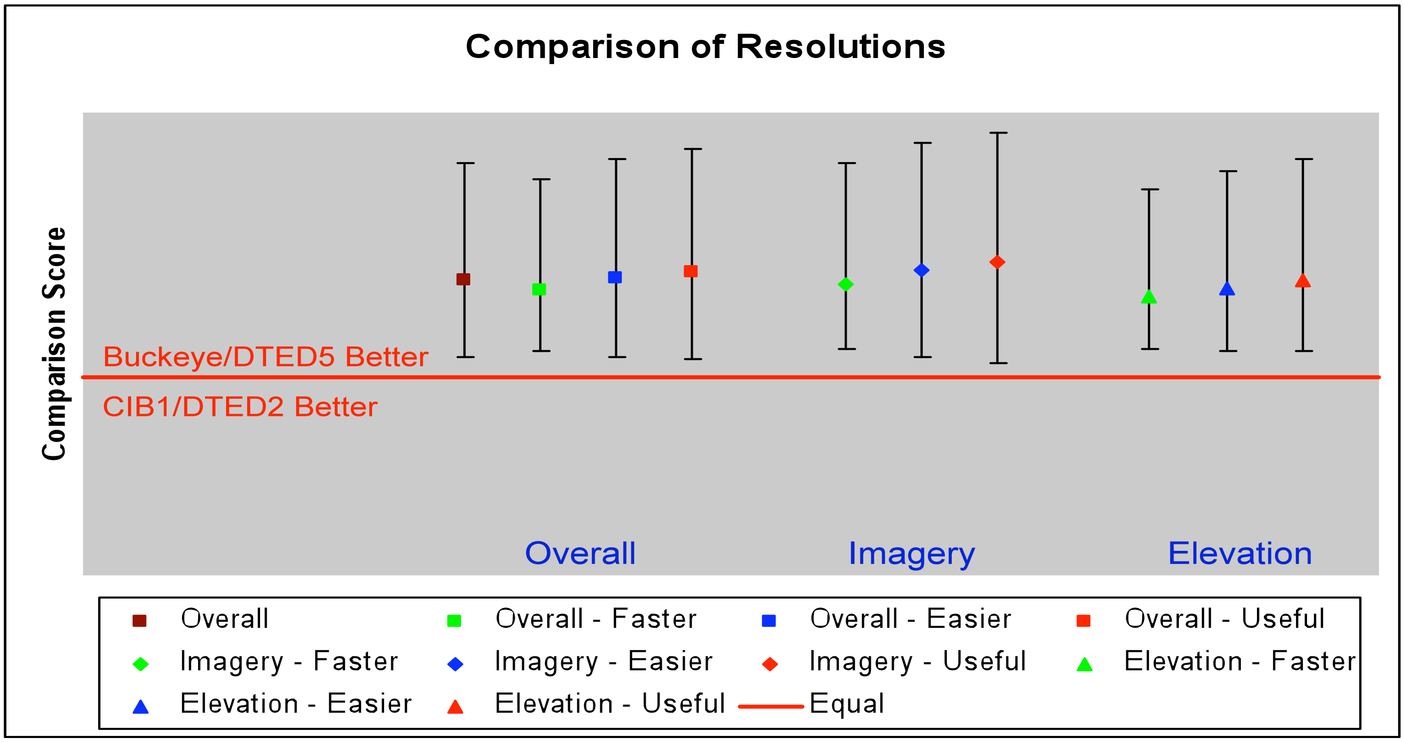
Two other interesting effects were noted:

1. High-resolution imagery and elevation data slowed the evaluation process by about 9%. This effect was probably due to the time required to assess the increased information provided by this data.
2. There was a learning effect. Even though the participants had previous experience with imagery and the training they received had been assessed as sufficient, the participants continued to learn how to evaluate the high-resolution data throughout the trials.

The results of this experiment are encouraging. Although the participants took four minutes longer to analyze the high-resolution Buckeye/LIDAR data, the potential saving in reduced RFIs is enormous. Processing RFIs can be so laborious that the time and resources saved in the overall planning, both inside and external to the unit, would offset the slight increase in time spent analyzing high-resolution data. For instance, a Marine sniper who participated in the experiment pilot test indicated that if he had access to Buckeye/LIDAR data, he could have shaved two days off a 5-day reconnaissance mission.

Additionally, the reduced uncertainty in this high-resolution data allowed the participants to glean more accurate information from the data. The participants were able to use the GDSPs to more accurately derive useful information from both imagery and elevation data. The information available from the imagery allowed the participants to better conceptualize the environment in which the VCPs were to be established. In response to specific questions, they were able to estimate vehicular and pedestrian traffic and determine how the urban terrain could help or hinder channeling traffic. Participants stated that the more accurate elevation data, and the Line of Sight (LOS) information generated from it, would be valuable in force protection decisions such as the placement of overwatch and sniper positions.






Overall, the results of the experiment help to determine the specific benefits to the warfighter of high-resolution imagery and elevation data. Many of the benefits can be generalized to missions other than the mostly defensive mission of establishing a VCP. Participant comments indicated that they saw value in using Buckeye/LIDAR data in other small unit operations such as routine patrols, assaults on fixed positions, reconnaissance, and intelligence gathering. Further analysis of the individual criteria RFI data will likely yield specific areas where Buckeye/LIDAR data would be useful and where future development efforts and experiments can be concentrated.

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