AFRL-RX-TY-TR-2012-0059

ROBOTIC RANGE CLEARANCE COMPETITION (R2C2)

Brian K. Skibba, Walter M. Waltz, Lucas M. Martinez
Airbase Technologies Division
Air Force Research Laboratory
139 Barnes Drive, Suite 2
Tyndall Air Force Base, FL 32403-5323

Andrew Schwartz
U.S. Army Corps of Engineers
Redstone Arsenal, AL 85898

David A. Malek
Applied Research Associates, Inc.
1750 Commerce Center Boulevard
Fairborn, OH 45324

Contract No. FA4819-09-C-0043

October 2011
Final Report

STINFO COPY

AIR FORCE RESEARCH LABORATORY
MATERIALS AND MANUFACTURING DIRECTORATE

■ **Air Force Materiel Command** ■ **United States Air Force** ■ **Tyndall Air Force Base, FL 32403-5323**

NOTICE AND SIGNATURE PAGE

AFRL-RX-TY-TR-2012-0059 HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION IN ACCORDANCE WITH ASSIGNED DISTRIBUTION STATEMENT.

__//Signature//__________________________
BRIAN K. SKIBBA
Work Unit Manager

__//Signature//_____________________
WALTER M. WALTZ
Program Manager

__//Signature//_________________
DONNA L. PILSON
Deputy Chief
Airbase Technologies Division

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
31-October-2011	Final	01-October-2009 - 13-August-2011

4. TITLE AND SUBTITLE
Robotic Range Clearance Competition (R2C2)

5a. CONTRACT NUMBER FA4819-09-C-0043
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER 0909999F

6. AUTHOR(S)
*Skibba, Brian K.; *Waltz, Walter M.; *Martinez, Lucas M.;
^Schwartz, Andrew; ^^Malek, David A.

5d. PROJECT NUMBER GOVT
5e. TASK NUMBER F0
5f. WORK UNIT NUMBER QF503020

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
^U.S. Army Corps of Engineers, Redstone Arsenal, AL 35898
^^Applied Research Associates, Inc., 1750 Commerce Center Boulevard, Fairborn, OH 45324

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
*Air Force Research Laboratory
Materials and Manufacturing Directorate
Airbase Technologies Division
139 Barnes Drive, Suite 2
Tyndall Air Force Base, FL 32403-5323

10. SPONSOR/MONITOR'S ACRONYM(S) AFRL/RXQES

11. SPONSOR/MONITOR'S REPORT NUMBER(S) AFRL-RX-TY-TR-2012-0059

12. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution A: Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES
Ref Public Affairs Case # 88ABW-2012-5009, 19 September 2012. Document contains color images.

14. ABSTRACT
This report documents the purpose, background, scope, preparation, and execution of the Robotics Range Clearance Competition (R2C2) sponsored by the Joint Ground Robotics Enterprise (JGRE), the US Army Corps of Engineers (USACE), and the Air Force Research Laboratory (AFRL). The purpose of the Robotic Range Clearance Competition was to quickly tap into the innovation and ingenuity of the commercial robotic technology sector to improve the safety and effectiveness of the four tasks traditionally associated with range clearing operations: 1) Vegetation Clearance, 2) Surface Clearance, 3) Geophysical Mapping, and 4) Subsurface Clearance. The competition events were held at Camp Guernsey, WY from Sunday, 7 August through Saturday, 13 August 2012. Three teams competed in the competition and a total of $1,750,000 in prize money was awarded to Team UXOD and Team D4C for their performance. Effort ended early .

15. SUBJECT TERMS
Robotics, Automation, Autonomy, Autonomous Systems, Unmanned Ground Vehicle, Range Clearance, Unexploded Ordnance, Military Munitions Response, Vegetation Clearance, Surface Clearance, Geophysical Mapping, Subsurface Clearance

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
Unclassified	Unclassified	Unclassified	SAR	260	Brian K. Skibba
					19b. TELEPHONE NUMBER *(Include area code)*

Reset

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

The Robotics Range Clearance Competition (R2C2) was sponsored by the Department of Defense's (DoD)'s Joint Ground Robotics Enterprise (JGRE) organization of the Office of the Undersecretary of Defense, Acquisition, Technology, and Logistics (OUSD/AT&L) Land Warfare and Munitions Directorate in collaboration with the United States Army's Corps of Engineers (USACE), and the Air Force Research Laboratory (AFRL). After two years of planning and organizing the R2C2 competition was successfully held and completed in August of 2011. The authors would like to extend their special thanks and gratitude to all of following who contributed to making the R2C2 a tremendous success:

- The participating teams: Team UXOD Automation led by Troy Takach, Team D4C led by Mike Tambroni, and Team Sky Research led by Roelof Versteeg. Without their participation the R2C2 would not have been possible.
- All of the R2C2 Competition Judges, including:
    - Chief Judge, Dr. Jim Overholt from Tank Automotive Research and Development Center (TARDEC)
    - Task and Performance Judges: Plyler McManus from the United States Army's Corps of Engineers (USACE) and Walt Waltz from the Air Force Research Laboratory
    - Autonomy Judge: Mike Bruch from Space and Naval Warfare Systems Command (SPAWAR)
    - Geophysical Mapping Judge: Andy Schwartz from the United States Army's Corps of Engineers (USACE)
    - Safety Judge: Lucas Martinez from the Air Force Research Laboratory

- The Joint Ground Robotics Enterprise (JGRE), including:
    - Mr. Rob Maline, JGRE Director
    - Mr. Jose Gonzalez, OSD/AT&L
    - Mrs. Ellen Purdy, JGRE Director during the initial R2C2 planning
    - Mr. Tony Melita, OSD/AT&L during the initial R2C2 planning
    - Bruce Donlin, Angela Duff, Ashley Snider and Randy Williams from Booz Allen Hamilton, JGRE support
- The Applied Research Associates/Joint Training and Experiment Center (ARA/JTEC) group, Travis Bruegger, Levi Jones, John Offe, Thomas Peterson, Les Atkinson, Phil Ibarra, Rob Hughes, Amilio Aviles, and the rest of the JTEC team, for streamlining the R2C2 event by providing outstanding logistical support (daily meals, site preparation, and range construction), and competition support (range bosses for daily competitions, site safety, safety engineering design and field test support, quality control teams, and data loggers).
- ARA's New England Division for supporting the geophysical mapping range preparations and for tireless support during the competition, especially John Wetzel, Matt Fordham, Jeremy Kolb, and Bryan Roth.
- Camp Guernsey's Joint Training Center, including COL Richard Knowlton, Garrison Commander and LTC Dave Herder, Deputy Garrison Commander for their support and the support of their excellent staff.

- The Camp Guernsey Emergency Medical Service group for providing 24/7 medical support.
- The Wintec contracting group, Bordie Casiple and Rommel Mandapat for safety field test support.

1. SUMMARY

This report documents the purpose, background, scope, preparation, and execution of the Robotics Range Clearance Competition (R2C2) sponsored by the Joint Ground Robotics Enterprise (JGRE), the US Army Corp of Engineers (USACE), and the Air Force Research Laboratory (AFRL). The Office of Secretary of Defense (OSD) in collaboration with the US Air Force and US Army conducted a Robotic Range Clearance Competition (R2C2) to foster the ability to clear training ranges of debris and unexploded ordnance (UXO) using robotic technologies. The purpose of the Robotic Range Clearance Competition was to quickly tap into the innovation and ingenuity of the commercial robotic technology sector to improve the safety and effectiveness of the four tasks traditionally associated with range clearing operations: 1) Vegetation Clearance, 2) Surface Clearance, 3) Geophysical Mapping, and 4) Subsurface Clearance.

The R2C2 Competition teams were:

- Team UXOD Automation - comprised of Kairos Autonomi, Autonomous Solutions, SAIC, Zonge Engineering, Vallon, WM Robots, VKR, Inc., and John Deere
- Team D4C - comprised of ECC, QinetiQ North America, and Bobcat
- Team Sky Research

Planning for the competition began in 2009 and was publicly announced with a kickoff meeting and briefings in Washington, DC in October 2009. The competition events were held at Camp Guernsey, WY from Sunday, 7 August through Saturday, 13 August 2012. Team UXOD Automation and Team D4C both competed in all four events. Team Sky Research only competed in the geophysical mapping event.

The results of the R2C2 were announced 17 August 2012 at the Association of Unmanned Vehicle Systems International (AUVSI) North America 2011 conference in Washington, D.C. Team D4C won both the Vegetation Clearance and Surface Clearance events and was awarded $500,000. Team UXOD - won the Geophysical Mapping event and the overall competition for achieving the highest total score. They were awarded a total of $1,250,000. Team Sky Research did not qualify for any awards and no prizes were awarded for the subsurface clearance event.

2. INTRODUCTION

This report documents the purpose, background, scope, preparation, and execution of the Robotics Range Clearance Competition (R2C2) sponsored by the Joint Ground Robotics Enterprise (JGRE), the US Army Corp of Engineers (USACE), and the Air Force Research Laboratory (AFRL).

2.1. Purpose

The purpose of the R2C2 was to quickly tap into the innovation and ingenuity of the commercial robotic technology sector to improve the safety and effectiveness of any or all of the four tasks traditionally associated with range clearing operations: Vegetation removal; Surface clearance; Geophysical mapping; and Sub-surface clearance. The ultimate aim was to be able to clear the millions of acres currently encumbered with spent training rounds and munitions debris and to place the land back into productive use.

2.2. Background

Range clearance operations as currently conducted are manpower intensive, time consuming, dangerous, and expensive. Due to ever-restrictive environmental regulations, the DoD has adopted the policy of building new ranges on existing impact areas. In addition, existing ranges require target maintenance, line-of-sight maintenance, and periodic surface clearance.

Data from robotic range clearance technology development efforts indicated the strong potential for significant reductions in the time and cost required to conduct range clearing operations. Experiments to date indicate the possibility of reducing range clearance times by two thirds and costs by one third if automated clearing equipment is used (Skibba, 2003 - Honey Lake Robotic Range Clearance Operations).

Additionally at the start of the competition process, there were no automated “commercial off the shelf” solutions available for the Department of Defense to procure. The traditional approach of establishing a research and development (R&D) program that could be transitioned into an acquisition program was not possible within the desired timeframe. By exercising the statutory authority to offer a cash prize for research and development achievements for this robotic range clearance application, it seemed possible to provide the desired capability in a significantly shorter amount of time.

(Section 2374a of title 10 United States Code as amended by Section 212 of the John Warner National Defense Authorization Act for Fiscal Year 2007 Public Law 109-364)

Therefore in 2009, the OUSD/AT&L JGRE, USACE, and AFRL intiated the R2C2 to be conducted at Camp Guernsey, Wyoming.

2.3. Scope

The tasks associated with range clearance that have the greatest potential for applying ground robotics technology include automated vegetation clearance, automated surface debris clearance, automated geophysical mapping, and automated Sub-surface anomaly excavation. The purpose of the competition was to assess the ability of the competitor systems to provide increased safety and operational effectiveness to range clearance operations. The competitor systems were expected to apply robotics technology to all or some combination of the inherent tasks in a range clearance operation. Because the competition was focused on increasing safety and operational effectiveness via robotics automation as well as reducing time and cost, competitors were not expected to attempt to develop improved vegetation removal tools or geophysical detection and identification sensor technology.

2.4. Goals & Objectives

The objective of this competition was to advance robotic technology used in range clearance operations in order to increase operational effectiveness while providing greater safety for range clearance team members. The technical goal was to advance the state of the art from remote controlled operation up to fully automated robotic operations. The Army was especially looking for solutions and approaches to the range clearance tasks that would yield manpower, cost, schedule, and safety benefits over production methods currently in use. While full automation was desired, it was not required to actually compete. The Army saw the competition as a way to prove the viability of the methods and to provide data that would assist them with defining their requirements for robotic range clearance.

3. THE COMPETITION

The JGRE solicited the help of AFRL's Materials and Manufacturing Directorate, Airbase Technologies Division's, Airbase Engineering Development Branch (AFRL/RXQE) Robotic's Group at Tyndall Air Force Base (AFB) to organize and manage the R2C2. AFRL/RXQE has extensive experience conducting research and development of automated range clearance systems. AFRL, USACE, and JGRE held a planning meeting in September 2009 at Camp Guernsey, Wyoming. Present were members representing AFRL, JGRE, USACE, and JTEC that would be responsible for the competition planning, logistics, and execution. Camp Guernsey was chosen as the competition site because of the availability of terrain suitable for vegetation clearance and the ability of the Camp to support the competition events. Figure 1 shows examples of Camp Gurensey terrain that were inspected during this initial meeting.

Figure 1. Examples of Terrain and Vegetation at Camp Guernsey

The planning meeting at Camp Guernsey set the basic structure of the competition, laid out a notional timeline, and established roles and responsibilities for conducting the competition. The competition director, Mr. Brian Skibba (AFRL/RXQE) then established a competition oversight integrated product team (IPT) as a mechanism to oversee competition preparations and planning.

A request for information (RFI) to industry was released to gauge the level of interest of potential competitors and solicit opinions from industry about the proposed competition structure. The competition was publically announced with a kickoff meeting and briefings in Washington, DC in October 2009, followed by an Industry Day at Tyndall AFB in December 2009. The Kickoff Meeting and the Industry Day events were designed to provide prospective teams with information about the proposed schedule, the nature of the tasks involved, the competition rules as then envisioned, lessons learned from AFRL about robotic range clearance, and to answer questions about the nature and purpose of the competition.

The remaining sections of this report document the activities and events leading up to and including the competition itself.

3.1. Competition Kickoff Meeting

The R2C2 Kickoff Meeting was held in Washington, D.C. on 6 October 2009. The meeting was publicly announced on the Fed Biz Ops (www.fbo.gov) website inviting anyone with an interest in the competition to attend. Seventy-five people attended the meeting that included briefings introducing the competition, the expected robotic range clearance, indefinite delivery-indefinite quantity (IDIQ) services contract with the US Army, describing the range clearance process, explaining AFRL lessons learned in the field, and describing the facilities available at Camp Guernsey. The meeting also included a question and answer (Q&A) session and time for the attendees to network.

Following the meeting, an informational website (roboticrangeclearance.com) was established (Figure 2) to publicize and inform those interested in the competition. A list of the attendees of the Kickoff meeting was posted, along with the results of the Q&A session. Eventually, the website would serve as the primary communication mechanism with the public as all versions of the rules and the regularly updated Q&A documents would be posted.

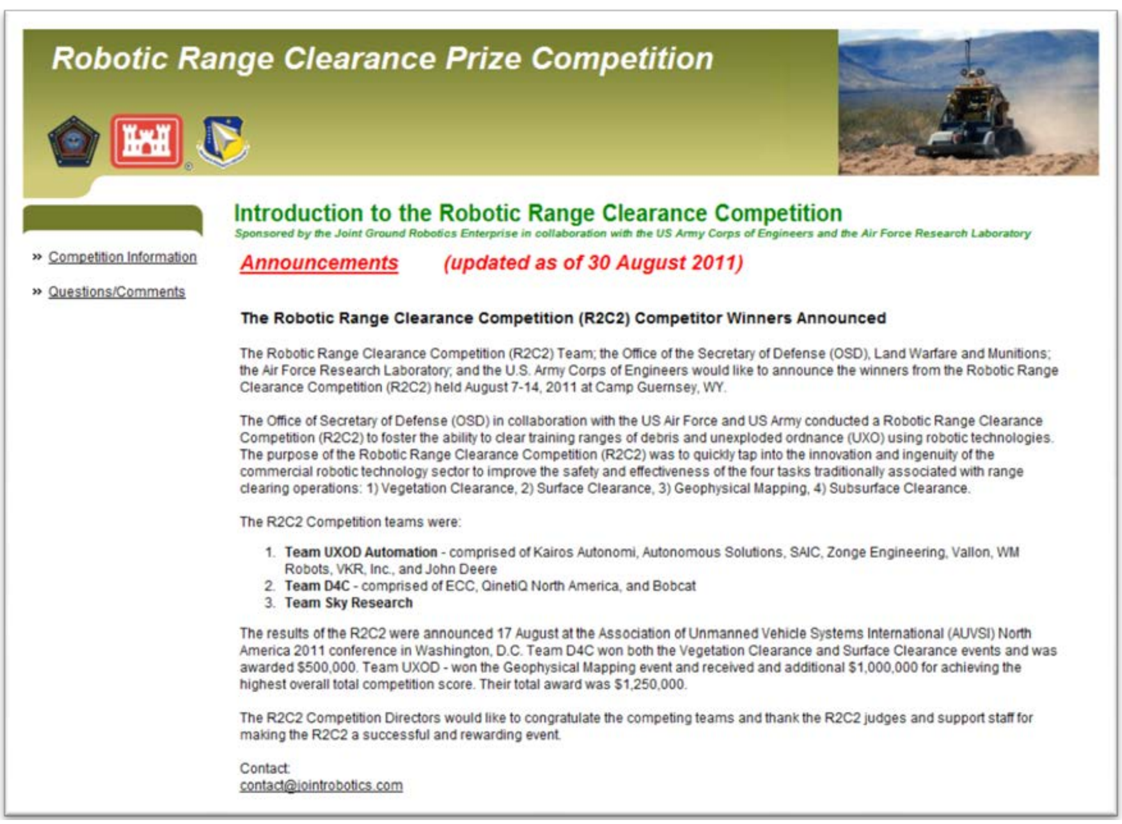


Figure 2. R2C2 Website

The Kickoff meeting emphasized that the competition was not about sensor or platform development, but it was an integration and robotic algorithm/behavior challenge (Appendix K: 2009 – Robotics Prize Competition Kick-off Meeting Briefing). The meeting also emphasized that there would be key decision points along the way.

The Kick-off Meeting intended to make a determination of industry's interest in both the competition and system development to support the Army's need for robotic range clearance. The high level of attendance at this meeting, 75 people representing more than 50 companies attended, and responses to the RFI, 18 total, showed that there was sufficient interest to continue with the competition. Based on the strong interest in the R2C2, the DoD decided to proceed with the competition and offer up to two million dollars in cash prizes. At this meeting, it was also announced that the systems would not to be compared against each other, but would be evaluated against a set of metrics specified for each of the designated tasks. The competition category task objectives would be finalized and announced at Industry Day.

3.2. Industry Day

The R2C2 Industry Day was held at Tyndall AFB on 10 December 2009. This event was aimed at providing potential competitors with lessons learned from AFRL robotic range clearance experience, explaining to competitors the competition rules as then envisioned, and conducting limited demonstrations of AFRL range clearance technologies. 49 people from 34 companies and government agencies registered for the Industry Day.

3.3. Rules and Metrics Formation

The R2C2 Oversight IPT created a Rules and Metrics IPT to develop the details of competition's rules and how they would be adjudicated. A two-day meeting was held in Huntsville, AL with representatives from AFRL and their support contractors, USACE, and the JGRE to initiate the competition rules development.

The R2C2 rules were driven by four main concerns: safety was the number one priority (safety of the competitors and spectators came before anything else), trying to appropriately incentivize the systems' autonomy level, a desire to not structure the competition to favor any solutions over others, and a desire to keep the scoring simple so the teams could easily understand and compute their own task scores. The metrics were structured around assessing range clearance performance outcomes, level of autonomy, and man-hours to complete the tasks. As a result, while range clearance outcomes were emphasized, autonomy was an important driver in the evaluation.

The Rules and Metrics IPT produced a baseline R2C2 Rules and Metrics document that would be periodically reviewed and updated. Appendix A includes the fifth and final version of the Rules and Metrics document as published immediately prior to the competition.

3.4. Letter of Intent

A Letter of Intent (LOI) was crafted by the Oversight IPT and the JGRE. The purpose of this letter was to obtain commitments to compete from potential teams. After legal review by the OUSD, the LOI was finally released 26 February 2010 to the competition website (Appendix E:

Letter of Intent). By signing the letter, each team and its members agreed to have a mid-progress review and appear at the R2C2 site for the competition at a mutually agreed upon time, ready to perform. It was not intended to be a legally binding contract, but rather an expression of intent, requiring written notification to the competition.

The R2C2 Oversight IPT received 12 LOIs (Sky Research, Autonomous Solutions (2 members), Zonge Engineering, Millenworks, SAIC, Kairos Autonomi (4 members), DOK-ing, Redux, Battelle (2 members), ECC (2 members), Rogers, and Raytheon) by the response deadline of 3 May 2011. These totaled 18 original team members.

3.5. The Teams

During the time between the LOIs were received and the competition event some of the competitors dropped out of the competition for various reasons. Some companies were not in a position to self-fund the technology development necessary for them to compete. Also, several of the competitors decided to collaborate, which resulted in many individual teams becoming a few, large teams. As of the spring of 2011, only three teams of the original twelve remained.

Team UXOD Automation (Figure 3) was comprised of Kairos Autonomi, Autonomous Solutions, SAIC, Zonge Engineering, Vallon, WM Robots, VKR, Inc., and John Deere (Team UXOD Automation later added VKR, Inc. and John Deere to their team).

Team D4C (Figure 4) was comprised of ECC, QinetiQ North America, and Bobcat.

Team Sky Research (Figure 5) was comprised of Sky Research, Inc.

Both Team UXOD Automation and Team D4C committed to compete in all four events while Team Sky Research only planned to compete in the Geophysical Mapping event, which made them ineligible for the Grand Prize.

Figure 3. Members of Team UXOD Automation

Figure 4. Members of Team D4C

Figure 5. Members of Team Sky Research

3.6. Validation Trials

A series of validation trials were planned by the R2C2 team to establish a baseline level of robotic performance possible and validate the competition rules. These validation trials were to be conducted at Camp Guernsey, WY, and would also serve to provide data to the USACE regarding robotic range clearance system performance for their planned robotic range clearance services IDIQ contract. During the week of 18-22 October 2010, the ARA JTEC group, with the University of Florida's (UF) Center for Intelligent Machines and Robots (CIMAR) lab, conducted the R2C2 validation trials.

The objectives of the validation trials were to validate the scoring criteria for the R2C2 competition and establish baselines for the scoring components (e.g., expected time and manpower requirements). These results were reported to the R2C2 Oversight IPT to serve as an empirical basis for modifying the scoring criteria and competition procedures, if necessary. The validation trials were held at Camp Guernsey's North Training Area, located north of Guernsey, WY, shown in Figure 6.

Figure 6. Map of Wyoming Showing General Location of R2C2 Ranges

ARA's JTEC group organized the logistics, prepared the ranges, integrated the automation hardware with the All-purpose Remote Transport System (ARTS) vehicles, instrumented the range boundaries with video, provided the system tele-operator, and supplied the human-machine interaction referee for the demonstration. The USACE's Andy Schwartz oversaw geophysical mapping tasks. Mr. Brian Skibba of AFRL/RXQE and Mr. Randy Williams of JGRE represented the R2C2 Oversight IPT and observed the trials. ARA's Northeast Division supported the baseline and demonstration geophysical mapping by providing their "Scout" geophysical mapping trailer system and the technical expertise to operate the sensors and data collection software. The University of Florida's CIMAR lab teamed with ARA to provide the hardware and software to automate the range clearance machinery. The validation trial participants are shown in Figure 7 with an autonomous ARTS, ARA's Scout Trailer, and a robotic Gyro-Trac mulching machine.

Figure 7. Attendees of the R2C2 October Validation Trials

The UF/ARA team acted as the notional competitor. The plan was to demonstrate some level of performance in all events in an effort to exercise the competition plan and to test the scoring plan. The UF/ARA team had a mix of autonomy levels. For geophysical mapping, they used a fully autonomous ARTS towing the ARA Scout trailer mentioned earlier (Figure 8).

Figure 8. ARTS Towing the Scout Trailer During the Geophysical Mapping Event

For the sub-surface clearance task, a tele-operated ARTS with a backhoe attachment was used. The system employed a GPS waypoint system to drive to the locations where the industry standard objects (ISO)s were buried, with the operator using tele-operation to accomplish the digging behavior (Figure 9).

Figure 9. The ARTS on the Sub-Surface Range Digging for ISOs

For the surface clearance task, a semi-autonomous ARTS system was used to tow a Cherrington beach cleaner (Figure 10). The ARTS again used GPS waypoint guidance for navigation and steering and tele-operation for the Cherrington functions.

Figure 10. ARTS with the Cherrington Beach Cleaner Attachment

For vegetation clearance task, the UF/ARA team used a fully autonomous GPS waypoint guided ARTS pushing a mowing deck for grass and small vegetation and a tele-operated Gyro-Trac mulching machine for trees. The outcomes of the validation trial confirmed that the facilities plan and the design of the competition ranges were appropriate for the competition and that the basic rules and metrics were appropriate to score the competition. The trials did point to some tailoring of the scoring criteria and other competition logistics issues. For a more complete description of the validation trial, (refer to Appendix B: Validation Trials). Some of the report's specific recommendations went in to the logistics planning for the actual competition. These included:

- The competitors will be given the opportunity to arrive at the competition 1 week prior to the start. They will be provided practice areas to fine tune and debug any last minute issues or failures of their systems during this time. For the competition they will then have their assigned time to complete the competition task. The only exceptions to this will be for weather, safety, or military priority issues that might delay or impede the competition activity.
- The dig map provided for the Sub-Surface UXO clearance tasks will include a "target strength value" to represent a realistic geophysical mapping product. The makeup of this value will be determined through consultation with Mr. Andy Schwartz, USACOE Geophysicist. In addition to assigning a weighted value to UXOs, we will not include the "small" type ISOs in Sub-Surface clearance ranges. However, we will keep the total number of ISOs at 50-60, or 25-30 Large ISOs and 30 Medium ISOs.
- A meeting between the JGRE director and Camp Guernsey Garrison Commander is suggested to discuss importance of this activity and commitment for a guaranteed level of lodging and support.
- The Oversight IPT should review the categories of human interaction to ensure that they reflect the intent of the competition. Currently, any automated behavior at all, no matter how little, results in 25% of the available human interaction points.

All of these issues were implemented or addressed for the actual competition.

3.7. In-Process Reviews

Each of the competitor teams were required to host in-process review (IPR) meetings. These meetings, held at the competitor team facilities, were designed to provide a status check on each team's safety preparations and evaluate the likelihood that they would be ready for the competition. The R2C2 Oversight IPT did not want to drive teams toward particular solutions, so part of the assessment was whether the teams' proposed solutions were going to fit within the rules, but not to judge their proposed solutions. At all IPR meetings, the R2C2 Oversight IPT members stressed that, while the nature of the tasks were range clearance, this was to be a robotics competition, which emphasized the automation of these tasks.

3.7.1. Teams D4C and UXOD Automation

Team D4C and Team UXOD Automation demonstrated a good understanding of the functional requirements and the equipment needed to perform tasks. At the time of the IPR visits, neither team had completed plans for doing subsurface clearance work due to challenges with reacquisition, method of excavation and separating seed items from excavated dirt. Both of these teams had complete geophysical operation plans based on extensive field experience and/or expert guidance. While autonomous control was readily possible, it was not clear at that point to what extent their equipment would be operated autonomously.

3.7.2. Sky Research

Team Sky Research's geophysical mapping plan was the most aggressive plan by proposing to build and integrate a waypoint following system essentially from scratch. Their team had established credentials in the geophysical mapping domain and appeared confident that they could succeed, but did not have any dedicated robots, engineers, and technicians on staff at that time.

3.7.3. General Observations

Team UXOD Automation appeared to have the greatest technical experience in robotic control, navigation and autonomous operations, but they were less experienced in actual field work. Team D4C appeared to have a better combination of technical and actual UXO field experience to successfully accomplish the competition tasks. Team Sky Research appeared to have an expertise advantage in the geophysical mapping task.

3.8. Logistics Effort

Hosting the competition required a large amount of logistical effort and equipment to facilitate the teams, judges, guests, and execution of the competition. The main base of control was a paddock set up to the northeast of the range area.

3.8.1. Paddock

The paddock was a fenced area that was the main control base for the competition (Figure 11).

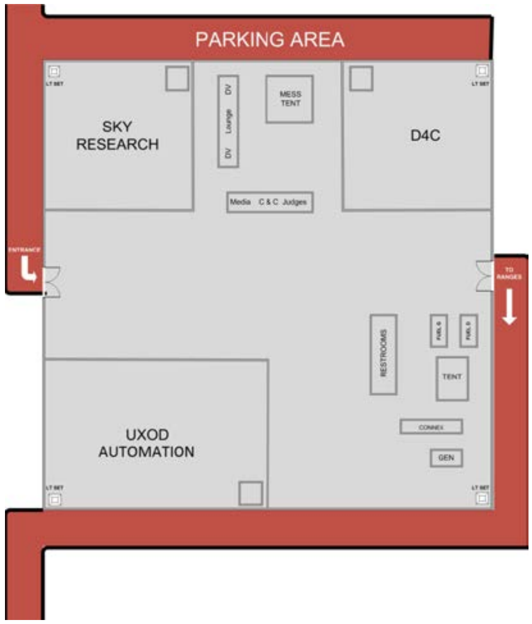


Figure 11. Diagram of the Paddock Layout

The teams and competition personnel worked in the paddock area when not on the ranges. Two hard sided work trailers were provided for command and control and judge's work space. The trailers had electricity, climate control, radios for communicating with personnel in the area, and served as the entry control point for teams to check in and coordinate movements with command and control. The paddock also included a mess tent where food was served. Three meals were served every day, with most days having the option of a hot lunch or sack lunch. Each team had a pit area where they stored and worked on their vehicles. Teams were provided with two tents in which to work, and power supplied from the main generator.

A large restroom trailer was rented for the paddock to provide adequate restroom facilities. The paddock also contained light towers for night work, fuel tanks for refueling competition vehicles, and gravel roads and paths. The compound was fenced and had a security guard each night to protect the competitor's equipment. Figure 12 shows the actual paddock area during the competition.

Figure 12. Paddock in Use during the Competition

3.9. Range Logistics

In addition to setting up and seeding the ranges with simulated UXO items as required by the rules, several logistical concerns were also addressed in preparation for the competition. Each range had a tent to work in, and a work trailer was placed at a central location for guests to view the operations. All personnel and equipment movement to and from the ranges was carefully controlled by command & control and each range boss.

3.10. Task List

The following is the high-level task list from the R2C2 integrated master schedule. The list illustrates the comprehensiveness of the preparation for the competition.

- R2C2 Competition Integrated Master Schedule
    - Assign staff to roles
    - Competition staff uniforms
    - Complete Environmental Assessment or Rec & Check
    - Team billeting/ Lodging
    - Competitor IPRs
    - Pass radios through spectrum management
    - Improve road network
- Create Competition Village
    - Hard-sided worksite trailer for R2C2 mgmt/support
    - Hard-sided worksite trailer for JGRE/Chief Judge/Distinguished Visitors
    - Mess tent
    - Maintenance tent
    - Command & Control trailer (JTEC Balboa)
    - Communications
        - Arrange for high-speed internet connections
        - Setup and test JTEC radio network
        - Setup Public Address System
    - Mens/womens latrines
        - Setup port-a-lets at each range
        - Setup main men/women latrine trailer by worksite trailers
        - Arrange for latrine servicing
    - Create Paddock
        - Survey paddock area
        - Install fencing
        - Position generators
        - Lighting trailers
        - Fuel Dump
        - Establish fueling area
            - Create fueling procedures
            - Plan daily fuel needs
- Create Competition Range Area
    - Signage

        - Arrange daily transportation to site
        - Meals
        - Emergency Medical Services
        - Construct Competition Ranges
            - Survey and mark range boundaries
            - Prepare ISOs and seed items
            - Seed ranges according to seeding and Quality Control (QC) plan
- Judge training
- Unloading
- Security
- Final Competitor Information Packets
    - Compile individual competitor information packets
    - Deliver to teams
- Competitor Practice
- Conduct Live Competition
    - Pre-competition briefing
    - Competitor safety checks
    - Team D4C Setup
    - Team D4C Geophysical Mapping
    - Team D4C Vegetation Clearance
    - Team D4C Surface Clearance
    - Team D4C Sub-Surface Clearance
    - Team UXOD Setup
    - Team UXOD Geophysical Mapping
    - Team UXOD Vegetation Clearance
    - Team UXOD Surface Clearance
    - Team UXOD Sub-Surface Clearance
    - Team Sky Research Setup
    - Team Sky Research Geophysical Mapping
    - Deliver meals according to daily schedule
    - Media and Distinguished Visitor Day

3.11. Required Equipment/ Supplies

The following list shows the equipment items that were needed for purchase or rental to illustrate what was needed to conduct the competition.

- Meals, kickoff dinner, snacks/drinks
- Water
- Signs
- Paddock Trailers
- Other paddock equipment: toilets, dumpster, fuel tanks, generators, lights, tents, fencing, con-ex, cords, spill kits, garbage cans, fire kits, rope, steel posts, gravel

- Command & control needs: Wifi Aircards, name tags, clocks, lightning detectors, furniture, Public Announcement (PA) system, Global Positioning System (GPS) supplies, Radios
- Services needed: Ambulance, security, electrician, fire truck
- Personnel clothing
- Tractor w/backhoe, mower, digger
- Rental Cars- Pickups, SUVs, Vans, and Fuel
- Tele-handler
- Motels, billeting
- Golf Carts
- Boundary cameras, trailers
- Sensor components
- Recreational Vehicles/Trailers for on-site lodging

3.11.1. The Competition Schedule

Once the number of competitors was finalized, the extent and time required for the competition was determined be two weeks including 5-7 practice days the week prior to the competition. The early August time frame was chosen because of the constraints at Camp Guernsey. Camp Guernsey is an Army National Guard staffed Joint Training facility and as such, on-Camp billeting is typically in short supply from May through the end of July. Table 1 shows the competition schedule that was originally proposed.

Table 1. Original R2C2 Schedule

Activity	Date	Time
Teams arrive at Camp Guernsey	31 July – 7 August 2011	varies
Practice site open	1-5 August 2011	0800-1700
Judges arrive at Camp Guernsey	3 August 2011	Varies
Judges training at site	4-6 August 2011	0900-1600
Safety Testing	6-7 August 2011	0900-1600
Opening Reception/Dinner	7 August 2011	1800-2000
Competition Events	8-10 August 2011	0600-1700
Media & Visitor Day	11 August 2011	0900-1400
Competition Events	12-13 August 2011	0600-1700
Final scoring and adjudication	14-15 August 2011	0800-1800
Personnel depart	16 August 2011	varies
Present Results at the Association for Unmanned Vehicle Systems International (AUVSI) conference	17 August 2011	1600-1700

The competition schedule began with a practice week (planned for Monday, 1 August through Friday, 5 August) followed by a day off on Saturday, 6 August. The competition was kicked off with a meeting and barbeque on Sunday, 7 August and the events running from Monday, 8 August through Saturday, 13 August. There were two overrun days built in to the schedule, the 14th and 15th of August, in case of inclement weather.

The only change to the schedule was the extension of practice week from the fifth of August through the afternoon of the seventh. The R2C2 competition director elected to extend practice week due to inclement weather delays during the scheduled practice week. In addition, the competitor teams all underestimated their need to practice and before they arrived on sight. As a result, all the teams were significantly behind schedule and unprepared for the competition at the end of the regularly scheduled practice week. The R2C2 had a two-day contingency built into the schedule (through the 19th) in case of more serious weather delays. Fortunately, the weather during competition week was good and the contingency weather days weren't needed.
The notional competitor schedule is shown in Figure 13.

Day/Team		Team 1	Team 2	Team 3
Aug 7	SUN	Safety Test	Safety Test	Safety Test
Aug 8	MON		MAP	VEG
Aug 9	TUE	MAP		
Aug 10	WED		VEG	MAP
Aug 11	THU	Media and Visitor Day		
Aug 12	FRI		SURF	SUB
Aug 13	SAT		SUB	SURF
Aug 14	SUN	Weather Days		
Aug 15	MON			

Figure 13. R2C2 Competition Week Schedule

Team 1 was Sky Research, Teams 2 and 3 were decided by a blind hat pull during the practice week. Team 2 was Team D4C and Team 3 was Team UXOD Automation. The daily event schedule is shown in Table 2.

Table 2. Daily Event Schedule

Activity	**Time**
Safety Brief	0545-600
Teams allowed on event site for range walk and setup/breakfast	0600-0800
Competition event begins	0800
Optional lunch break	varies
Competition event ends	1600-1700
Initial scoring and data validation, Documentary video editing	Endex-2100

Each competition event lasted 8 working hours from the event start with up to 1 hour of optional sustenance breaks for a total of 9 hours maximum. If team personnel worked on any equipment or computers during the sustenance break, that time was charged as working time.

3.11.1.1. The Competition Judges

The judging duties were distributed across six official judges for the competition.
They were:

- Chief Judge - Dr James Overholt – United States Army/ Tank and Automotive Research Development and Engineering Center (USA/TARDEC),
- Safety Judge – Mr. Lucas Martinez – United States Air Force/ Air Force Research Laboratory (USAF/AFRL),
- Autonomy Judge – Mr. Michael Bruch – United States Navy/ Space and Naval Warfare Systems Center – Pacific (USN/SPAWAR),
- Geophysical mapping Judge – Mr. Andrew Schwartz – United States Army Corps of Engineers (USA/USACOE),
- Task Judges – Mr. Walter Waltz USAF/AFRL and Mr. Plyer McManus USA/USACOE.

The duty of each judge was to oversee the events for their responsible areas and then to adjudicate the scoring for that event. Data collection assistants and field referees assisted the judges.

- The Chief Judge was responsible to supervise the judges, data collection assistants, and field referees, verify and validate the scoring of all events, and interpret the rules as applied to competition adjudication matters.
- The Safety Judge was responsible to conduct and supervise all of the safety tests, verify and validate the safety test methods, and observe all of the team events to judge any perceived safety violations or issues.
- The Autonomy Judge was responsible to supervise the autonomy data collection assistants and observe all of the team events and related autonomy data to judge the level of autonomy of the robotic systems.
- The Geophysical mapping Judge was responsible to supervise the geophysical mapping data collection assistants, verify the condition of the event site, observe all of the geophysical mapping events, collect the geophysical mapping data from the teams, and process/calculate the geophysical mapping data to judge the performance to the rules.
- The Task Judges were responsible to supervise the data collection assistants, verify the condition of the event sites, observe all of the team events, inspect the condition of the sites and debris/collection areas post event, and to judge the task performance for each event.

3.11.1.2. R2C2 Team

The R2C2 team (Figure 14) included the Director of the JGRE, Mr. Rob Maline; his support from Booz Allen Hamilton; the competition judges; the competition Director; the safety assessment team made up of members of Wintec Inc.; the video production team made up of members of Integration Innovation, Inc. and the ARA/JTEC group.

Figure 14. The R2C2 Team

3.11.2. Preparing the Ranges

An overhead layout of the practice and competition ranges can be seen in Figure 15. Individual practice ranges were constructed for each competition task and designated to each team (denoted by the prefix P1, 2, and 3). For the actual competition, each team was assigned their own vegetation clearance, surface debris, and sub-surface clearance range (denoted by the prefix R1 & 2). All teams used the same geophysical mapping competition range for the geophysical mapping task.

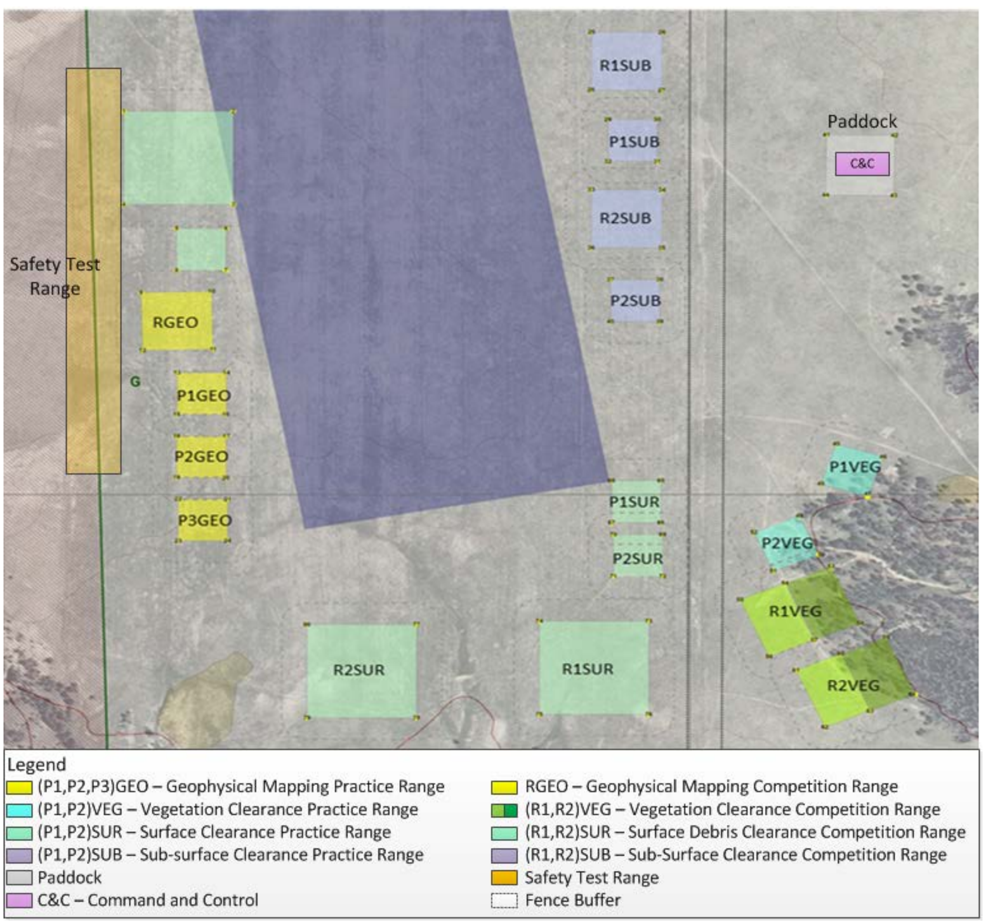


Figure 15. R2C2 Competition Map Overview

The ranges were allocated as follows:

- P1(GEO, SUB, SUR,VEG) & R1(SUB, SUR, VEG) – Team UXOD Automation
- P2(GEO, SUB,SUR, VEG) & R2(SUB, SUR, VEG) – Team D4C
- P3GEO – Team Sky Research
- RGEO – All Teams

3.11.2.1. Vegetation Clearance Ranges

The vegetation clearance ranges were collocated near each other to best represent one another in terrain and vegetation variation. Although the vegetation ranges were not identical, they were constructed in a manner to ensure no competitor had an advantage (Figure 16 shows these ranges).

Each range contained an equal amount of grass/brush for mowing and the same number of trees to be removed. The vegetation clearance ranges comprised of a 3-acre plot. The first half was relatively flat and predominantly covered with grass, while the second half lay on a slope with ravines and variations of vegetation (grass, shrub, and trees).

Team D4C Mowing Area — Team UXOD Automation Mowing Area

Team D4C Tree Removal Area — Team UXOD Automation Tree Removal Area

Figure 16. Mowing and Tree Removal Areas of Vegetation Clearance Ranges

3.11.2.2. Geophysical Mapping Range

All teams shared the same geophysical mapping range (Figure 17) during the competition. The geophysical mapping range was constructed over an area of 1.6 acres. Two obstacles were placed within the area reducing the required coverage area to approximately 1.58 acres. One hundred and twenty six ISOs (63 small, 58 medium, and 5 large) were buried in known locations throughout the range according to the R2C2 Geophysical Mapping Range Seeding Work Plan and QC Plan document. All pipe sections were buried in a vertical orientation, which produced a single mono-pole anomaly in horizontal loop electromagnetic induction metal detectors. These seed items can be seen in the right side of Figure 17. Later during the competition, the geophysical mapping range was reduced by approximately 25% to better meet the R2C2's objectives of having all competitors complete a designated area within the allotted time.

Figure 17. Common Geophysical Mapping Range and ISO Seed Items

3.11.2.3. Surface Clearance Ranges

The surface clearance ranges were located adjacent to each other to minimize variations in terrain to the extent possible. The surface clearance ranges were both comprised of five acres with two railroad tie obstacles each (Figure 18 shows what these ranges looked like.)
Each range was mowed in preparation for seeding and was seeded with 120 small ISOs, 120 medium ISOs, and 310 standard pieces of steel plate and steel angle.

Figure 18. Surface Clearance Ranges: Team D4C Range (left); Team UXOD Automation Range (right)

The seeding was randomly distributed to simulate a real impact range with UXO and target debris. The seed items can be seen in Figure 19.

Figure 19. Surface Clearance Range Seed Items (ISOs and Steel Plate and Angle)

3.11.2.4. Sub-Surface Clearance Ranges

The sub-surface clearance ranges were also located adjacent to each other to minimize variations in terrain to the extent possible. The sub-surface clearance ranges were both two acres (Figure 20).

Each range was mowed and then seeded with 25 large ISOs and 25 medium ISOs in a grid pattern. The ISOs were buried in the same manner as the ISOs for the Geophysical Mapping Range. All of the ISO locations, depths, and orientations were recorded. Two weeks prior to the start of the competition, the teams were provided the seed item locations in Universal Transverse Mercator (UTM) coordinates.. This information included “shapefiles” of their ranges, a dig list for their sub-surface range, and descriptions for nomenclature and file naming conventions. The dig list information included approximate ISO size information, approximate depth range, local UTM dig coordinates, and horizontal error information (30 cm).

Figure 20. Sub-Surface Clearance Ranges: Team D4C Range (left);
Team UXOD Automation Range (right)

3.12. Safety Test Requirements

Before each team could begin any operations on the practice ranges and participate in the competition, they were required to demonstrate their robotic systems met all of the R2C2 safety requirements.. The following safety requirements for each of the competitor’s robotics system were observed and evaluated with a pass or fail according to the "R2C2 Competition Rules and Metrics Document" found in Section 3 of the R2C2 Rules and Metrics (Refer to Appendix A).

Emergency Stop: The system shall have an Emergency Stop (E-Stop). The system must halt within 15 meters and cease all equipment operations when the E-Stop is initiated.

Warning Devices: Each vehicle shall be equipped with a warning light that is activated according to the state of the E-Stop system. Each vehicle shall display one or more flashing amber warning lights, the combination of which results in visibility 360 degrees azimuthally around the vehicle. The warning light(s) shall operate when the vehicle is not in an E-stop state, i.e., RUN mode. The vehicle may not commence movement until the warning light(s) has been in operation for 5 seconds. The warning light(s) shall comply with SAE Class 1 standards for warning lights and shall not produce light(s) than can be confused with those of public safety vehicles such as law enforcement, fire, or ambulance.

Loss of Communications Stop: The system shall automatically halt and cease operations if communications with the system are lost or interrupted for a maximum of 2 seconds and may travel no farther than 30 meters.

No Freewheel: The systems shall not be capable of motion when stopped or un-powered. For example, systems that would roll downhill if shut off are considered freewheeling and are un-safe for competition.

If a test was failed, the team was allowed to address the problem and retest the system until it passed given that there was sufficient time left in the competition schedule, and that the R2C2 director was satisfied that the system performance was repeatable.

If a competitor had made any significant hardware or software changes anytime during the competition they were required to re-qualify that particular robotic system to meet all R2C2 safety requirements. Hardware and software changes were defined as the following:

- Hardware changes – Any hardware configuration changes to the robotic system that could render it unsafe during static and mobile operation; changing tool implements (like tree-cutting shears, buckets, mulching heads, etc.) were not considered a qualifying change as long as they were an OEM or aftermarket part designed for the system. Electrical hardware changes such as electronic sensor and control modules that were part of the robotic control system were considered to be significant changes and would require a retest.
- Software changes – Any software source code change that could compromise the safety of the robotic system according the R2C2 safety metric. The teams were required to report any software changes for the R2C2 management to evaluate and determine if a retest was required.

A sample of the safety evaluation forms are found in Appendix G: Safety Evaluation Form.

3.12.1. Safety Test Setup

All of the safety requirements except the freewheel test were conducted at a distance of 800 meters away from the operator control unit (OCU). The tests (e-stop, loss of communications stop, and warning devices) were conducted at this distance because each robotic system was required to be operable from 800 meters. This requirement was intended to replicate the work constraints of a real-world robotic range clearance operation, where personnel must be located at a remote area to provide a safe standoff from the blast fragmentation radii of UXO.

3.12.1.1. Safety Base Equipment Setup

Figure 21 illustrates how the safety range and equipment was setup to validate each competitor's robotic system. An enclosed trailer was used to house the competitor's OCU, the safety test equipment, radio frequency (RF) communication system, 120VAC generator, and provide shelter from adverse weather conditions.

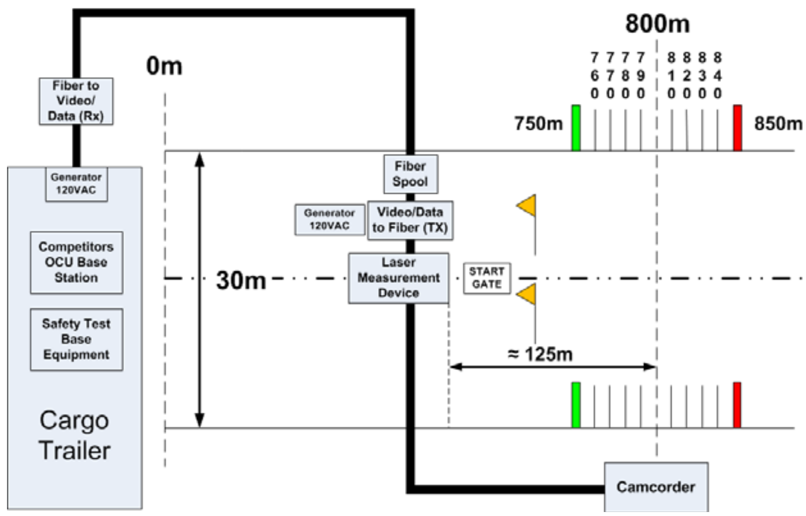


Figure 21. Safety Test Setup

The test equipment was built into a pelican case enclosure containing a fiber optic media converter, customized electronics and firmware entitled "RX". This system controlled the power provided to the competitor's RF communications link used for the "loss of communications stop" test. The RX box was used to acquire the laser data measurements and display real-time information onto two monitors for the tests conducted downrange. The monitors were setup inside the trailer to allow the safety officer to easily observe and evaluate the tests. Additionally, each test was recorded onto a digital video recorder (dvr.) file to review any disputes protested by the competitor, and for record and review by the safety officer. Figure 22 shows the trailer where the tests were observed.

Figure 22. Safety Testing OCU Base Station(left); RX Box Video Output

3.12.2. Downrange Test Equipment

The safety test equipment located downrange comprised of a 120VAC generator, laser altimeter, a second pelican case entitled "TX" that housed a fiber optic media converter with RS-232 data and video input for the laser data and test video, respectively. The data was hardwired via fiber optic cable, which was transmitted to the RX box located at the base station. A laser altimeter, being used as a rangefinder, was used to accurately measure the distances travelled for the e-stop and loss of communications stop test. The laser altimeter was mounted on a tripod and bore-sighted prior to the competition. Figure 23 shows the test equipment setup in the field and the laser altimeter on the tripod.

Figure 23. Downrange Test: Test Equipment Setup (left); Laser Ranger Finder (right)

3.12.3. No Freewheel Test

The no freewheel test site was located on a hillside next to the safety test base station. The hillside worked well as it naturally met the 10-12 degree slope for the test requirement (Figure 24).

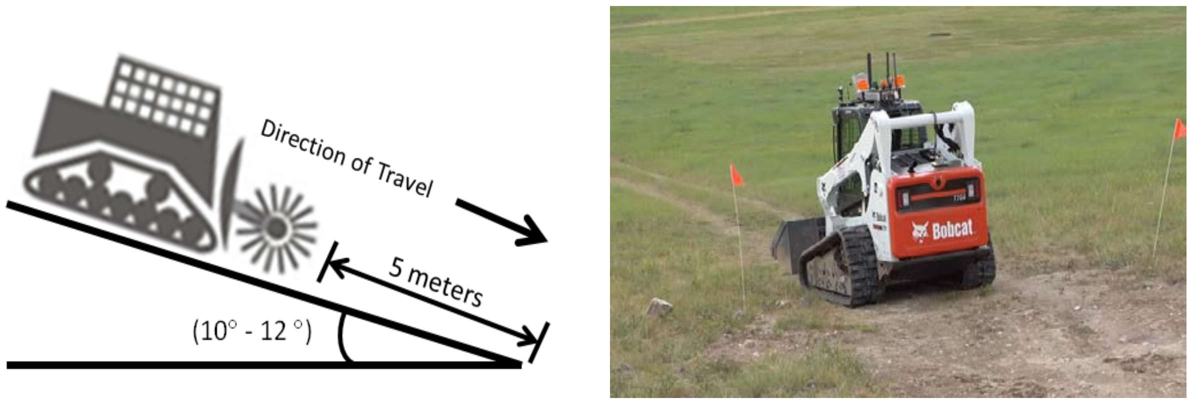


Figure 24. No Freewheel Test: Diagram (left); Vehicle on Freewheel Test Hell (right)

3.13. Team Arrival and Practice Week

Teams began arriving at Camp Guernsey on 1 August 2011. Upon arrival to Camp Guernsey each team checked in with the JTEC office to pick up their final competition information packets and their room keys. All of the competitor team members were provided lodging at Camp Guernsey. The packets included R2C2 staff contact information, medical and safety contact information, competition schedule, directions to the competition site, important Camp Guernsey regulations and procedures, and general information about area eateries, stores, gas stations, pharmacies and hospitals. The packet is included in Appendix B.

After check in, each team transported their equipment to the competition paddock area, unloaded their equipment and positioned it in their designated pit areas. The competition director and the safety judge conducted walk around inspections to access the overall safety features of the robotic systems such as warning lights, e-stops, etc.

Before each R2C2 competitor could begin operating on the practice ranges and participate in the competition, they were required to demonstrate their robotic systems could meet all of the R2C2 safety requirements at the safety test range. If a vehicle failed a test the competitor was allowed to modify their systems and rerun the tests as often as needed, but would have to pass all safety requirements before being allowed to practice and compete.

The competitors' robotics systems were tested and observed for the following safety requirements and evaluated with a pass or fail according to the Rules section of the “R2C2 Competition Rules and Metrics Document" found in Appendix A.

4. COMPETITION RESULTS AND DISCUSSION

4.1. Safety Test Results

The safety tests were completed successfully for all robotic vehicles, prior to competition. Most of the system's testing was completed prior to the practice events and since no significant changes were made most systems did not have to be re-qualified. Team Sky Research's system failed the initial no free wheel test and had to have the brake actuation system modified. This system passed this test successfully with the modification. Team UXOD Automation made a significant hardware change to their feller buncher system by adding a large external generator to it between the surface clearance and sub-surface clearance events. Due to this change, they were required to complete all safety tests for this system again. This was accomplished the day prior to their sub-surface clearance event and the system successfully passed all the tests in the new configuration.

4.2. Competition Site Access

The teams were not allowed access to the event ranges until the morning of the event. Starting at 0600 the competing team was allowed to begin setting up their equipment on the event range and conduct a site walk. They were allowed to survey the terrain, and measure items of interest such as trees, ravines, boundaries, etc. however, they were not allowed to physically mark anything within the boundary. The competitors also used this time to set up their operational area and ready their machines to begin the competition at 0800.

Competition time was planned for 0800-1700 and would be offset pending any weather interruptions. Each team was allotted 8 hours of operational time and along with an optional one-hour break (for lunch, rest, etc.) if the competitor deemed necessary however during break times, no maintenance or robotic activity could be performed.

In order for a team member to go down-range, they would have to E-Stop all robotic systems and request permission from the competition director. This simulates the real-world operation of requesting Explosive Ordnance Disposal (EOD) escort support prior to entering any UXO range area. Any time used during a down range event counted against the overall 8-hour runtime allotted.

In the event an E-Stop was initiated by any of competition staff (judges, range boss, director, etc), time was stopped for the competitor until the situation was assessed and operations were authorized to resume either by the Range Boss, Task Performance Judge or Competition Director.

4.3. Media and Visitor Day

A media and visitor day was conducted on Thursday August 11, 2011 to provide the opportunity for the teams to describe and demonstrate their technologies to interested parties and potential military users. Over 100 people attended the events including representatives from the Army, Air Force, law enforcement, academia, participating companies, elected officials, local business leaders, and a middle school Lego Robotics league team. Major General Luke Reiner, USA, Adjutant General for Wyoming & Commander Wyoming National Guard, was the ranking military member in attendance. BG Harold Reed, USAF, Chief of Staff for the Wyoming Air National Guard was also in attendance. Reporters representing regional media outlets covered the event including: K2TV - ABC Affiliate Casper, Wyoming, the Platte County Records Times, and the Lusk Herald.

The teams each had time to describe their systems and technologies to the group and then demonstrate the systems in action. The teams were provided an area to demonstrate all the events they competed in. To accommodate the demonstration, 3 previously felled trees were “planted” for each of the vegetation clearance competitors to cut down. This was accomplished by boring a large hole with an auger and then inserting the base of fallen tree in to the hole like a telephone pole so it would stand upright. After the demonstrations, the visitors were taken on a window tour of the actual competition sights before departing (Figure 25 and Figure 26)

Introductions and Welcome

Team UXOD Media Interview

Team UXOD presentation

Team UXOD Demonstration

Figure 25. Media & Visitor Day Photos

Team D4C presentation

Team D4C Demonstration

Team SKY Research presentation

MG Reiner & BG Reed talk with Mr. Skibba and Dr Overholt

Figure 26. Media & Visitor Day Photos

4.4. Vegetation Clearance Event Results

4.4.1. Competing Teams

The two teams that competed in the Vegetation Clearance event were Team D4C and Team UXOD Automation. Team Sky Research did not participate in this event.

4.4.2. Task Description

The vegetation clearance task of the R2C2 was designed to simulate a real-world UXO clearance activity as closely as possible and allow for scoring. Vegetation clearance is typically one of the initial tasks completed to prepare a site for the surface clearance, geophysical mapping, and sub-surface clearance. This vegetation typically includes all trees, bushes, grass, etc. Typically, for a real world operation the vegetation must be cut low enough to allow for the final intended use of the range or to enable the next operation in the range clearance process. This may be to just provide line of sight to a target or to provide access for surface clearance and geophysical mapping.

For the purpose of this competition, the trees were required to be cut down to 8cm or less in height and all vegetation debris either removed from the sight or mulched to 15cm or less in height. The event score was determined by measuring the height of the tree stumps and vegetation residue left on the event range. Points were deducted for each tree or stump remaining greater than 8cm above the surrounding grade and any remaining vegetation or vegetation residue greater than 15cm above the surrounding grade.

For the vegetation clearance task, the teams had eight hours to clear a five-acre site of 50 trees and mow all of the remaining vegetation down to a height of 15cm or less. Tree stumps had to be 8cm or lower and felled trees had to be either removed from the site or mulched in place to less than 15cm' depth.

4.4.3. Team UXOD Vegetation Clearance

Team UXOD Automation conducted the vegetation clearance task using a robotic John Deere Skid Steer and feller buncher. These normally manned systems were converted to remote control using a Kairos Autonomi robotics kit with Autonomous Solutions Mobius system being used for command and control.

Team UXOD accomplished this task by using a combination of teleoperation and semi-autonomous driving using both their skid steer w/grappling attachment and feller buncher. An operator would teleoperate the machines during the more difficult tasks such as aligning, capturing and cutting down a tree. Then the robot would take over a use waypoint driving to semi-autonomously carry the tree back to a collection point where scripted behaviors were used to dump the tree and then drive back to the next tree to be cut (Figure 27). The skid steer was used after the mowing task was complete during the vegetation removal operation.

Figure 27. Team UXOD Feller Buncher & Skid Steer Vegetation Removal

For the mowing task, the Team UXOD robotic skid steer system was comprised of a flail mower mounted on the front to grind up midsize vegetation such as shrubs and a towed array of mowers attached to the rear to cut the grass and remaining vegetation remnants. The skid steer was autonomously controlled using a Zamboni pattern to cover the area (Figure 28). Team UXOD Automation successfully cut and removed all the trees and completed the mowing task, although their large feller buncher did leave some heavy ruts which cost them some points for the surface damage category (Figure 29).

Figure 28. Team UXOD Skid Steer Mowing Task Operation

Figure 29. Team UXOD Surface Damage

For the most part, their system of systems performed very well and they efficiently were able to mow the small vegetation and cut trees simultaneously running both the robotic skid steer and feller buncher at the same time. However, they did have some difficulties which cost them time in completion of the task to recover and reset their systems.

The first incident was when the feller buncher engaged a tree too hard causing the top half of the tree to break and fall onto the top of the feller buncher (Figure 30). The tree dislocated the communication antenna causing the system to lose communications and cease operations per the safety design. As per the event procedures all operations on this range were halted and the R2C2 staff inspected the system to make sure it was safe to allow team UXOD to initiate recover of the system. The system was found to be stable and team UXOD was given permission to remove the tree, fix and recover the feller buncher system. The event clock was paused during the R2C2 staff inspection and was restarted as soon as the team was notified that they could proceed with the recovery operations. The damage to the system was minor and was fixed by team UXOD replacing the antenna cable and reattaching it to the machine (Figure 31).

Figure 30. Team UXOD Feller Buncher Loss Communications Incident

Figure 31. Team UXOD Communication Antenna Repair

The second incident occurred when Team UXOD's robotic skid steer was using the flail mower to mow the hilly area between the trees (Figure 32). The system was being teleoperated at the time and the operator was driving downhill with the flail in the raised position. The system tilted forward and came to rest against the flail due to the forward center of gravity that this configuration imposed on the system. They were unable to upright the system remotely so the event was halted for a second time for the R2C2 staff to determine that the situation was safe and stable. Again the situation was safe, the event clock was restarted and team UXOD given permission to recover the vehicle. They manually used their feller buncher system to pull the skid steer upright so a technician could enter the cab and lower the flail. Both systems were reset to their approximate positions when the event happened and robotic operations were allowed to resume once all personnel were safely off the range and in the designated crew or observer areas.

Figure 32. Team UXOD John Deer Skid Steer Roll-over Incident

Team UXOD used the entire 8hrs to complete this task and exceeded their allotted man-hours by 8 hours since their program manager joined the crew to assist in the recovery operations. They achieved a total score of 158.62 out a possible 250 points. Detailed scoring sheets are shown in Table 3.

Overall their systems did a good job of achieving the event goals of cutting trees to less than 8cm in height and mowing the vegetation and vegetation residue to less than 15cm in height. The feller buncher system was very fast and efficient, but it was difficult for them to quickly cut the stumps to less than 8cm in height. The feller buncher had skids that kept the cutter head 10cm off the ground (Figure 33). In order to achieve the required stump height they had to tilt the head up at an angle and dig the skids into the ground on both sides of the tree. This slowed the operation significantly and cost them time to finish the task. Their combination flail mower in front of the skid steer towing an array of finish mowers behind did an excellent job of mowing the grass and brush areas. The flail mower broke up all the large items and rocks and the finish mowers cut the remaining residue and vegetation to a consistent height. The system was operated entirely in GPS waypoint mode for this part of the task and performed very well driving straight consistent patterns over the subject area.

Figure 33. Team UXOD Feller BuncherTree Stump Cut

Table 3. Team UXOD Vegetation Clearance Scores

Team UXOD Automation			
Vegetation Clearance Event Score	**158.62** out a possible **250** points		
Metric Categories	Total for each Metric	Weight	
System Task Performance	203.83	50%	
Level of Human Interaction	91.75	40%	
Man Hours to Perform the Task	200.00	10%	
Competition Level Metrics	Points/Violation	Violations	Total
Perimeter or No-go area violation	50	0	0
Exclusion zone violation	DQ		
Surface (>15cm)	2	8	16
Surface grade (>15cm)		0	0
Total Penalty			16
System Task Performance (250) Points	203.83		
	Possible Points		
Vegetation Tree Removal (>8cm)	115.25		
Vegetation Residue Removal (>15cm)	104.58		
Level of Human Interaction (250)	91.75		
	Possible Points	(from Human Interaction Judge)	
Description of Level of Human Interaction	250		
Near zero human interaction	100%	63%	
Minimal interaction	75%		
Moderate Interaction	50%		
Frequent Interaction	25%		
Continuous Interaction (completely tele-operated)	0%		
Man Hours to Perform the Task (250) Points	200.00		
		Start Time	End Time
Elapsed Time	8:00:00	8:00:00	16:00:00
Number of people on site	5		
Total Man-Hours	40.00		
Man Hours Allotted	32		

4.4.4. Team D4C Vegetation Clearance

Team D4C used two Bobcat skid steer loaders controlled by the QinetiQ Robotic Control Kits for the vegetation clearance task. They employed a tree shear on one system while the second system used a brush mower over the non-treed area (Figure 34 and Figure 35). Like Team UXOD Automation, Team D4C used teleoperation for the more difficult chores, such as engaging and cutting the trees and autonomous waypoint driving for the simpler tasks of mowing the open areas and travel to and from the collection area. Team D4C successfully cut and removed all the trees to the specification and completed the mowing task while leaving no damage on the site.

Figure 34. Team D4C Bobcat Tree Sheer

Figure 35. Team D4C Bobcat Mower

The Team D4C solution was very efficient and smooth. The operators seemed to be well practiced and was extremely efficient in cutting down the trees and carrying them to the collection pile. The process they used was to drive to a spot near the tree using waypoint guidance, switch to teleoperation and have the operator engage the tree and cut it with the shear. After the tree was felled, the operator used the open shear to straddle and grab the butt of the tree and then either teleoperate or waypoint drive the system to the collection pile and dump the tree.

While this was being done, the second Bobcat robotics skid steer was performing the mowing task using a rough cut field mower on the front of the skid steer system. The mowing was accomplished using GPS waypoint driving. The rough cut mower did not cut as cleanly as the Team UXOD finish mower, but its final product was sufficient to meet the requirement. Once the mowing task was complete, the mower deck was removed and a grapple attachment placed on the 2nd Bobcat skid steer. This allowed the team to speed up the tree cutting process as the tree shear equipped robot could concentrate on just cutting trees and the grapple robot could move them to the collection pile (Figure 36). This required a 2^{nd} operator to teleoperate the system during the grapple engagement and dumping. The travel to the pile was still completed using GPS waypoint driving.

After all trees were removed, a mulching head was attached to the 1st Bobcat and the mower deck was put back on the 2nd Bobcat and then used to clear midsize vegetation such as small trees and shrubs, and mow in between the tree areas until the time had expired, respectively (Figure 37). Team D4C had no incidents which caused them to have to recover their systems. They also used the entire 8 hrs to complete the task but did not exceed their allotted man-hours. They achieved a total score of 177.38 out a possible 250 points. Detailed scoring sheets are shown in Table 4.

Figure 36. Team D4C Bobcat Grapple

Figure 37. Team D4C Bobcat Midsize Vegetation Removal and Mowing

Table 4. Team D4C Vegetation Clearance Scores

Team D4C			
Vegetation Clearance Event Score	**177.38** out a possible **250** points		
Metric Categories	Total for each Metric	Weight	
System Task Performance	235.17	50%	
Level of Human Interaction	87.00	40%	
Man Hours to Perform the Task	250	10%	
5			
Competition Level Metrics	Points/Violation	Violations	Total
Perimeter or No-go area violation	50	0	0
Exclusion zone violation	DQ		
Surface (>15cm)	0	0	0
Surface grade (>15cm)		0	0
Total Penalty			0
System Task Performance (250) Points	235.17		
	Possible Points		
Vegetation Tree Removal (>8cm)	123.50		
Vegetation Residue Removal (>15cm)	111.67		
Level of Human Interaction (250)	87.00		
	Possible Points	(from Human Interaction Judge	
Description of Level of Human Interaction	250		
Near zero human interaction	100%	65%	
Minimal interaction	75%		
Moderate Interaction	50%		
Frequent Interaction	25%		
Continuous Interaction (completely tele-operated)	0%		
Man Hours to Perform the Task (250) Points	250.00		
		Start Time	End Time
Elapsed Time	8:00:00	8:00:00	16:00:00
Number of people on site	4		
Total Man-Hours	32.00		
Man Hours Allotted	32		

4.4.5. Comments

The following comments are based from the event judge Walt Waltz:

1) The flail mower used by UXOD was not very effective when used alone in this type vegetation. The west surface area was mowed exceptionally well where the flail mower

was used in conjunction with lawn mowers. The only damage occurred in grid 29 was a result of the feller/buncher's cutting head contacting the ground while moving.

2) The feller buncher was used in a downhill cutting approach resulting in a tipping of the head to try to achieve the lowest cut possible. It would be interesting to see how the cut would be from an uphill perspective. When the cuts were made, there appeared to be significant vehicle travel after the cut was made due to momentum or possible reaction time of the operator. An uphill cut might be more controllable.

3) The skid steer behavior after initiating auto-travel mode was very oscillatory often sweeping the vehicle very severely. Further work to smooth this motion is needed.

4) The footprint of the track vehicles used rendered very little surface damage in either competitor's areas, especially team D4C as no surface damage was measured. The majority of the surface damage was a result of the large feller buncher tires.

Overall:
Team UXO-D got off to a slow start and didn't appear they would achieve the objective of removing all 50 trees. Only four to five trees were removed in the first two hours where team D4C had over 20 trees cut and felled but not yet removed from the operational area. It was clear that UXO-D's operator was improving significantly by cutting and removing two or three trees at a time and made up significant time by mid afternoon. It was also obvious that team D4C's operator was very skilled and his methodology of cutting, falling and dragging his trees to the top of the hill was very effective. A significant amount time was used with the feller buncher in traversing the cut trees up over the hill to the designated dumping area. This might have been sped up using their skid-steer (V2) more in the removal process with the grapple bucket.

Using the flail-mower without the other mowers also didn't do very well on the grassy vegetation. An alternative attachment like the mulching one used by D4C would have been more effective reducing stump height and smoothing the surface damage. D4C spent significant time to mulch and back-drag their entire hill area which resulted in no violation points for surface damage and only two minor tree-stump violations.

4.5. Surface Clearance Event Results

4.5.1. Competing Teams

The two teams that competed in the Surface Clearance event were Team D4C and Team UXOD Automation. Team Sky Research did not participate in this event.

4.5.2. Task Description

The surface clearance task of the R2C2 was designed to simulate surface debris removal from target impact zones. For the purpose of the competition only ferrous debris were used to simulate typical artillery and mortar ordnance scrap and allow for effective scoring. On a typical target range there is a great amount of ordnance scrap, in addition to the UXO items left on the surface that must be removed prior to surveying the area with detection systems. This scrap can be from a variety of sources including: range targets, munitions debris/fragmentation, and unexploded ordnance (UXO). A large part of the debris field consists of ferrous metal objects that magnetic collection devices will retrieve, however most real world sites contain non-ferrous materials as well. For the competition, the surface field was only seeded with only ferrous items of interest (IOI), including two fixed obstacles to simulate targets like tanks, vehicles, etc.

The purpose of this event was for each team to collect as many of the seeded ferrous objects as possible and deposit them at the designated collection area. The collection piles were scored for pile cleanliness as well as the number of items recovered. Therefore it was important that the teams chosen method minimized the collection of non-scrap objects such as vegetation, soil, and rocks. This is due to the fact the explosive ordnance disposal technicians have to go through the collected debris, and it is much more dangerous if the items have to be separated from contamination such as dirt and vegetation.

The IOIs consisted of a mix of two pipe diameters, three angle iron types and two sizes of flat plate. 550 IOIs were randomly deposited throughout the range area and a few were randomly depressed into the soil (Figure 38). Competitors could use a variety of techniques such as magnets, surf rakes, etc to collect these items and transport them to the designated collection area.

Figure 38. Industry Standard Objects of Interest

4.5.3. Team UXOD Surface Clearance

Team UXOD Automation once again employed a multiple robotic solution for the surface clearance task. They used their Kubota UTV to tow a permanent magnet trailer and the skid steer to carry the electromagnet system and generator. Both systems used waypoint driving and scripted behaviors for the majority of this work (Figure 39 and Figure 40).

Figure 39. Team UXOD Automation Robotic Solutions for Surface Clearance


Figure 40. Team UXOD Automation Robotic Solution for Surface Clearance

Team UXOD started with just the Kubota UTV operating until it had several passes complete to get a head start and some clearance from the 2nd robot the John Deere skid steer with the electromagnet. They used a down and back modified zamboni pattern. This approach was very successful eventually recovering 393 of 550 items (Figure 41). The electromagnet was much more effective at collecting and holding the items than the weaker permanent magnet system. However, their two-robot solution worked against them as the second robot –the skid steer - drove over the items the first robot left in the collection area, causing them to lose many points for pile cleanliness. They achieved a total score of 161.86 out of a possible 250 points. Detailed scoring sheets are shown in Table 5.

Figure 41. Team UXOD Collection Piles of Surface Clearance Task:
Clean Collection Pile (top); Buried IOI's (bottom)

In addition they had one incident that cost them time when their Kubota UTV robot system drove into a natural swale that was part of their surface range area. The operators monitoring the system became alarmed and e-stopped the system when they observed the system rapidly tip nose down as it entered the swale. They tried to teleoperate the system to back out of the swale but could not exit that way as the system could not get enough traction. Eventually, they teleoperated the system through the swale and up and out the other side where it resumed its course and waypoint driving pattern.

It should be noted that all teams had two hours prior to the start of the event to walk the range and note any features to incorporate into their plan. They were also provided detailed map coordinates for their event areas two weeks prior to the event. Team UXOD did not take sufficient advantage of this time and map data to plan for the natural features so their system's would not encounter problems with terrain that they could not handle. In addition, all teams were encouraged to incorporate obstacle detection and avoidance technologies and choose not to do so. On real world UXO ranges the terrain is composed of many impact craters and irregularities from the ordnance items that must be planned for or negotiated by systems with suitable mobility.

Table 5. Team UXOD Surface Clearance Scores

Team UXOD				
Surface Clearance Event Score	**161.86** out a possible **250** points			
Metric Categories	Total for each Metric	Weight		
System Task Performance	154.3	50%		
Level of Human Interaction	149.25	40%		
Man Hours to Perform the Task	**5.** 250	**6.** 10%		
Competition Level Metrics	Points/Violation	Violations	Total	
Perimeter or No-go area violation	50	0	0	
Exclusion zone violation	DQ			
Surface (>15cm)	0	0	0	
Surface grade (>15cm)		0	0	
Total Penalty			0	
System Task Performance (250) Points	154.32			
	Possible Points	Score	number of seeded items	number collected
Percent of debris removed	125	89.32	550	393
Pile cleanliness	125	65.00		
Level of Human Interaction (250)	149.25			
	Possible Points	(from Human Interaction Judge)		
Description of Level of Human Interaction	250			
Near zero human interaction	100%	40.3%		
Minimal interaction	75%			
Moderate Interaction	50%			
Frequent Interaction	25%			
Continuous Interaction (completely tele-operated)	0%			
Man Hours to Perform the Task (250) Points	250.00			
Elapsed Time	8:00:00			

Number of people on site	5		
Total Man-Hours	40.00		
Man Hours Allotted	40		

6.1.1. Team D4C Surface Clearance

Team D4C employed just one of their robotic Bobcat systems with a permanent magnet mounted to the skid plate to sweep the site (Figure 42). This task was completely waypoint driven with scripted behaviors for the dumping of the collected items. They used a “U” shaped pattern that was very effective for minimizing travel distance and allowing them to cleanly dump their debris at both ends of the pattern. It was important to minimize carrying the collected items any further than needed as the terrain or machine vibrations could knock off some of the items from the magnet face. Their permanent magnet only solution was not as effective as the electromagnet that Team UXOD used, but team D4C completed the sweep in less than the full eight hours and recovered 243 of the 550 items with very clean debris piles (Figure 43).

Figure 42. Team D4C Bobcat Solution for Surface Clearance

Distribution A: Approved for public release; distribution unlimited. 88ABW-2012-5009, 19 September 2012.

Figure 43. Team D4C IOI's Collection Pile

They did not have any interruptions once the event started and the system ran well on its own with just monitoring by the operators through the whole operation. They achieved a total score of 191.91 out of a possible 250 points. This is due to half of the score for both the surface and subsurface clearance tasks were for collecting all of the seeded items, and the other half was for clean debris piles. Detailed scoring sheets are shown in Table 6.

Table 6. Team D4C Surface Clearance Scores

Surface Clearance Event Score	**191.91** out a possible **250** points			
Metric Categories	Total for each Metric	Weight		
System Task Performance	178.23	50%		
Level of Human Interaction	194.5	40%		
Man Hours to Perform the Task	250.00	10%		
Competition Level Metrics	Points/Violation	Violations	Total	
Perimeter or No-go area violation	50	0	0	
Exclusion zone violation	DQ			
Surface (>15cm)	0	0	0	
Surface grade (>15cm)		0	0	
Total Penalty			0	
System Task Performance (250) Points	178.23			
	Possible Points	Score	number of seeded items	number collected
Percent of debris removed	125	55.23	550	243
Pile cleanliness	125	123.00		
Level of Human Interaction (250)	194.50			
	Possible Points	(from Human Interaction Judge)		
Description of Level of Human Interaction	250			
Near zero human interaction	100%	22.20%		
Minimal interaction	75%			

Moderate Interaction	50%		
Frequent Interaction	25%		
Continuous Interaction (completely tele-operated)	0%		
Man Hours to Perform the Task (250) Points	250.00		
Elapsed Time	8:00:00		
Number of people on site	3		
Total Man-Hours	24.00		
Man Hours Allotted	24		

6.1.2. Comments

The following comments are based from the event judge Walt Waltz:

1) This competition was made extremely simple from a real-world application. Most areas would be littered throughout with a mix of ferrous/non-ferrous material along with a host of other debris. It would have been more practical to require competitors to gather more than just ferrous items that would require very different techniques and that would be much more aggressive than magnetic pick up devices.

2) D4C's method of dumping in the collection area resulted in point deductions for pile cleanliness due to the fact that the rotation caused some IOI's to be covered from the track mounding up soil. Also executing pivot turns at the end of each run resulted in losing IOIs off the magnet.

3) Team UXO-D employed a combination of techniques, one of which (the electromagnet) proved to be very effective for removing large ferrous items without rolling off the magnet.

4) Team UXO-D used a lot of autonomous operation and to do so, ran a pattern that took them over the top of previously dumped IOIs. By running this heavy equipment over the top of UXO and twisting/turning resulted in burying several IOIs. This resulted in a significant deduction for creating a contaminated area in the collection area.

6.2. Geophysical Mapping Event Results

6.2.1. Competing Teams

All three teams (Team D4C, Team UXOD Automation, and Team Sky Research) competed in the Geophysical Mapping event.

6.2.2. Task Description

The geophysical mapping challenge was intended to demonstrate a robotic system navigating a digital geophysical mapping platform towing a geophysical sensor array within the designated area. The system was to tow a time domain electromagnetic induction metal detector and record its data over 100% of the designated area at a line spacing of 50cm. The positional accuracy of the digital geophysical should have been sufficient to detect and locate buried metallic objects to 30cm or better. The collected raw geophysical data should have been at or below an objective noise level determined at the site.

For the geophysical mapping task, the teams also had eight hours to provide the most accurate map of the buried items while maintaining consistent speed and control of the system to maximize the performance of the sensor. The system also had to deal with some simulated obstacles meant to represent blown-up targets that would be found on real target ranges.

For all teams, the geophysical mapping task was the most automated, as the systems just had to tow a precision path across the field while avoiding the two obstacles. Teams were given coordinates of the competition areas and obstacles two weeks prior to the competition to simulate *a priori* data available to real-world operations. Some teams did manual path planning while others had automated path planning as part of their control solution

6.2.3. Team D4C Geophysical Mapping

Team D4C conducted the geophysical mapping task using a Bobcat Skid Steer with a QinetiQ North America robotics kit to tow an electromagnetic sensor over the 1.6 acre site that was seeded with simulated buried UXO (Figure 44). The teams original path plan did not incorporate the obstacles due to an oversight by their programmers. To accommodate the obstacles, they implemented a diagonal pattern that purposely avoided large strips of the range. This pattern caused them to use a large portion of their travel time in the turns and not scanning the range areas of interest. This task was completed with almost no human interaction, as the system conducted waypoint driving over the course to complete the mapping task, finding 92 of the 125 items. They achieved a total score of 165.30 out of a possible 250 points. Detailed scoring sheets are shown in Table 7.

Team D4C acquired geophysical mapping data for 58.41% of the total coverage area (Figure 45) and accurately located 92 targets (Figure 46).

Figure 44. Team D4C Geophysical Mapping Task

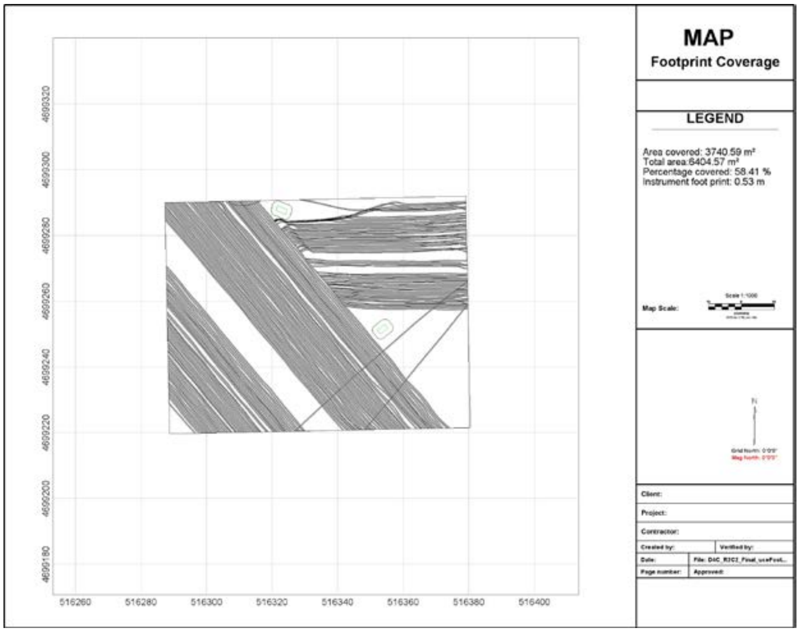


Figure 45. Team D4C Geophysical Coverage Map

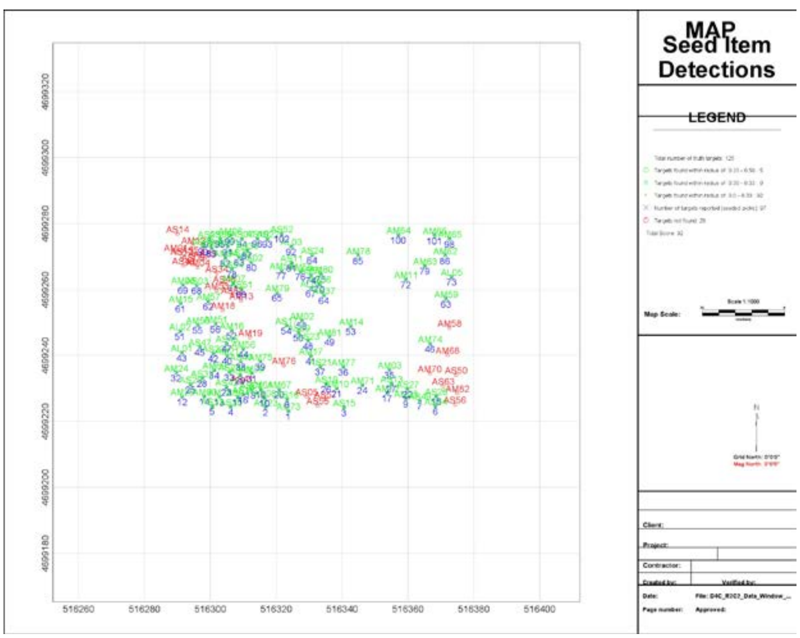


Figure 46. Anomaly Location Accuracy for Team D4C

Table 7. Team D4C Geophysical Mapping Scores

Team D4C			
Surface Clearance Event Score	**165.30** out a possible **250** points		
Metric Categories	Total for each Metric	Weight	
System Task Performance	174.00	50%	
Level of Human Interaction	133.25	40%	
Man Hours to Perform the Task	250.00	10%	
Competition Level Metrics	Points/Violation	Violations	Total
Perimeter or No-go area violation	50	0	0
Exclusion zone violation	DQ		
Surface (>15cm)		0	0
Surface grade (>15cm)		0	0
Total Penalty			0
System Task Performance (250) Points	174.00		
	Possible Points	Violations	Total
Delivery of Raw Data (correct format within 48hrs)	250	0	0
Noise Level	70		70
Sensor Coverage	60		39
Anomaly Location Accuracy	60		45
Survey Speed	60		20
Level of Human Interaction (250)	133.25		
	Possible Points	(from Human Interaction Judge)	
Description of Level of Human Interaction	250		
Near zero human interaction	100%	46.7%	
Minimal interaction	75%		
Moderate Interaction	50%		
Frequent Interaction	25%		
Continuous Interaction (completely tele-operated)	0%		
Man Hours to Perform the Task (250) Points	250.00		
Elapsed Time	8:00:00		
Number of people on site	3		
Total Man-Hours	24.00		
Man Hours Allotted	24		

6.2.4. Team Sky Research Geophysical Mapping

Team Sky Research only entered in the geophysical mapping event. Their robotic solution used a Kubota UTV outfitted with a Topcon autosteering system for waypoint driving and steering control towing a Sky Research sensor (Figure 47). Sky Research personnel converted the Kubota and adapted the Topcon system for use as an independent robotic solution, since the Topcon is normally intended for use to augment a manned machine. The team had many software problems during the day that slowed their progress. They spent a great deal of time troubleshooting and trying to implement fixes to their system to complete the course. Due to these problems they were only able to complete about half of the mapping course, finding 69 of the 125 items. They achieved a total score of 133.30 out of a possible 250 points. Detailed scoring sheets are in Table 8.

Figure 47. Team Sky Research Geophysical Mapping Task

Team Sky Research acquired geophysical mapping data for 40.06% of the total coverage area (Figure 48) and accurately located 69 targets (Figure 49).

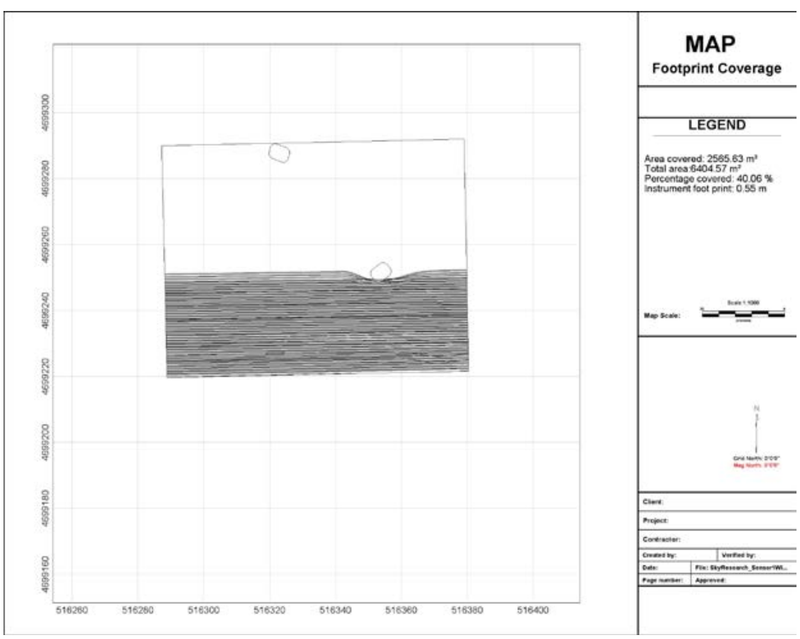


Figure 48. Team Sky Research Geophysical Coverage Map

Distribution A: Approved for public release; distribution unlimited. 88ABW-2012-5009, 19 September 2012.

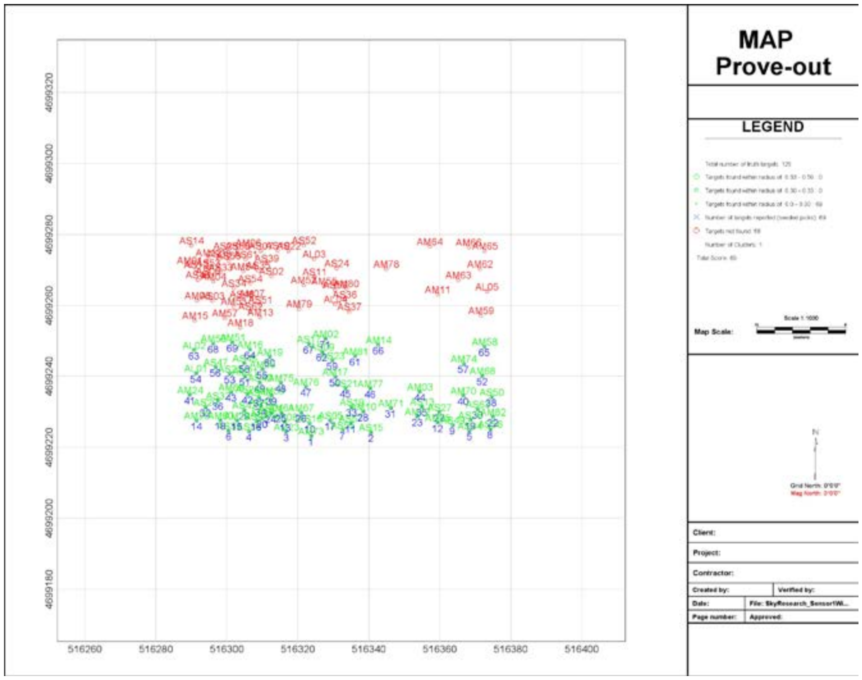


Figure 49. Anomaly Location Accuracy Analysis for Sky Research

Table 8. Team Sky Research Geophysical Mapping Scores

Surface Clearance Event Score	**133.3** out a possible **250** points		
Metric Categories	Total for each Metric	Weight	
System Task Performance	102.00	50%	
Level of Human Interaction	143.25	40%	
Man Hours to Perform the Task	250.00	10%	
Competition Level Metrics	Points/Violation	Violations	Total
Perimeter or No-go area violation	50	1	50
Exclusion zone violation	DQ		
Surface (>15cm)		0	0
Surface grade (>15cm)		0	0
Total Penalty			50
System Task Performance (250) Points	102.00		
	Possible Points	Violations	Total
Delivery of Raw Data (correct format within 48hrs)	250	0	0
Noise Level	70		70
Sensor Coverage	60		28
Anomaly Location Accuracy	60		34
Survey Speed	60		20

Level of Human Interaction (250)	143.25		
	Possible Points	(from Human Interaction Judge)	
Description of Level of Human Interaction	250		
Near zero human interaction	100%	42.7%	
Minimal interaction	75%		
Moderate Interaction	50%		
Frequent Interaction	25%		
Continuous Interaction (completely tele-operated)	0%		
Man Hours to Perform the Task (250) Points	250.00		
Elapsed Time	8:00:00		
Number of people on site	3		
Total Man-Hours	24.00		
Man Hours Allotted	24		

6.2.5. Team UXOD Geophysical Mapping

Team UXOD Automation used their robotic Kubota UTV towing a Zonge electromagnetic sensor system (Figure 50). As with all of UXOD's systems, the Kairos kit provided the robotic control of the UTV with ASI's Mobius being used for the path planning and waypoint control. The UXOD system was very stable and performed a perfectly boring job over the course, successfully mapping all 125 seeded items. Approximately halfway through the event Team UXOD halted their system to do a manual download of their data to that point. Sometime after restarting this download, their system quit logging the geophysical mapping data. Fortunately for them, all of the lost mapping data was in an area designated for ground truth and noise measurements so it contained no simulated UXO items. The missing data can be clearly seen in their map plot in Figure 52. They achieved a total score of 205.70 out of a possible 250 points. Detailed scoring sheets are shown in Table 9. Team UXOD acquired geophysical mapping data for 83.96% of the total coverage area (Figure 51) and accurately located all 125 targets (Figure 52).

Figure 50. Team UXOD Geophysical Mapping Task

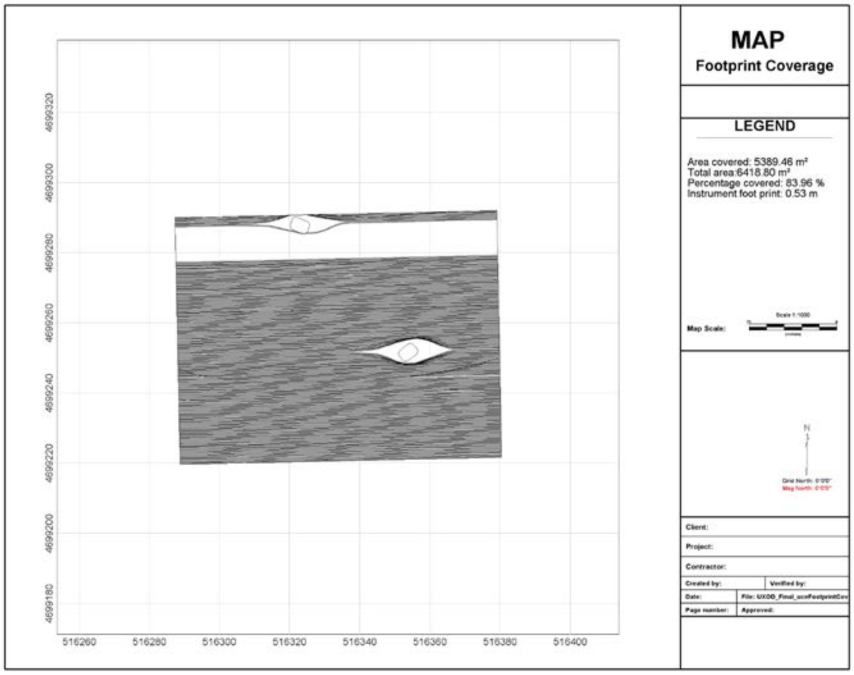


Figure 51. Team UXOD Geophysical Coverage Map

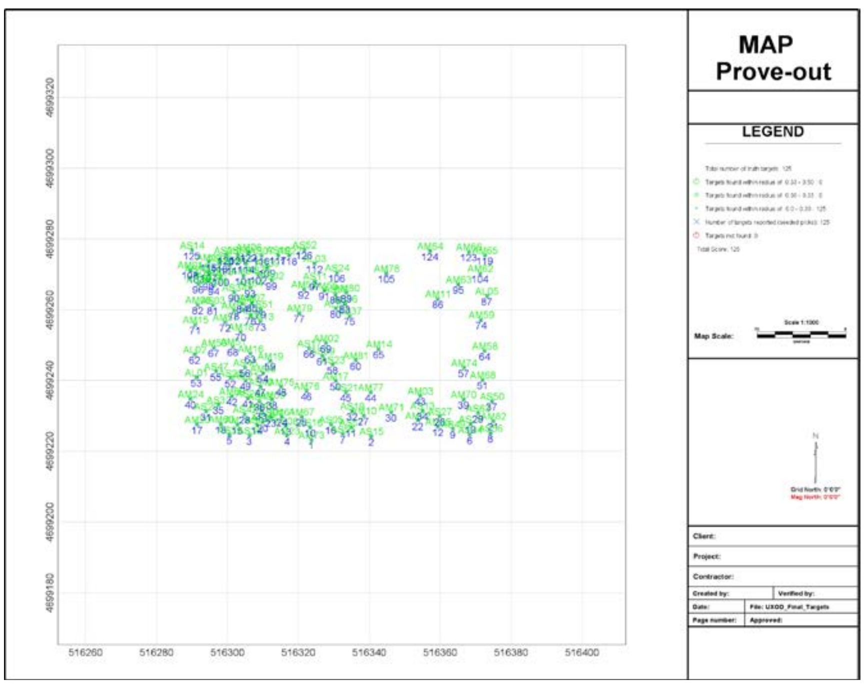


Figure 52. Anomaly Location Accuracy for Team UXOD

Table 9. Team UXOD Geophysical Mapping Scores

Team UXOD			
Geophysical Mapping Event Score	**205.7** out a possible **250** points		
Metric Categories	Total for each Metric	Weight	
System Task Performance	189.00	50%	
Level of Human Interaction	215.5	40%	
Man Hours to Perform the Task	250.00	10%	
Competition Level Metrics	Points/Violation	Violations	Total
Perimeter or No-go area violation	50	0	0
Exclusion zone violation	DQ		
Surface (>15cm)		0	0
Surface grade (>15cm)		0	0
Total Penalty			0
System Task Performance (250) Points	189.00		
	Possible Points	Violations	Total
Delivery of Raw Data (correct format within 48hrs)	250	0	0
Noise Level	70		70
Sensor Coverage	60		54
Anomaly Location Accuracy	60		60
Survey Speed	60		5
Level of Human Interaction (250)	215.50		
	Possible Points	(from Human Interaction Judge)	
Description of Level of Human Interaction	250		
Near zero human interaction	100%	75.0%	
Minimal interaction	75%		
Moderate Interaction	50%		
Frequent Interaction	25%		
Continuous Interaction (completely tele-operated)	0%		
Man Hours to Perform the Task (250) Points	250.00		
Elapsed Time	8:00:00		
Number of people on site	5		
Total Man-Hours	40.00		
Man Hours Allotted	40		

6.2.6. Comments

Geophysical data from the three competitors were analyzed following the methods outlined in the final R2C2 Rules and Metrics document. All data analysis was performed in the same manner for each of the three competitor's data. All scores were determined using the processes described in the R2C2 Rules and Metrics document. Refer to Appendix D for further details and the in depth analysis for scoring of the geophysical mapping event provided by the event judge Andy Schwartz.

6.3. Sub-surface Clearance Event Results

6.3.1. Competing Teams

The two teams that competed in the Sub-surface Clearance event were Team D4C and Team UXOD Automation. Team Sky Research did not participate in this event.

6.3.2. Task Description

The sub-surface clearance challenge was intended to demonstrate the removal of all seeded metallic items from the supplied dig list. The seeded metallic item depths did not exceed 1 meter and the site was seeded with metallic items 60mm in width or greater. The dig list included a relative signal strength of the buried UXO items to simulate a real geophysical mapping product. All seeded metallic items recovered from the clearance site were to be placed in a designated sub-surface collection area off of the range. This was the least automated task for all the teams as most of the robotic operations were teleoperated throughout the entire sub-surface clearance event. The operations for this task were very slow and inefficient as neither team instrumented their backhoe arms to know the precise location where they were digging. In addition their technique of digging for the items and trying to visually see it in their camera view was very poor. Both teams struggled with the subsurface clearance and neither team achieved the minimum score to be award a prize for this event.

During the subsurface clearance event, both competing teams had difficulty locating buried items with sufficient accuracy for extraction. This problem seems to stem from a failure to properly calibrate differential GPS systems. The DGPS systems used by the competitors and the R2C2 staff provide extremely high position accuracy relative to other points, but the entire set of points may be off in the global reference frame unless post-processing is used to adjust the alignment. To mitigate any alignment problems the teams were provided with marked localization points they could use to shift the coordinate plane of their GPS system to the provided coordinates. Failure to properly shift coordinate planes could result in position errors as great as 1 meter.

The R2C2 staff demonstrated the accuracy of the location data provided to the teams by repeatedly and reliably finding corner points and buried ISOs before and after the competition. Furthermore, the crew from ARA's New England Division, who verified the geophysical mapping range using a completely different DGPS system, was able to do the appropriate coordinate shift with the data provided to the teams. This indicates that there was no systematic problem with the GPS data but care must be taken when translating GPS data to properly localize points.

6.3.3. Team UXOD SubSurface Clearance

Team UXOD Automation again used their John Deere equipment with the skid steer employing an equipment plate-mounted excavator bucket and the feller buncher modified to carry an electromagnet and generator (Figure 53). Team UXOD Automation used waypoint driving to guide the skid steer to the location of the buried items and then teleoperated the system to dig up and look for the buried UXO. Once they uncovered an item through visual verification, they used waypoint driving to drive over the feller buncher and then pick up the item with the electromagnet. The feller buncher would sometimes pick up multiple recovered UXO items before using waypoint driving to take them to the collection area.

Team UXOD started out very slow only recovering a few items in the first several hours of the event. They eventually changed their technique from that of trying to dig up the item from a hole where they thought it was to digging a trench and searching for an item. This trenching method proved to be much more effective and their retrieval rate went up significantly. In addition, the use of the electromagnet was very successful in picking up the items cleanly to take back to the collection area. Unfortunately, they did not collect all of the items that were dug up. The judges found one UXO item left on the surface next to one of their excavated holes during the scoring of the range.

In addition, Team UXOD had an incident in this event where they teleoperated their skid steer into the hole they were excavating (Figure 54). Once again the event was halted and the situation inspected for safety. They were then allowed to recover their system and continue the event. Unfortunately, when the system went into the hole it damaged their excavator attachment, they attempted to repair it unsuccessfully with the excavator attachment detaching shortly after they resumed digging. At this time they decided to switch to their blade attachment and concentrate on backfilling the holes (Figure 55). Overall, the team recovered 14 of the 50 buried items and achieved a total score of 97.00 out of a possible 250 points (Figure 56). Detailed scoring sheets are shown in Table .

In addition, Team UXOD had an incident in this event where they teleoperated their skid steer into the hole they were excavating (Figure 54). Once again the event was halted and the situation inspected for safety. They were then allowed to recover their system and continue the event. Unfortunately, when the system went into the hole it damaged their excavator attachment, they attempted to repair it unsuccessfully with the excavator attachment detaching shortly after they resumed digging. At this time they decided to switch to their blade attachment and concentrate on backfilling the holes (Figure 55). Overall, the team recovered 14 of the 50 buried items and achieved a total score of 97.00 out of a possible 250 points (Figure 56). Detailed scoring sheets are attached in Section 4.7.5.

Figure 53. Team UXOD Sub-surface Clearance Task

Figure 54. Team UXOD Skid Steer Hole Incident


Figure 55. Team UXOD Sub-surface Backfill


Figure 56. Team UXOD Sub-surface Recovered IOI's

6.3.4. Team D4C SubSurface Clearance

Team D4C used two robotic Bobcats for this final task, one with an equipment plate mounted excavator and the other with a custom made screener basket (Figure 57). Like Team UXOD Automation, Team D4C used waypoint driving to go to the site of the buried items and then teleoperation to do the actual digging. Since they did not have an instrumented backhoe arm they attempted to mark they target location by having the skid steer spin in place over the GPS coordinate of the suspect item. This left a distinctive circle of dirt from the bobcat tracks that they then dug over. They also were visually searching for the items as they dug, which proved to be very challenging. They were not finding many items as they would dig and then search the dirt pile or hole for an item and then dig some more.

Figure 57. Team D4C Sub-surface Task

The second bobcat with the screener bucket was not employed effectively due to technical issues of operating the two systems in close proximity to each other. The original plan was for them to drop the dirt into the screener bucket and then shake it until an ISO item was found. Since they couldn't operate the two system near each other at the same time, they had to just visually search for ISO in their dirt piles using the on-board cameras. As they day wore on, D4C did not make any changes to their tactics and collected only seven of the 50 buried items (Figure 58). They achieved a total score of 70.00 out of a possible 250 points. Detailed scoring sheets are attached in section 4.7.5.

Figure 58. Team D4C Recovered IOI's

6.3.5. Scores

Table 10. Team UXOD Sub-surface Clearance Score

Surface Clearance Event Score	**97** out a possible **250** points		
Metric Categories	Total for each Metric	Weight	
System Task Performance	62.00	50%	
Level of Human Interaction	102.5	40%	
Man Hours to Perform the Task	250.00	10%	
Competition Level Metrics	Points/Violation	Violations	Total
Perimeter or No-go area violation	50	0	0
Exclusion zone violation	DQ		
Surface (>15cm)	2	4	8
Surface grade (>15cm)		0	0
Total Penalty			8
System Task Performance (250) Points	62.00		
	Possible Points	number of seeded items	number collected
Sub-surface Seed Removal	250	50	14
Level of Human Interaction (250)	102.50		
	Possible Points	(from Human Interaction Judge	
Description of Level of Human Interaction	250		
Near zero human interaction	100%	59.0%	
Minimal interaction	75%		
Moderate Interaction	50%		
Frequent Interaction	25%		
Continuous Interaction (completely tele-operated)	0%		
Man Hours to Perform the Task (250) Points	250.00		
Elapsed Time	8:00:00		
Number of people on site	5		
Total Man-Hours	40.00		
Man Hours Allotted	40		

Table 11. Team D4C Sub-surface Clearance Score

Surface Clearance Event Score	**70** out a possible **250** points		
Metric Categories	Total for each Metric	Weight	
System Task Performance	35.00	50%	
Level of Human Interaction	68.75	40%	
Man Hours to Perform the Task	250.00	10%	
Competition Level Metrics	Points/Violation	Violations	Total
Perimeter or No-go area violation	50	0	0
Exclusion zone violation	DQ		
Surface (>15cm)	0	0	0
Surface grade (>15cm)		0	0
Total Penalty			0
System Task Performance (250) Points	35.00		
	Possible Points	number of seeded items	number collected
Sub-surface Seed Removal	250	50	7
Level of Human Interaction (250)	68.75		
	Possible Points	(from Human Interaction Judge	
Description of Level of Human Interaction	250		
Near zero human interaction	100%	73.0%	
Minimal interaction	75%		
Moderate Interaction	50%		
Frequent Interaction	25%		
Continuous Interaction (completely tele-operated)	0%		
Man Hours to Perform the Task (250) Points	250.00		
Elapsed Time	8:00:00		
Number of people on site	3		
Total Man-Hours	24.00		
Man Hours Allotted	24		

6.3.5.1. Comments

This task proved to be the most difficult challenge of the competition. Both teams, UXOD and D4C, experienced frequent problems in recovering the buried ISO items. Predominantly, these problems were associated with accurately geolocating the position of the ISO item with respect to their manipulator arm and dig tool coordinate system along with their handling techniques for recovery. For example, both teams recovered ISO items in their bucket and did not realize it so the inadvertently buried the ISO into the dirt pile lying next to the dig site. This caused them to overlook the item and continue digging, while other times they did not dig close enough to the exact spot of the buried ISO and could not recover it.

6.4. Overall Scores

Table 12. R2C2 Overall Scores.

R2C2 Event Scores			
	Team UXOD	Team D4C	Team Sky Research
Vegetation Clearance	158.62	177.38	Did not participate
Surface Clearance	161.86	191.91	Did not participate
Geophysical Mapping	205.70	165.30	133.30
Sub-Surface Clearance	97.00	70.00	Did not participate
Total Scores	623.18	604.60	133.30

6.5. R2C2 Scoring Procedures

6.5.1. Range QC Procedure

For the purposes of QC inspection, each range was divided into grids using the differential GPS system. After the competitors completed each event, the corners of the grid were marked with red flags to facilitate inspection and each grid section was manually inspected for any of the relevant failures. Each grid section was only counted as a failure once for each type of failure.

Competitors were penalized if they significantly damaged the competition ranges by operating their systems. The R2C2 Quality Control (QC) team checked for surface damage (either digging ruts, or piling up material), grade changes (changing the entire surface of a section of the range), vegetation that was not removed from the vegetation clearance ranges, and tree stumps that were not properly removed from the vegetation clearance ranges. QC inspections were performed by the range judges supported by the QC team.

Tree stumps were not graded using the grid system. Exactly 50 trees were left on each vegetation clearance range at the beginning of the competition. Trees were marked before the competition and inspected afterward to determine if they had been sufficiently cut.

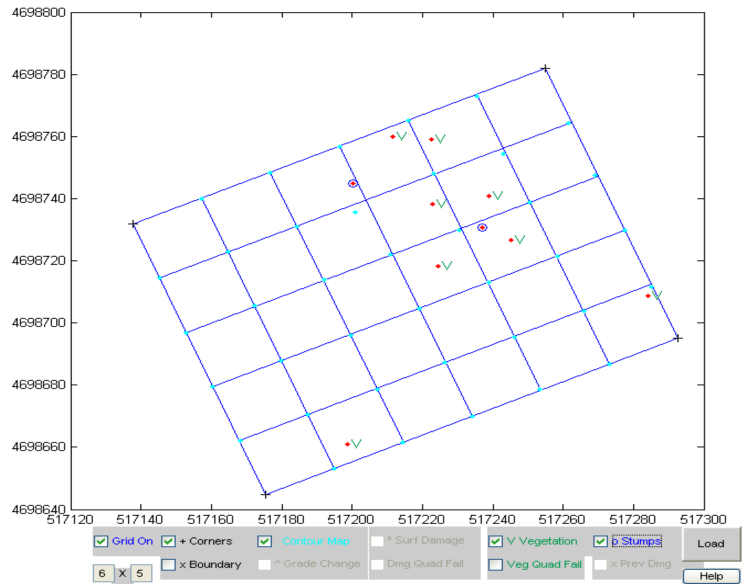


Figure 59. Team D4C Quality Control Results for the Vegetation Clearance Range

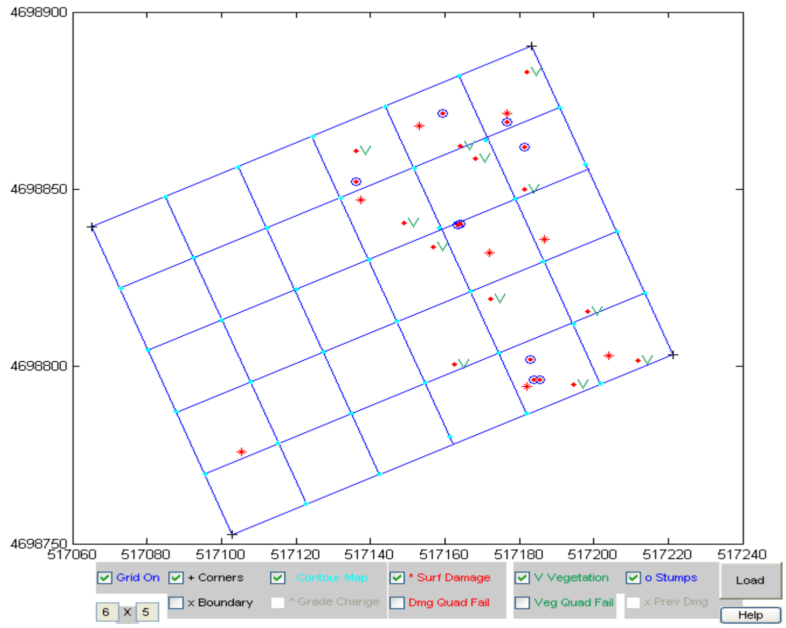


Figure 60. Team UXOD Quality Control Results for the Vegetation Clearance Range

Refer to Appendix E for complete quality control results.

6.5.2. Surface Damage Criteria

The failure criteria for Surface Damage were defined as follows: A pile of material failed if it was continuously above 15 cm in height above the local grade over a length of at least 1 meter. Holes constituted a failure if it had a continuous depth of 15 cm below the local grade over a length of at least 1 meter. Height and Depth were measured with a measuring tape and a long rigid object (where necessary). Piles were normalized by the QC team by compressing down the dirt to compact or disperse loose soil. Holes were not normalized. Failures were documented with GPS marking and photographs per the documented procedure (Figure 61).

Figure 61. Surface Damage Failures, (left) Pile, (right) Hole

6.5.3. Vegetation Failure Criteria

The failure criteria for vegetation residue was defined as: vegetation residue will fail if it extends above 15cm in height above the local grade over an area of 1 square meter. A theoretical cylinder (of height 15cm and diameter 1m) was proposed to define a failed area. If a significant portion of the vegetation inside the area extended through the top of the cylinder, the area constituted a grid failure (Figure 62). This standard was applied to uncut (or insufficiently cut) grass and small shrubs inside the vegetation removal area.

Figure 62. Vegetation Failures

6.5.4. Tree Stump Failure Criteria

The failure criteria for insufficiently cut tree stumps was defined as: A tree stump will fail if the height of the stump above the local grade is greater than 8 cm. The height was measured on the shortest side of the stump. If the stump is not cut evenly (e.g. if it has been mulched), the evaluator will stand on the stump to compress any parts that may be sticking up. The height is measured to the top of the uncompressible portion of the stump (i.e. the bottom of the evaluator's shoe) – (refer to Figure 63 for an example).

Figure 63. An Example of Tree Stump Failure

In all cases the final decision for passing or failing damage, vegetation, or tree stumps was decided by the range judge. The range judge recorded the height of failed stumps and graded each as marginal or significant failure.

6.5.5. Existing Damage Mitigation

All ranges were checked prior to the competition and both the subsurface and vegetation clearance ranges were deemed to have existing damage that would count as a failure. To ensure that no team was penalized for existing damage, the fields were either normalized or the damage was documented.

The vegetation clearance ranges were normalized by the QC team. Using shovels and rakes, mounds that came close to the 15 cm limit were spread out and holes that came close to the 15cm depth limit were filled in. The existing damage in the Vegetation Clearance ranges was minimal and easy to mitigate.

The vegetation ranges also had several tree stumps that exceeded the 8 cm limit. Existing stumps were either cut down to a passing state or marked by cutting an X into the top of the stump. To further mitigate this concern, the 50 trees that were targets for the competitors were marked with white paint at the base of the tree trunk. Failing trees that were left by the competitors had remnants of the white paint on their trunks. These techniques greatly simplified identification of stump failures.
The subsurface clearance ranges both had some existing surface damage (including a road through each field and deep tire tracks. It was deemed infeasible to flatten out the entire surface of the ranges. Instead the QC team checked each range for damage before the competition. All damage that could potentially cause a failure was GPS tagged and photographed. In all cases, the existing damage was easily differentiated from new damage, and no competitor caused surface damage failures that coincided with existing damage.

6.5.6. Range QC Summary Rulings

Based on the rulings of the range judges, the following QC checks were deemed unnecessary and were therefore not performed. All other QC checks were performed per the procedure. This refers specifically to the QC procedures performed by the QC team as outlined in the GPS field manual and does not include other assessments of competitor performance.

- Surface Clearance Ranges: Surface Damage and Grade Change checks were deemed unnecessary as there was no apparent damage to either range.
- Geophysical Mapping Range: Surface Damage and Grade Change checks were deemed unnecessary, but the QC team was asked to verify the position of the obstacles after a competitor robot impacted one of them. No movement of the obstacle was detected.
- Vegetation Clearance Range: Grade Change QC was deemed unnecessary
- Subsurface Clearance Range: Grade Change QC was deemed unnecessary

6.5.7. Human Interaction Monitoring

During each event, the level of human interaction was monitored for each team/system. R2C2 staff members were selected and trained as Human Interaction (HI) monitors. Two observers were selected as primaries for each event and the same observers monitored both teams for a given event to ensure consistency in record keeping. Alternate HI monitors and the HI judge did take over for brief periods to relieve the primary observers as necessary.

HI monitors recorded all interactions on printed sheets. The first line of the first sheet was open for notes about the competitor's control setup. These notes listed the number of robots, number or control units, and number of operators. The abbreviations were defined for the robots and computers used. After the initial notes, the record sheets had lines with start and stop times, a list of operational modes (e.g. waypoint following, teleoperated, paused, etc.), and a space for notes. HI monitors noted the time of any interactions, and made notes any time an operator interacted with the competitor systems.

Human Interactions were defined as any time a user entered a command that changed the state of the system. This included driving a robot, initiating or changing a waypoint maneuver, moving actuators, moving cameras, inputting waypoints, stopping the robots, doing maintenance, manually driving a robot, etc. Pure monitoring activities (e.g. observing video feeds, or downloading and graphing Geophysical data) were not counted as interaction even if the user was using a computer to view the data.

6.5.8. Video boundary monitoring

Each range had cameras placed to monitor the boundaries in order to catch boundary violations (Figure 64). Three or more cameras were used, at least one pointed down each of the three sides on which a boundary violation could occur. The range entrance/exit edge was not monitored and competitors were not penalized for crossing this edge.

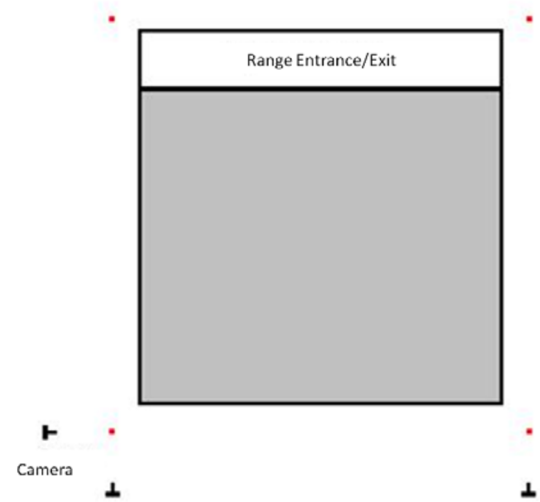


Figure 64. Minimal Camera Setup Diagram (3 Cameras)

According to the R2C2 rules, the teams would be penalized if their robot went more than 3m beyond the 30m exclusion zone. The boundary cameras were set up on the corners of the 33m boundary rectangle and pointed along the edges at a post on the opposite corner. If a vehicle went out-of-bounds the post would be blocked and a boundary violation was known to have occurred. All cameras were wired back to a common control point for monitoring and recording. All boundary video was recorded and archived, and as violations occurred a line judge noted the violation in their logbook.

Although a minimum of three cameras were needed for each range, some ranges needed additional cameras and posts because of rough topography that did not allow line of sight for the full distance of an edge. Each vegetation range, for instance, needed eight cameras to monitor the entire range boundary.

6.5.9. Human Interaction Logging

As part of a competitor's autonomy assessment, the Autonomy Judge instituted a method for documenting human interactions referred to as Human Interaction Logs. During each competition one or more representative(s) from the Human Interaction Team would record all interactions instance with competitor's robotic platforms in a method dictated by the Human Interaction Judge. A Human Interaction Instance was defined as any time a user entered a command that changed the state of the system. This included driving a robot, initiating or changing a waypoint maneuver, moving actuators, moving cameras, inputting waypoints, stopping the robots, doing maintenance, manually driving a robot, etc. Pure monitoring activities (e.g. observing video feeds, or downloading and graphing Geophysical data) were not counted as interaction even if the user was using a computer to view the data.

To further maintain consistency, beyond just common definitions, each event had a Primary Human Interaction Team Member (PHITM) and an Assistant Human Interaction Team Member (AHITM) both of which were dedicated to that event class in an effort to alleviate potential subtle style differences. An exception was made for Geophysical Mapping, which was judged as needing only a PHITM. Each Human Interaction Team member focused on specific Human

Machine Interfaces (HMIs) discovered during a pre-competition interview with each team. The AHITM was responsible for setting up and monitoring a video log of the event which was placed to record as much human interaction as possible without being a hindrance to the competitors (This video was referred to as the Human Interaction Video Log). AHITMs and PHITMs also acted as relief for each other such that there was never a gap in observations. Before the event the PHITM created a naming convention for each HMI that was used throughout the specific event. The naming convention along with general competitor strategy notes were documented on the back of the first page in Human Interaction Logs.

Human Interaction Logs were composed of preformatted templates that described specific interaction instances. The first page of a Human Interaction Log (top lines shown in Figure 65) gave the Human Interaction Team a place to insert basic notes including number of robots and number of HMI's. Each interaction instance was appended with a human interaction instance number. Human Interaction Instances were generally classified into two types: instantaneous and on-going. Instantaneous interactions were characterized as taking less than 30 seconds to accomplish and were indicated by only listing a start time. On-going interactions took more than 30 seconds and had both a start and end time. (NOTE: Times were recorded by Synchronized Atomic clocks given to the Human Interaction Team).

	Robotic Range Clearance Competition					Human Interaction Log
	Starting Notes: Types of interfaces and what they do: Number of operators and robots:					
1	Start:		End:		Description:	TO WPT VC SA Anomaly Pause
	Comments					

Figure 65. Human Interaction Log Form

Additionally, interactions were sub-classified by circling one of the description identifiers of the Human Interaction Instance as described in Table 13. Further, a comments section was provided to the Human Interaction Team to write more details (when merited) about the interaction.

After every competition the Human Interaction Log was hand delivered to the Autonomy Judge after a tabulation of interaction classification (instantaneous or on-going) as well as a summation of on-going type human interaction minutes. The above mentioned Human Interaction Video Log was also made available to the Autonomy Judge during judging sessions.

Table 13. Human Interaction Identifier Definitions

Identifier	Definition
TO	Tele-operation: A Human Machine interaction at directly controlled movement
WPT	Way Point Tracking: A automated method for vehicle navigation
VC	Vector Controlled: A partially automated method for dictating control by the system state
SA	Scripted Action: A single Human Interaction which cause the machine to run a script
Anomaly	Anomaly: Anything not covered by other Identifiers
Pause	Pause: An operational pause in the event

6.6. Competition Outcomes

The competition resulted in monetary awards to two different teams and the crowning of an overall winner. However, it is interesting to note that the overall winner only won a single event, but was the only team to qualify for the overall award by achieving at least a minimum score in each event.

6.6.1. Other Observations

Despite the incentives for increasing autonomy, both of the teams who competed in all the events relied on a high level of tele-operation for events which required dynamic and rapid decision making and flexibility and uncertainty in planning (such as the vegetation clearance and subsurface clearance events). Conversely, when the events were amenable to simple path planning algorithms (such as the geophysical mapping and surface clearance events), teams used more autonomy in the form of waypoint following applications.

6.6.2. Category Winners and Overall Winner

"The results of the R2C2 were announced 17 August at the Association of Unmanned Vehicle Systems International (AUVSI) North America 2011 conference in Washington, D.C. Team D4C won both the Vegetation Clearance and Surface Clearance events and was awarded $500,000. Team UXOD - won the Geophysical Mapping event and received and additional $1,000,000 for achieving the highest overall total competition score. Their total award was $1,250,000."

These were the words posted to the competition website after the winners of the competition were announced at AUVSI North America 2011. A few weeks later, an official press release from OSD was posted to the competition website to officially announce the results. The text of that press release appears here.

"The Robotic Range Clearance Competition (R2C2) Team; the Office of the Secretary of Defense (OSD), Land Warfare and Munitions; the Air Force Research Laboratory; and the U.S. Army Corps of Engineers would like to announce the winners from the Robotic Range Clearance Competition (R2C2) held August 7-14, 2011 at Camp Guernsey, WY.

The Office of Secretary of Defense (OSD) in collaboration with the US Air Force and US Army conducted a Robotic Range Clearance Competition (R2C2) to foster the ability to clear training ranges of debris and unexploded ordnance (UXO) using robotic technologies. The purpose of the Robotic Range Clearance Competition (R2C2) was to quickly tap into the innovation and ingenuity of the commercial robotic technology sector to improve the safety and effectiveness of the four tasks traditionally associated with range clearing operations: 1) Vegetation Clearance, 2) Surface Clearance, 3) Geophysical Mapping, 4) Subsurface Clearance.

The R2C2 Competition teams were:

1. *Team UXOD Automation - comprised of Kairos Autonomi, Autonomous Solutions, SAIC, Zonge Engineering, Vallon, WM Robots, VKR, Inc., and John Deere*
2. *Team D4C - comprised of ECC, QinetiQ North America, and Bobcat*
3. *Team Sky Research*

The R2C2 Competition Directors would like to congratulate the competing teams and thank the R2C2 judges and support staff for making the R2C2 a successful and rewarding event."

7. CONCLUSIONS

The Robotic Range Clearance Competition successfully met its primary objective of incentivizing industry to develop robust, fieldable solutions to address the problem of munitions range clearance. Traditional range clearance operations are manpower intensive, time consuming, dangerous and expensive. Data from AFRL and the Army Corps robotic range clearance technology experiments showed the strong potential for significant reductions in the time and cost required to conduct range-clearing operations — the possibility of reduced time by two-thirds and cost by one-third. However, there was no automated “commercial off the shelf” solutions available for procurement at the time of the competitions initiation.

The prize competition mechanism was selected to quickly tap into the innovation and ingenuity of the commercial robotic technology sector to meet this need. The Department of Defense intended for the R2C2 to result in viable systems that can be procured and placed into service clearing ranges more efficiently than the manpower intensive methods historically employed. The results of the competition prove that industry is ready to respond to these needs with robotic systems capable of performing the necessary range clearance tasks. The unmanned systems used for the competiton demonstrated the ability to perform all the tasks successfully in a reasonable time frame and in an operational environment. The systems were operated almost continually for two weeks with relatively few failures of the machines or unmanned system components. The only task that was not awarded a prize (subsurface clearance) was due to poor technique selection and lack of proper instrumentation by the teams rather than inability of the equipment to achieve the task.

Despite the competition incentives for increasing autonomy, the teams relied on a high level of tele-operation for events which required dynamic decision making and flexibility to deal with uncertainty in planning (such as the vegetation clearance and subsurface clearance events). Conversely for the simpliler tasks (such as the geophysical mapping and surface clearance events), teams used more autonomy in the form of path planning & waypoint following algorithms.

The US Army Corp of Engineers is currently planning and preparing to release a request for proposal for Robotic Range Clearance Services based on the results of the competition. The ultimate aim of this effort and future contract is to efficiently return to productive use the millions of acres currently encumbered with spent training rounds and debris.

8. RECOMMENDATIONS

This report documented the scope, preparation, and execution of the R2C2 sponsored by the JGRE, the USACE, and AFRL. The overall competition was highly succesful and met the primary objectives of the sponsors, but there are a few recommendations that will improve any subsequent DoD prize competitions.

The competition event(s) should be held near a large metropolitan area or military installation. The remote nature of the Camp Guernsey site made it a challenge to support the competition and encourage relevant stakeholders to participate and attend.

Competitors should be incentivized to compete with seed funds to ensure an adequate number and viable field of competitors. Many viable competitors with promising solutions were intially attracted to participate but were unable to secure funding and had to drop out.

9. REFERENCES

Skibba K. Brian, Honey Lake Robotic Range Clearance Operations, AFRL-RX-TY-TR-2010-0003, Tyndall AFB: AFRL Materials and Manufacturing Directorate, 2003

Appendix A: R2C2 Brochure

Robotic Range Clearance Competition

August 7-15, 2011, Camp Guernsey, WY

Introduction

The Office of Secretary of Defense (OSD) in collaboration with the US Air Force and US Army is conducting a Robotic Range Clearance Competition (R2C2) to foster the ability to clear training ranges of debris and unexploded ordnance (UXO) using robotic technologies. The purpose of R2C2 is to quickly tap into the innovation and ingenuity of the commercial robotic technology sector to improve the safety and effectiveness of the four tasks traditionally associated with range clearing operations: 1) Vegetation removal, 2) Surface clearance, 3) Geophysical mapping, and 4) Subsurface clearance.

Experience to date with robotic range clearance suggests a significant potential for time and cost savings as well as increases in the safety for the personnel conducting these activities. The ultimate aim is to return to productive use the millions of acres currently encumbered with spent training rounds and debris. The Department of Defense (DoD) intends for this Competition to result in viable systems that can be procured and placed into service clearing ranges.

Background

Range clearance operations as currently conducted are manpower intensive, time consuming, dangerous, and expensive. Initial data from robotic range clearance technology development efforts indicate the strong potential for significant reductions in the time and cost required to conduct range clearing operations. Experiments to date indicate the possibility of reducing range clearance times by two thirds and costs by one third if automated clearing equipment is used. Currently there are no automated “commercial off the shelf” solutions available to the Department to procure. The traditional approach of establishing an R&D program that can be transitioned into a development and acquisition program is not possible within the desired quick turn- around timeframe as none of the uniformed services have programmed funding for this traditional approach. OSD AT&L is exercising the statutory authority under Section 2374a of title 10 United States Code as amended by Section 212 of the John Warner National Defense Authorization Act for Fiscal Year 2007 Public Law 109-364 to offer a cash prize for the development of robotic range clearing applications. The goal is to provide the desired range clearance capabilities in a significantly shorter amount of time.

Scope

The tasks associated with range clearance that likely have the greatest potential for applying ground robotics technology include automated vegetation clearance, automated surface debris clearance, automated geophysical mapping, and automated subsurface anomaly excavation. The competition will assess the ability of competitor systems to provide increased safety and operational effectiveness to range clearance operations. The competitor systems are expected to have applied robotics technology to all or some appropriate combination of the inherent range clearance tasks in a range clearance operation. Because the competition is focused on increasing safety and operational effectiveness via robotics automation as well as reducing time and cost, competitors are not expected to attempt to develop improved vegetation removal tools or geophysical detection and identification sensor technology.

Schedule

The competition will be conducted from August 7-15, 2011 with a Media/Visitor day scheduled for Thursday August 11. R2C2 competitor practice and setup activities will be conducted August 1-5. Each competition event will be conducted over an 8 hour shift to represent 1 work day starting at 8am until 5pm local time. Depending on the day, up to two teams will be competing simultaneously in separate events.

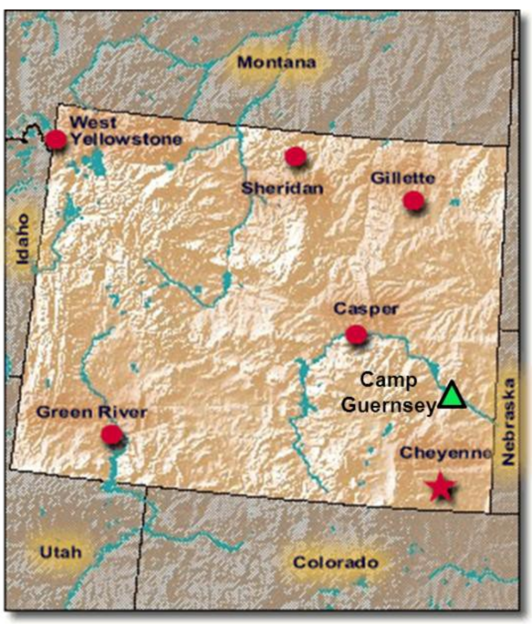
Events in the schedule are abbreviated as follows: Geophysical Mapping (MAP), Vegetation Clearance (VEG), Surface Clearance (SURF), and Sub-surface Clearance (SUB).

R2C2 Competition Schedule

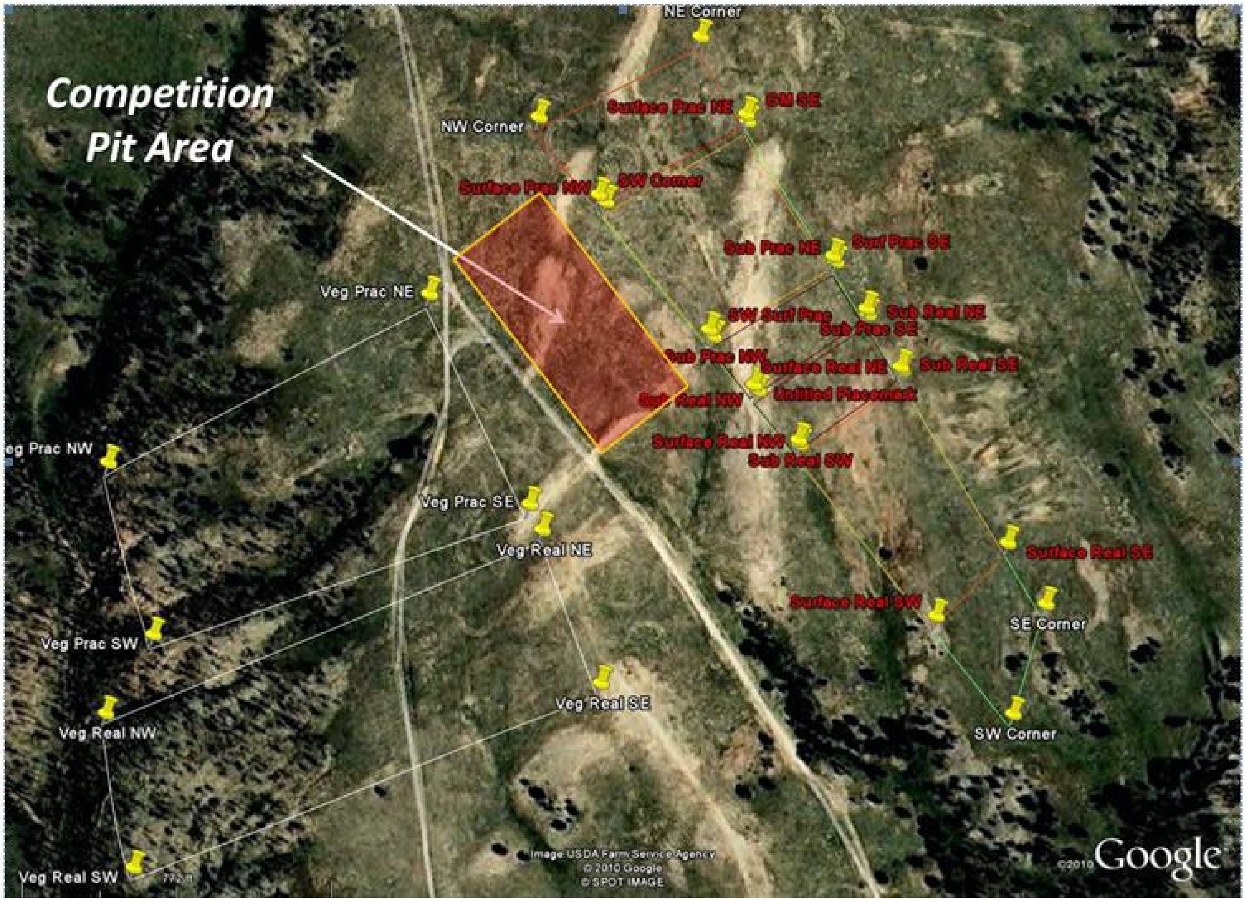
Day/Team		Team 1	Team 2	Team 3
Aug 7	SUN	Safety Test	Safety Test	Safety Test
Aug 8	MON		MAP	VEG
Aug 9	TUE	MAP		
Aug 10	WED		VEG	MAP
Aug 11	THU		Media and Visitor Day	
Aug 12	FRI		SURF	SUB
Aug 13	SAT		SUB	SURF
Aug 14	SUN		Weather Days	
Aug 15	MON			

Location

The competition will be held at Camp Guernsey, WY, located in eastern Wyoming approximately 100 miles north of Cheyenne. Camp Guernsey is an Army National Guard Facility with a large Air Force presence consisting of over 77,000 acres of maneuver area, training ranges, and state-of-the-art facilities. A dedicated, fully qualified staff currently supports over 240,000 customer man-days annually of combat training 24/7/365.



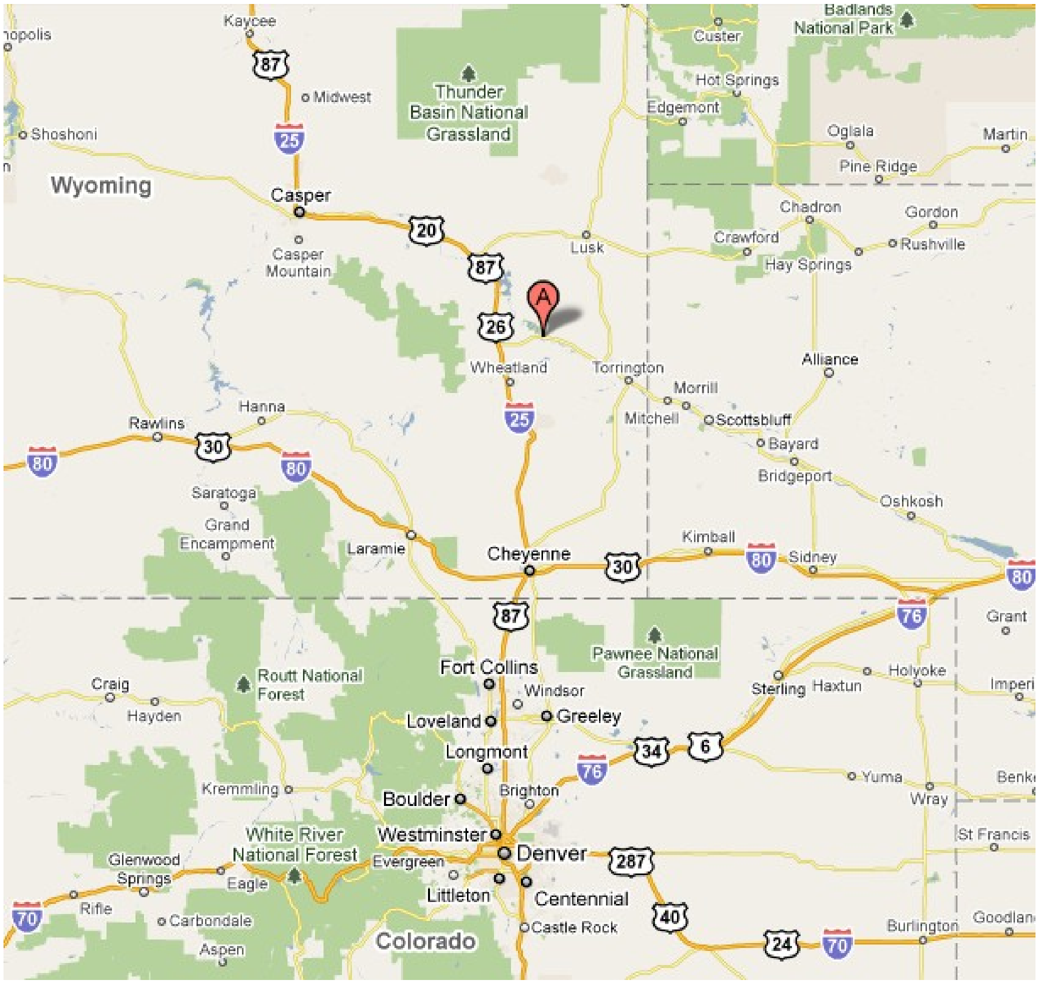
Robotic Range Clearance Competition



Notional R2C2 Competition Site Layout.

Site/Event Description

The R2C2 events will be conducted on the northern training areas at Camp Guernsey, WY, approximately 25 miles from the main camp. The surrounding area is comprised of mixed grass and sagebrush upland plains with sections of lodgepole pines and cottonwoods. These competition sites are all contained within a 600–acre continuous area at an elevation of approximately 5000 ft. The sites are representative of military impact areas and training ranges that are in need of unexploded ordnance (UXO) clearance. Note: this area has no known history of UXO.



Lodging and Travel Information

Lodging for the teams and visitors is being provided on Camp Guernsey in billeting. Appropriate accommodations are available for all ranks and grades of personnel. Transportation will be provided from Camp Guernsey to the event and back each day. Meals are being provided by the camp mess and will be available at the competition area and in Camp Guernsey.

The closest airport with airline service is Cheyenne Regional Airport (CYS), Cheyenne, WY. Rental cars are available. It is approximately a 1.5 hour drive to Camp Guernsey driving I-25N and taking exit 92 onto US-26 E toward Guernsey/Torrington.

Points of Contact

Air Force Research Laboratory (AFRL)

Mr. Brian Skibba
Robotic Range Clearance Competition Director
AFRL/RXQE Robotics Research Team
(850) 283-3725
brian.skibba@tyndall.af.mil

Joint Ground Robotics Enterprise (JGRE)

Mr. Robert Maline
Director, JGRE OUSD
(AT&L)/PSA, LW&M
(703) 693-9414
robert.maline@osd.mil

U.S. Army Corps of Engineers (USACE)

Mr. Plyler McManus
Chief, Ordnance and Explosives Design Center
US Army Engineering and Support Center, Huntsville
(256) 895-1709
samuel.p.mcmanus@usace.army.mil

Camp Guernsey, Wyoming

David W. Herder, LTC, WY ANG
Deputy Garrison Commander
(307) 836-7730
david.herder@us.army.mil

Joint Training and Experimentation Center (JTEC)

Mr. David A. Malek
JTEC Group (937)
873-8166
dmalek@ara.com

Appendix B: Validation Trials

Appendix B: Validation Trials

Joint Ground Robotics Enterprise
ROBOTIC RANGE CLEARANCE COMPETITION (R2C2)

Validation Trials After Action Review and Recommended Rules Changes

v. 28 MAY 2011

Document Change Summary

Section	Description	Date
N/A	Changed version date to reflect new document version	7 DEC 2010
Validation Trials (pp. 16-24)	Added Summary Results of Each Trial; added score sheets for each event	7 DEC 2010
Analysis… (p. 25)	Added section called Analysis to Illustrate Different Levels of Autonomy	7 DEC 2010
Recommended… (pp. 27-28)	Added/ clarified illustrations of impact of scoring differences for various rules changes/ clarifications	7 DEC 2010
The Ranges and Pit Area… (p. 13)	Replaced picture in Figure 13.	13 DEC 2010
N/A	Published as final.	28 MAY 2011

CONTENTS

Introduction

Purpose

The purpose of this document is to record the results of the R2C2 validation trials held at Camp Guernsey, WY during the week of 18-22 October 2010 and to make recommendations for any changes to the existing competition rules or procedures.

Scope

This document will describe the validation trials, how they were conducted, an overview of the results, and recommended changes to rules and procedures.

Objectives

The objectives of the trials held at Camp Guernsey, WY during the week of 18-22 October 2010 were to validate the scoring criteria for the R2C2 competition, to establish baselines for the scoring components (e.g., expected time and manpower requirements), and to report the results of the trials back to the R2C2 Oversight IPT to serve as an empirical basis on changing scoring criteria and competition procedures, if necessary.

Validation Trials

The validation trials were held at Camp Guernsey's North Training Area, located north of Guernsey, WY, shown in Figure 1. The purpose of these trials was to act as a dry run for the actual competition, scheduled to be held in 2011, and as a way to validate the competition scoring.

Figure 1. Map of Wyoming Showing General Location of R2C2 Ranges.

ARA's JTEC group organized the logistics, prepared the ranges, integrated the automation hardware with the ARTS vehicles, instrumented the range boundaries with video, provided the system tele-operator, and supplied the human-machine interaction referee for the demonstration. The US Army Corps of Engineers' Andy Schwartz oversaw geophysical mapping tasks. Mr. Brian Skibba of AFRL/RXQF and Mr. Randy Williams of JGRE represented the R2C2 Oversight IPT and observed the trials. ARA's Northeast Division supported the baseline and demonstration geophysical mapping by providing their Army Night Vision Labs sponsored UXO Trailer and the technical expertise to operate the sensors and data collection software. The University of Florida's CIMAR lab teamed with ARA to provide the hardware and software to automate the range clearance machinery. Attendees are shown in Figure 2 with an autonomous ARTS, the UXO Trailer, and a robotic Gyro-Trac mulching machine.

Figure 2. Attendees of the R2C2 October Validation Trials.

The Ranges and Pit Area for the Validation Trials

The ranges and the pit area for the validation trials were located in the North Training Area of Camp Guernsey, WY. Figure 3 shows a Google Earth image of all ranges that were constructed and the location of the pit area.

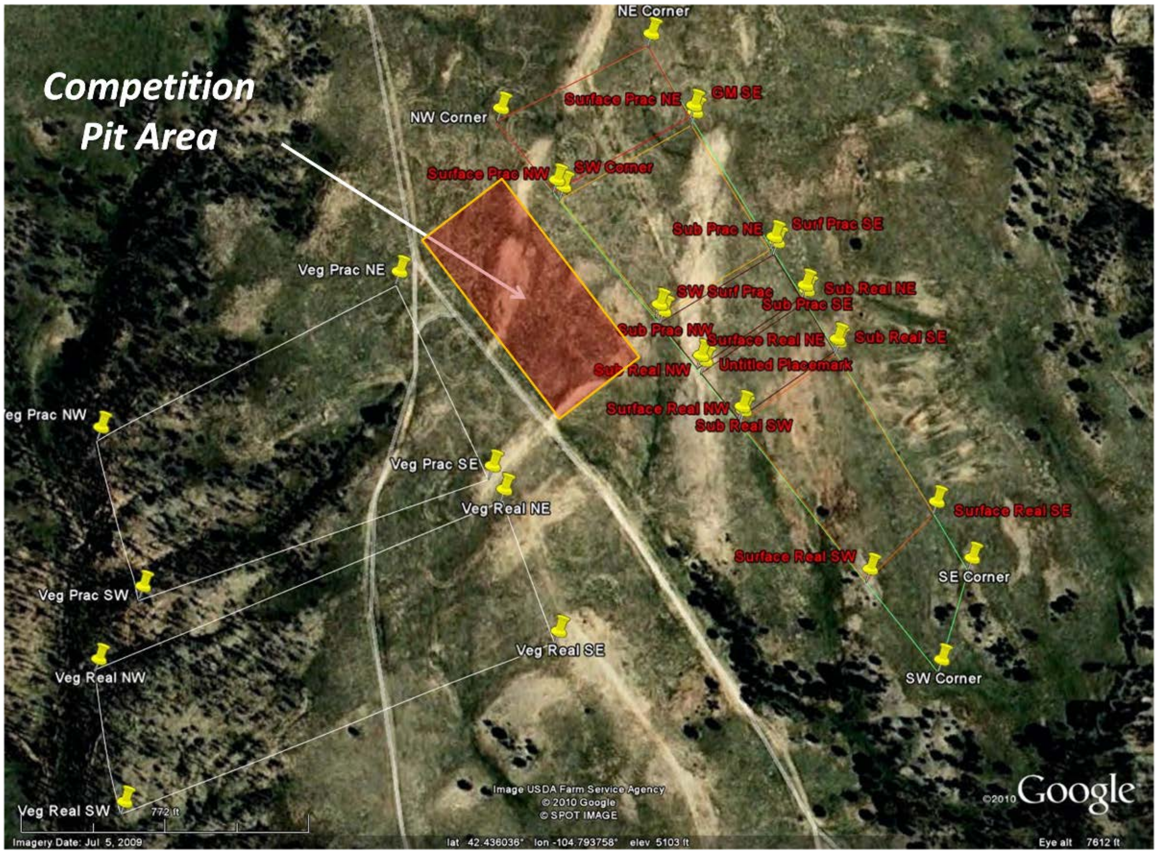


Figure 3. Locations of R2C2 Ranges Being Constructed in Camp Guernsey NTA.

Ranges

Seven ranges were created to simulate R2C2 competition ranges. One geophysical mapping range was created, along with two surface clearance ranges, two Sub-surface clearance ranges, and two vegetation clearance ranges. A pit area was also created to house a command trailer, a mess tent, a maintenance tent, generators, and outdoor lighting rigs. A picture of the pit area is shown in Figure 4.

Figure 4. The Pit Area for the R2C2 Validation Trials.

Range Preparation Process

The R2C2 logistics team prepared the ranges by surveying in the corner posts for each range. Then each range was surveyed and seeded according to the range seeding plan. The geophysical mapping range seeding work plan is included as Appendix A.

The logistics team installed video monitoring equipment for the back boundary of all ranges and adjusted camera locations to also monitor side boundaries of each range when it was active. Video monitoring allowed the team to establish when vehicles exceeded range boundaries, resulting in a boundary penalty. Video monitoring is described in more detail later in this document.

Geophysical Mapping Range

After boundary surveying, the geophysical mapping range was mowed and cleared of all vegetation taller than 8 cm. The logistics team then placed railroad tie obstacles on the range in random locations. A picture of the range is shown in Figure 5.

Figure 5. Geophysical Mapping Range with Railroad Tie Obstacles.

The logistics team then performed a baseline geophysical survey of the range using a UXO trailer built by ARA's New England Division. The NED UXO Trailer is a towed trailer featuring a Minelab Single Transmit Multiple Receive (STMR) metal detection array. The detection array is a Time domain electromagnetic induction sensor. The trailer is shown in Figure 6.

Figure 6. The ARA/NED UXO Trailer Towed by the ARTS.

After the baseline was complete, the data were examined to plan the optimal locations for the Industry Standard Object (ISO) seeds. ISO seed locations were chosen to correspond to areas having lower baseline noise levels.

We then seeded the range with 126 small and medium ISOs (63 of each). The team, with assistance from Andy Schwartz of USACE, dug the seed locations, placed the ISOs, surveyed and recorded their locations in latitude, longitude, and depth in centimeters, and buried the ISOs according to the procedures outlined in the seeding plan. Localization was performed with an Ashtech Magellan ProMark 3 RTK GPS survey kit shown in Figure 7.

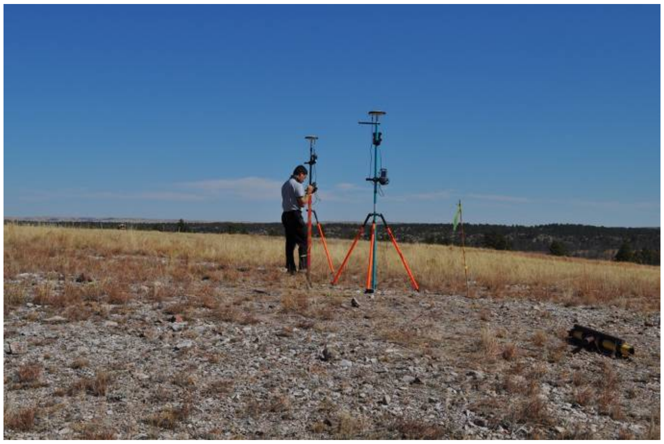


Figure 7. Ashtech Magellan ProMark 3 RTK Surveying Equipment in Use.

Seeding Procedures

Using the analyzed baseline data, the logistics team determined, with recommendations by the project geophysicist, the approximate locations of each of the 63 medium and 63 small ISO being used as seeds.

All seed locations were selected so that no other anomaly, either pre-existing or another planned seed, was within 2 meters of a seed location. All seed items were either the small or medium ISO. (Only localized sensor responses were needed to assess how well robotic systems measure where EM data are collected. Therefore, large ISOs were not needed.) Examples of these ISOs are shown in Figure 8.

Figure 8. Picture of ISOs Required for the R2C2.

Size descriptions for each of the ISOs are presented in Table 1.

Table 1. ISO Descriptions and Specifications.

Item	Nominal Pipe Size	Outside Diameter	Length	Part Number[1]	ASTM Specification
Small ISO	1"	1.315" (33 mm)	4" (102 mm)	44615K466	A53/A773
Medium ISO	2"	2.375" (60 mm)	8" (204 mm)	44615K529	A53/A773
Large ISO	4"	4.500" (115 mm)	12" (306 mm)	44615K137	A53/A773

[1] Part number from the McMaster-Carr catalog.

All seeds were buried perpendicular to the local ground surface (i.e., vertical with respect to the local topography). Coordinate accuracy was +/-2cm in x, y, and z vertical orientation will be accurate to +/-5 degrees.

All seeds were placed in the ground at a depth of either 5 or 7 times their diameter. All depth measurements were to the center of the items. This required that for each size of

ISO, an offset representing the distance from the end of the ISO (the top, when buried vertically) to its center, was added to each survey measurement if that measurement was taken at the top of each ISO. Figure 9 shows a small ISO being surveyed prior to burial.

Figure 9. An ISO Being Surveyed in its Burial Location.

Since obstacles were placed on the range, no ISOs were seeded within the buffer surrounding these obstacles (approximately 1 meter).

The burial team ensured that the ISOs were buried at the appropriate depth by double checking that the ISO for burial was the appropriate size and that the depth was 5 to 7 times the diameter of the ISO. The burial team surveyed each burial location (x, y, and z) and recorded it in the seeding log.

Surface Clearance Range

After surveying, the surface clearance range was seeded with 400 pieces of material, including small plate, angle iron, and small, medium, and large ISOs. Each seed item was painted in a high-visibility color for easier visual identification. Figure 10 shows the surface clearance range with the ARTS towing a Cherrington beach cleaner attachment.

Figure 10. A Picture of the Surface Clearance Range.

Sub-Surface Clearance Range

After surveying, the range was seeded with 20 small, 20 medium, and 20 large ISOs. The pattern was arbitrarily chosen as two notional target points with seeded items radiating out from each. Each ISO location was buried according to the seeding plan and each location was surveyed and logged. Figure 11 shows the ARTS being teleoperated on the sub-surface clearance range.

Figure 11. The ARTS on the Sub-Surface Range Digging for ISOs.

Vegetation Clearance Range

For the purposes of the validation trials, the real vegetation clearance range was divided so that a section dominated by trees and another section was all high prairie grass and very small vegetation. The area with the trees was the westernmost area of the range, while the area with grass was east, shown in Figure 12. The grassy area was created to demonstrate mowing, while the treed area was created to demonstrate tree felling and mulching.

Figure 12. Real Vegetation Clearance Range is Southernmost Range.

For the treed area, trees were thinned so that each tree to be cut was separated by the next tree by approximately 10 meters. This was done to demonstrate range standardization and to prevent downed trees from hanging up on other trees, complicating the tree cutting process. Figure 13 shows the GyroTrac cutting trees on the vegetation clearance range's western portion.

Figure 13. The GyroTrac Cutting Trees on the Vegetation Clearance Range.

Validation Trials

The University of Florida/ARA team acted as the notional competitor. The plan was to demonstrate some level of performance in all events in an effort to exercise the competition plan and to test the scoring plan.

The UF/ARA team had a mix of autonomy levels. For geophysical mapping, they used a fully autonomous ARTS towing the ARA/NED UXO Trailer described earlier and shown in Figure 14 below.

Figure 14. ARTS Towing the UXO Trailer During the Geophysical Mapping Event.

For sub-surface clearance, they used a mostly tele-operated ARTS with a backhoe attachment, using autonomy to drive to the dig locations, but tele-operating the digging behavior (shown in Figure 11).

For surface clearance, they used a semi-autonomous ARTS system towing a Cherrington beach cleaner (see Figure 15). The ARTS navigation and steering behavior was autonomous, but the beach cleaner behavior was tele-operated.

Figure 15. ARTS with the Cherrington Beach Cleaner Attachment.

And finally, for vegetation clearance, the UF/ARA team used a fully autonomous ARTS pushing a mowing deck for grass and small vegetation and a tele-operated Gyro-Trac mulching machine for trees.

Video Monitoring/Boundary Instrumentation

Four cameras mounted on posts monitored three edges of the active range out-of-bounds as depicted in Figure 16. The fourth edge was designated as the entrance/exit to the range and was not monitored. This entrance/exit area is a subset of the Range thus competitors will not be penalized if they enter this area.

For the competition we will add an additional Pan, Tilt, Zoom (PTZ) Camera that will be placed outside of the Area of Operations to monitor competitor progress and ensure potential safety hazards are quickly addressed during the competition.

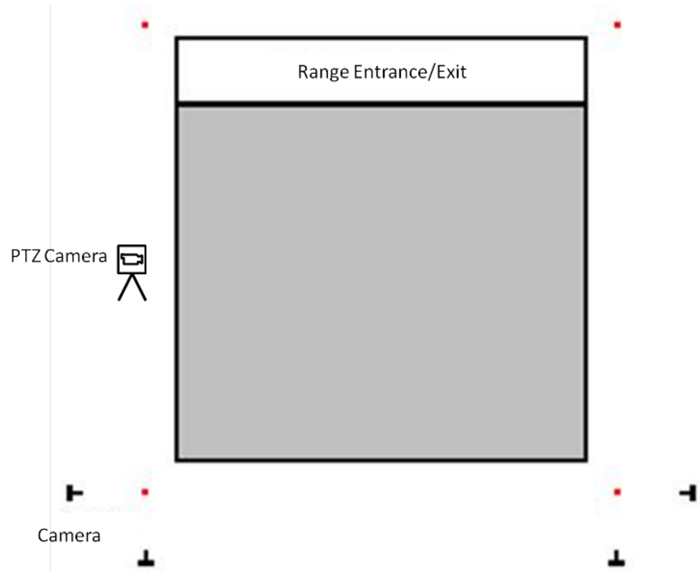


Figure 16. Camera Positions for the Range Boundary Monitoring System.

Range out-of-bounds posts, 8 foot PVC pipe, were placed in line with the camera as a boundary reference point as marked in Figure 17.

Figure 17. Out of Bounds Posts as Shown on Video Image.

Range operations and boundary violations were monitored and recorded on a DVR. After a violation was identified, a visual verification and event documentation was performed. Figure 18 shows one of the boundary violations recorded during the geophysical mapping event.

During the competition painted lines will be added to each range to more easily denote the range boundaries, AO boundaries, and penalization boundary to allow definitive Q&A results to potential AO violations. In addition we will explore the use of video display overlays to mark boundaries for easier boundary violation judging.

Figure 18. A Boundary Violation is Visible in this Scene.

We plan on using the same boundary instrumentation in the actual competition as that used during the validation trials, but with better resolution cameras and DVR to improve the video quality and our ability to make these critical judgments.

Summary Results of Each Trial

Each trial will be summarized to include the system performance, level of human interaction, man hours to perform, total time on the range, and relevant comments characterizing the competitor event performance. In addition, the competitor's score sheet will be presented for each trial.

The overall score of our notional competitor team was 547.9 out of 1000 possible points. This score and its breakdown by event, shown in Figure 19, comes with some caveats.

Notional Competitor Overall Score	547.9
Vegetation Clearance	152.5
Surface Clearance	113.5
Geophyiscal Mapping	238.0
Sub-surface Clearance	43.9

Figure 19. Overall Notional Competitor Score Sheet.

First, none of the validation trial events were completed. Once a general performance pattern was established and enough data were collected to evaluate our scoring criteria, we halted events. As individual event score sheets show, the longest time spent during any event was six hours. Since we cap event durations for each team in the actual competition at eight hours, we would expect that these notional scores would only increase. Each score sheet shows the separate score buildups by category (explained more in each following section.) They also show competiton event-level metrics in the form of violations. For example, perimeter violations are worth 50 points each, each surface damage penalty and surface grade penalty were worth 1 point each (see Rules document for more explanation.)

Geophysical Mapping Trial

Scores and Comments

The event score was 238 out of 250 possible (see Figure 20.) This represents the revised score after removing the boundary violations (which would have made the actual score less than negative 2,000, with each boundary violation counting as a 50 point penalty.)

Geophysical Mapping Event Score	238.02		
System Task Performance	226.05		50%
Level of Human Interaction	250		40%
Man Hours to Perform the Task	250		10%
Competition Level Metrics			
	Points/violation	Violations	Total
Perimeter or No-go area violation	50	0	0
Exclusion zone violation	DQ		
Surface Damage (>15 cm)	1	0	0
Surface Grade (>15 cm)	1	0	0
Total Point Penalty			0
System Task Performance (250 points)	226.05		
	Possible points	Violations	Total
Delivery of Raw Data (correct format within 48 hrs)	250	0	0
Noise Level	70		70
Sensor Coverage	60		57
Anomaly Location Accuracy	60		59.05
Survey Speed	60		40
		Design Speed	
		0.6	m/s
Level of Human Interaction (250 points)	250		
	Possible points		
Description of Level of Human Interaction	250	Human Interaction Pct	
Near zero human interaction	100%	100%	
Minimal Interaction	75%		
Moderate Interaction	50%		
Frequent Interaction	25%		
Continuous Interaction (completely tele-operated.)	0%		
Man Hours to Perform the Task (250 points)	250		
		Start Time	End Time
Elapsed Time	4:58:06	12:21:24	17:19:30
Number of people on site	2		
Total Man-Hours	9.94		
Man Hours Allotted	16		

Figure 20. Notional Competitor Geophysical Mapping Event Score Sheet.

System Performance

The system task performance score was based on initial data analysis, but is close enough to what the actual score would have been for the purposes of this analysis. The only reason that sensor coverage and anomaly detection scores were not higher was that the trial was halted before the system had managed to completely cover the mapping range.

Level of Human Interaction

The Level of Human Interaction was determined to be near zero, so 100% of those points were awarded. There was actually some amount of human interaction, but most of it can be attributed to not wanting to damage the UXO Trailer. So even though there were approximately 70 human interactions during this event, their total duration accounted for only 1% of the event's elapsed time. Also, most of these interactions happened very early during the event, while the team was being cautious about the system and taking time to build trust.

Man Hours to Perform

Man Hours were calculated as 9.94 (2 people times 4 hours 58 minutes elapsed time) out of 16 baseline hours, so the maximum amount of man hour points were awarded. Baseline man hours for each event were assumed to be 16 hours (Maximum event time of 8 hours multiplied by 2 people: Two people are assumed to be the minimum required for safety.) The current rules calculate the man hours score as awarding the maximum man hours score to any man hours total at or below the baseline and greater man hours amounts as proportionally fewer points. Since, functionally, the maximum number of man hours points that are awarded at the event level is 25 (10% of 250), the overall impact of changes in man hours is relatively small.

Sub-Surface Removal Trial

Scores and Comments

The event score was 43.9 out of 250 possible (see Figure 21.) This event was done using autonomy to move the vehicle into digging position over the dig location, but completely tele-operated digging behavior. A number of problems complicated the teleoperation aspect. There was high video latency and poor video quality (frame rate, resolutions, poor gain resulting in extreme lighting contrast, and compression artifacts) as a result the digging operation was hard to control and the ISOs were hard to see in the video, and so progress was slow. Small ISOs were used in addition to medium and large ISOs.

Sub-surface Clearance Event Score	43.90		
System Task Performance	12.5		50%
Level of Human Interaction	62.5		40%
Man Hours to Perform the Task	166.5		10%
Competition Level Metrics			
	Points/violation	Violations	Total
Perimeter or No-go area violation	50	0	0
Exclusion zone violation	DQ		
Surface Damage (>15 cm)	1	0	0
Surface Grade (>15 cm)	1	4	4
Total Point Penalty			4
System Task Performance (250 points)	12.5		
	Possible points	Number removed	Possible seeds
Sub-surface Seed Removal	250	3	60
Level of Human Interaction (250 points)	62.5		
	Possible points		
Description of Level of Human Interaction	250	Human Interaction Pct	
Near zero human interaction	100%	25%	
Minimal Interaction	75%		
Moderate Interaction	50%		
Frequent Interaction	25%		
Continuous Interaction (completely tele-operated.)	0%		
Man Hours to Perform the Task (250 points)	166.46		
		Start Time	End Time
Elapsed Time	6:00:27	12:51:18	18:51:45
Number of people on site	4		
Total Man-Hours	24.03		
Man Hours Allotted	16		

Figure 21. Notional Competitor Sub-Surface Clearance Event Score Sheet.

System Performance

The system task performance score was 12.5 points based on recovering 3 out of 60 possible seed items. The vehicle navigation behavior was extremely accurate, but two factors contributed to less than optimal digging. One was that the system did not provide any feedback on the position of the backhoe, so it was difficult for the tele-operator to always accurately position the bucket.

Level of Human Interaction

The Level of Human Interaction was determined to be frequent, so 25% of those points were awarded. The vast majority of the event duration time was spent tele-operating the bucket. When digging for a particular ISO was completed, the vehicle was put into an autonomous navigation mode where it moved to the pit area to dump the ISO and then autonomously navigated to the next dig location.

Man Hours to Perform

Man Hours were calculated as 24 (4 people times 6 hours elapsed time) out of 16 baseline hours, so only 166 of the maximum man hour points were awarded. Baseline man hours for each event were assumed to be 16 hours (Maximum event time of 8 hours multiplied by 2 people). Two people are assumed to be the minimum required for safety. In this case, additional people were needed to troubleshoot system problems, so their presence, no matter how brief, was added to the team’s total.

Surface Clearance Trial

Scores and Comments

The event score was 113.5 out of 250 possible (see Figure 22.) This event was performed with an autonomously navigated ARTS pulling and powering a Cherrington Beach Cleaner attachment. Adjustments to the beach cleaner, such as changing the rake position or dumping the bucket, were "tele-operated", in that they were activated from the command trailer by operators monitoring the system's progress and then activating these functions with key presses.

Surface Clearance Event Score	113.5		
System Task Performance	27		50%
Level of Human Interaction	187.5		40%
Man Hours to Perform the Task	250		10%
Competition Level Metrics			
	Points/violation	Violations	Total
Perimeter or No-go area violation	50	0	0
Exclusion zone violation	DQ		
Surface Damage (>15 cm)	1	0	0
Surface Grade (>15 cm)	1	0	0
Total Point Penalty			0
System Task Performance (250 points)	27		
	Possible points		Score
Percent debris removed	125		14
Pile cleanliness	125		13
Level of Human Interaction (250 points)	187.5		
	Possible points		
Description of Level of Human Interaction	250	Human Interaction Pct	
Near zero human interaction	100%	75%	
Minimal Interaction	75%		
Moderate Interaction	50%		
Frequent Interaction	25%		
Continuous Interaction (completely tele-operated.)	0%		
Man Hours to Perform the Task (250 points)	250		
		Start Time	End Time
Elapsed Time	2:10:25	11:41:55	13:52:20
Number of people on site	2		
Total Man-Hours	4.35		
Man Hours Allotted	16		

Figure 22. Notional Competitor Surface Clearance Event Score Sheet.

System Performance

The system task performance score was 27 points based on recovering 44 out of 400 possible seed items, and also having particularly dirty debris piles because no shaker table was used. The ARTS seemed a little underpowered at times while towing the Cherrington attachment, and the large ISOs were particularly problematic, jamming the machine several times. The angle iron and the smaller ISOs were picked up fairly well, but the steel plate was missed. However, these performance issues may have been solved with more practice time and system tuning. The system suffered a mechanical failure after the tool attachment face of the ARTS struck the Cherrington hydraulic pump. As no spares were on hand, this event ended the trial after significant troubleshooting.

Level of Human Interaction

The Level of Human Interaction was determined to be minimal, so 75% of those points were awarded. The vast majority of operators’ time was spent monitoring the system for problems and when attachment adjustments needed to be made.

Man Hours to Perform

Man Hours were calculated as 4.35 (2 people times 2 hours 10 minutes elapsed time) out of 16 baseline hours, so the maximum man hour points were awarded. Baseline man hours for each event were assumed to be 16 hours (Maximum event time of 8 hours multiplied by 2 people). Two people are assumed to be the minimum required for safety. In terms of the overall elapsed time, a significant portion was dedicated to troubleshooting the system.

Vegetation Clearance Trial

Scores and Comments

The event score was 152.5 out of 250 possible (see Figure 23.) This event was performed using two vehicles. The ARTS was used to autonomously position a mowing deck over the portion of the range that was only tall grass and very small shrub. The Gyro-Trac mulching machine, in a complete tele-operation mode, was used to cut trees and mulch them over the portion of the range with trees. The score was the combined score of the two phases.

Vegetation Clearance Event Score	152.5		
System Task Performance	155		50%
Level of Human Interaction	125		40%
Man Hours to Perform the Task	250		10%
Competition Level Metrics			
	Points/violation	Violations	Total
Perimeter or No-go area violation	50	0	0
Exclusion zone violation	DQ		
Surface Damage (>15 cm)	1	0	0
Surface Grade (>15 cm)	1	0	0
Total Point Penalty			0
System Task Performance (250 points)	155		
	Possible points	Violations	
Vegetation Tree Removal (>8 cm)	125	34	40
Vegetation Residue Removal (>15 cm)	125	4	115
Level of Human Interaction (250 points)	125		
	Possible points		
Description of Level of Human Interaction	250	Human Interaction Pct	
Near zero human interaction	100%	50%	
Minimal Interaction	75%		
Moderate Interaction	50%		
Frequent Interaction	25%		
Continuous Interaction (completely tele-operated.)	0%		
Man Hours to Perform the Task (250 points)	250		
		Start Time	End Time
Elapsed Time	1:41:00	10:15:00	11:56:00
Number of people on site	2		
Total Man-Hours	3.37		
Man Hours Allotted	16		

Figure 23. Notional Competitor Vegetation Clearance Event Score Sheet.

System Performance

The system task performance score was 155 points based on having successfully mowed half of the range and having cut down 16 of 50 trees on the range, but only successfully mulching 12 of the 16 trees. Had the mowing not been as successful, with swaths left unmowed, the score would have been reduced vegetation residue removal penalties.

Level of Human Interaction

Since the “mowing” portion was done using no human interaction and the tree cutting portion was done completely tele-operated, the aggregate level of human interaction was determined to be 50%. During the mowing phase, there was one human interaction with the system to change the speed of the machine.

Man Hours to Perform

Man Hours were calculated as 3.37 (2 people times 1 hour 41 minutes elapsed time) out of 16 baseline hours, so the maximum man hour points were awarded. Baseline man hours for each event were assumed to be 16 hours (Maximum event time of 8 hours multiplied by 2 people). Two people are assumed to be the minimum required for safety. It was assumed that the two different phases occurred simultaneously. They did not during the trials, but the score would not change appreciably regardless.

Analysis to Illustrate Different Levels of Autonomy

To give the reader a sense of how different autonomy levels change event scores, see Figure 24. The chart illustrates the changes in event score as a function of autonomy level, ranging from completely tele-operated (0%), moving to a more balanced competitor solution (50% autonomy), to a nearly completely autonomous solution (100%).

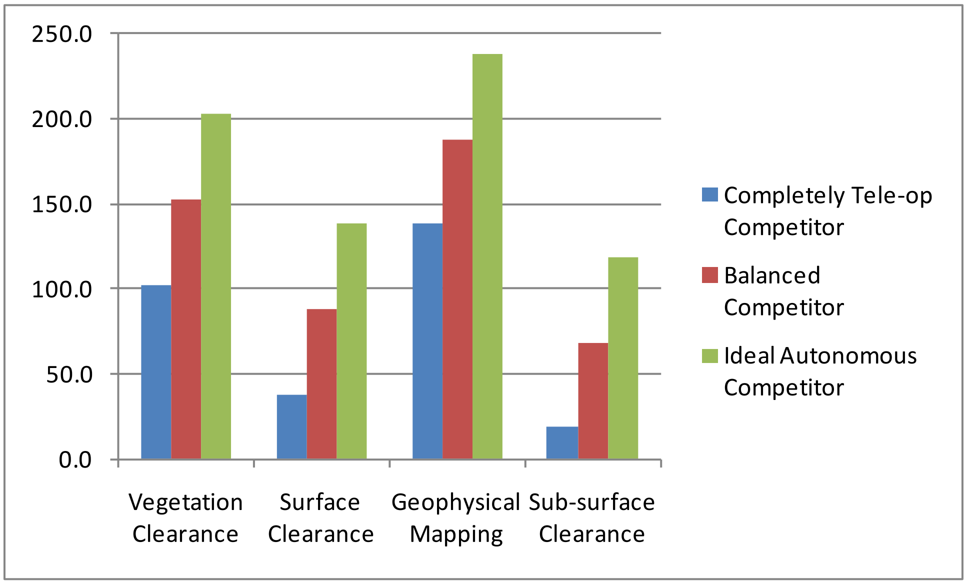


Figure 24. Event Score as a Function of Autonomy Level.

These scores were calculated using the system performance and man hours scores that were found during the validation trials. Under the current scoring scheme, moving from a 0% autonomy score to a 50% autonomy score results in a 50 point increase. The same increase occurs moving from 50% to 100% autonomy. What is not captured is how an increase in autonomy might enable a team finishing sooner, or more significantly, attaining a higher system performance score as a result. But it is clear that higher levels of autonomy will result in significantly higher scores, even if performance is unaffected.

Outcomes

Validated Range Construction Approach and Logistics

Finding: Facilities and competition ranges were appropriate for this test.
Recommendation: Two hard sided "worksite trailers" will be provided for the support of competition management and distinguished visitors. One trailer will be for the R2C2 mgmt/support team the second trailer will be reserved to support business needs of the JGRE director, Chief Judge, and any distinguished visitors (i.e. military commanders/ generals, congressional personnel, etc.). The management trailer configuration will be selected by JTEC personnel. The Distinguished Visitor (DV) trailer should have at least two private offices and a conference area with comfortable chairs, internet connections, and a couch.

Validated Scoring Criteria

Finding: The range perimeter established for this test was too restrictive and resulted in numerous (~45) excursions (penalized at 50 points each).
Recommendation: The setup of the competition areas will be modified so that the area of operation will be defined as 30 meters around the perimeter of the target area. The penalty area will be 3 meters outside of this area of operation.

Additional Recommendations

The following represent additional recommendations for the actual competition:

- The competitors will be given the opportunity to arrive at the competition 1 week prior to the start. They will be provided practice areas to fine tune and debug any last minute issues or failures of their systems during this time. For the competition they will then have their assigned time to complete the competition task. The only exceptions to this will be for weather, safety, or military priority issues that might delay or impede the competition activity.

- The dig map provided for the Sub-Surface UXO clearance tasks will include a "target strength value" to represent a realistic geophysical mapping product. The makeup of this value will be determined through consultation with Mr. Andy Schwartz, USACOE Geophysicist. In addition to assigning a weighted value to UXOs, we will not include the “small” type ISOs in Sub-Surface clearance ranges. However, we will keep the total number of ISOs at 50-60, or 25-30 Large ISOs and 30 Medium ISOs.

- A meeting between the JGRE director and Camp Guernsey Garrison Commander is suggested to discuss importance of this activity and commitment for a guaranteed level of lodging and support.

- The Oversight IPT should review the categories of human interaction to ensure that they reflect the intent of the competition. Currently, any automated behavior at all, no matter how little, results in 25% of the available human interaction points.

Recommended Changes to Competition Rules

The outcomes of the validation trials in October suggest that the following changes to the rules be considered.

Area of Operation Boundary

The Area of Operation Boundary will be defined as being 30 meters beyond the range boundary and the language in the Rules document will be changed for consistency of terminology.

This change results from the number of boundary excursions that occurred during the geophysical mapping trials. The Notional competition team "lost" 2,050 points due to their excursions (a 50 point penalty for each), resulting in a net negative score. It was determined that the boundary was too restrictive as it was operationalized for the validation trials. A larger boundary to allow machinery to turn around with incurring a penalty has been recommended.

We will add a graphic to the rules document that assists in term clarification as shown in Figure 25.

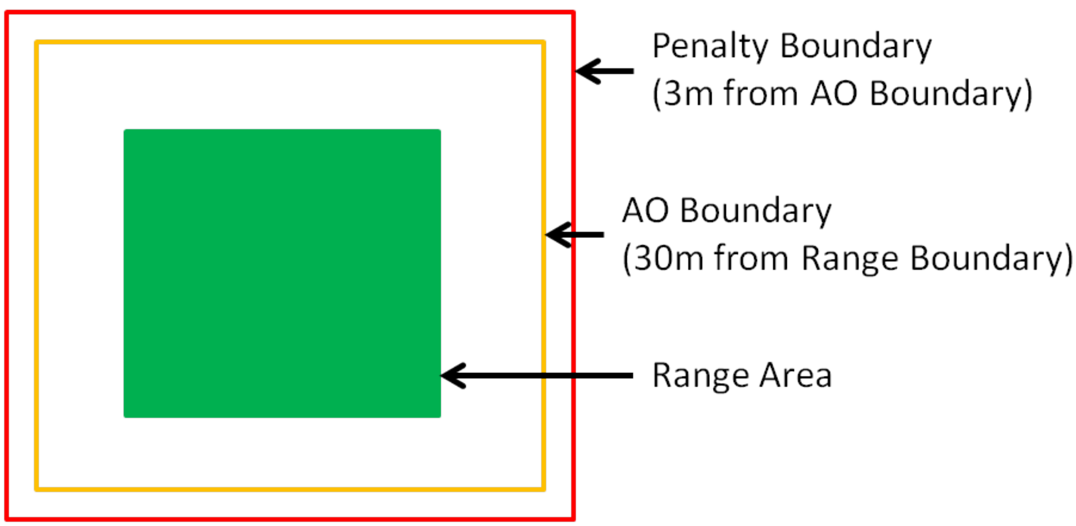


Figure 25. Graphical Depiction of different areas.

Surface Clearance QC Pickup

In Surface Clearance section, rule "A.c" will be changed from referring to "weight" of the QC pickup to "number". This will greatly simplify the QC check for this event.

The current rule states that the material in the QC pickup will be weighed to determine the performance penalty. However, given the number of pieces and their high-visibility color, it was determined that it will be easier to count the pieces than it will be to accurately weigh them.

Standoff Range

Currently, the Rules document states that all competitors must remain outside of the exclusion zone during an event, which is 870 meters. This distance is impractical to enforce during the competition due to site size considerations. We will modify the rules document to state that all systems must be capable of operating at 870 meters, to simulate the minimum safe standoff distance for large artillery disposal operations, but during the competition, competitor personnel must remain outside the Area of Operation. Further the term “Exclusion Zone” section in the Rules and Metrics Document should be changed to “Standoff Capability Parameters” to better reflect the intent of this section.

Continual Effort

During an event, each Competitor Team must make a continual effort to complete the event until the goal or the 8-hour time limit has been reached. If a Competitor Team stops attempting to make progress toward the event goal, their score for the entire event will be zero. A continual effort shall constitute any and all efforts to fix, repair, rework or brainstorm solutions to non-functioning equipment. If it is determined by an R2C2 observer that continual effort is not being made the observer will inform the competitor’s team leader by giving one warning. If the observer does not see efforts resumed immediately, the competitor shall be given a score of zero for the entire event.

The purpose of this suggested rule change is to prevent teams from preserving their man hours and human-interaction scores by not performing. Currently, the rules do not preclude a competitor from simply declaring that they have begun the competition and then immediately declaring they have completed the competition without actually doing anything. If a competitor were to do that under the current rules, they could actually receive 125 points out of 250 for any event they entered. This strategy needs to be discouraged as it does not meet the intent of the competition.

Theshold Performance

It is expected that for any competitors to win an event, they must have completed a certain portion of that event to ensure that the JGRE can be satisfied that winners are recognized for having performed reasonably well, and not just less poorly than other competitors (i.e., no winners by default.) Therefore, in order to be eligible for prize money in any event, competitors will have had to complete at least 25% of the goal for that event.

Vegetation Clearance

A rule change is recommended in vegetation clearance scoring to count any tree that is not cut as a tree removal penalty and also as a residue removal penalty. The intent of this rule change is to put more emphasis on cutting trees and less emphasis on keeping mulch to a manageable depth.

Currently, the scoring for vegetation clearance is equally weighted (125 points) between tree cutting and mulch depth management. However, consider two teams that both maximize their human interaction score and their man hours score. One of the teams cuts all of its trees down, but gets penalized an equal number of points for failure to keep mulch under the maximum 15cm depth. That team’s score would be 187.5 under the current rules.

This is an illustration of the impact of the current scoring system on Vegetation Clearance. Both score sheets assume perfect scores for human interaction and man hours. The first score (187.5), in Figure 26, represents cutting all trees, but receiving 125 points in penalties for leaving mulch at too great a depth. The second score (203.125), in Figure 27, represents cutting only 25% of the trees, but no residue penalty.

Vegetation Clearance Event Score	187.5		
System Task Performance	125		50%
Level of Human Interaction	250		40%
Man Hours to Perform the Task	250		10%
Competition Level Metrics			
	Points/violation	Violations	Total
Perimeter or No-go area violation	50	0	0
Exclusion zone violation	DQ		
Surface Damage (>15 cm)	1	0	0
Surface Grade (>15 cm)	1	0	0
Total Point Penalty			0
System Task Performance (250 points)	125		
	Possible points	Violations	
Vegetation Tree Removal (>8 cm)	125	0	125
Vegetation Residue Removal (>15 cm)	125	125	0

Figure 26. Current Scoring System - Cutting All Trees with Maximum Residue Penalty.

Vegetation Clearance Event Score	203.125		
System Task Performance	156.25		50%
Level of Human Interaction	250		40%
Man Hours to Perform the Task	250		10%
Competition Level Metrics			
	Points/violation	Violations	Total
Perimeter or No-go area violation	50	0	0
Exclusion zone violation	DQ		
Surface Damage (>15 cm)	1	0	0
Surface Grade (>15 cm)	1	0	0
Total Point Penalty			0
System Task Performance (250 points)	156.25		
	Possible points	Violations	
Vegetation Tree Removal (>8 cm)	125	93.75	31.25
Vegetation Residue Removal (>15 cm)	125	0	125

Figure 27. Current Scoring System - Cutting 25% Trees with No Residue Penalty.

So, under the current scoring scheme, cutting ¼ of the trees perfectly results in a higher score than cutting all of the trees imperfectly.

There are at least two ways to handle this. **1) Consider a non-felled tree as not only a tree removal penalty, but also a residue penalty**. That way, there is no advantage to leaving trees standing while focusing on mulching. If a competitor only cut 25% of the trees in this case, they would only receive a total of 25% of the System Task Performance points, resulting in a maximum possible total event score of 156.25 (shown in Figure 28.)

Vegetation Clearance Event Score	156.25		
System Task Performance	62.5		50%
Level of Human Interaction	250		40%
Man Hours to Perform the Task	250		10%
Competition Level Metrics			
	Points/violation	Violations	Total
Perimeter or No-go area violation	50	0	0
Exclusion zone violation	DQ		
Surface Damage (>15 cm)	1	0	0
Surface Grade (>15 cm)	1	0	0
Total Point Penalty			0
System Task Performance (250 points)	62.5		
	Possible points	Violations	
Vegetation Tree Removal (>8 cm)	125	93.75	31.25
Vegetation Residue Removal (>15 cm)	125	93.75	31.25

Figure 28. Proposed Rule Clarification - Cutting 25% Trees with Equal Tree and Residue Penalty.

2) Change the point distribution between clearance and mulching. One possibility is to change the point values so that tree removal is worth 200 points and the maximum residue penalty is 50 points.

In that scoring scenario, the same performance situation results in a 50 point advantage for cutting all trees versus cutting only 25% of the trees with no mulch penalty. Figures 29 and 30 show the scoring illustration.

It should be noted that this scenario is only valid if the maximum mulch (residue) penalty is capped. If the penalty can be greater, then this effect is lessened. The reason is that in this rules interpretation, there can only be a residue penalty for a tree that has been cut. Any tree not cut will not count against the residue penalty part of the score. So it will not hurt a competitor to leave trees (besides the existing tree cutting penalty).

Vegetation Clearance Event Score	225		
System Task Performance	200		50%
Level of Human Interaction	250		40%
Man Hours to Perform the Task	250		10%
Competition Level Metrics			
	Points/violation	Violations	Total
Perimeter or No-go area violation	50	0	0
Exclusion zone violation	DQ		
Surface Damage (>15 cm)	1	0	0
Surface Grade (>15 cm)	1	0	0
Total Point Penalty			0
System Task Performance (250 points)	200		
	Possible points	Violations	
Vegetation Tree Removal (>8 cm)	200	0	200
Vegetation Residue Removal (>15 cm)	50	50	0

Figure 29. Proposed New Scoring - Cutting All Trees with Maximum Residue Penalty (Point Value Change).

Vegetation Clearance Event Score	175		
System Task Performance	100		50%
Level of Human Interaction	250		40%
Man Hours to Perform the Task	250		10%
Competition Level Metrics			
	Points/violation	Violations	Total
Perimeter or No-go area violation	50	0	0
Exclusion zone violation	DQ		
Surface Damage (>15 cm)	1	0	0
Surface Grade (>15 cm)	1	0	0
Total Point Penalty			0
System Task Performance (250 points)	100		
	Possible points	Violations	
Vegetation Tree Removal (>8 cm)	200	150	50
Vegetation Residue Removal (>15 cm)	50	0	50

Figure 30. Proposed New Scoring - Cutting 25% Trees with No Residue Penalty (Point Value Change).

Therefore, to simplify any rules change, the **final recommendation is to implement the first option and include a residue penalty if a tree remains standing**. This change will really be only a rules clarification, and not a substantial change.

Appendix A

Range Seeding Work Plan, QA Plan, and Field Manual

Introduction

Purpose

The purpose of the work plan for seeding the geophysical mapping range is to ensure that the range build requirements are clearly documented and that the process for creating the range and burying all of the seed items is clearly understood and accepted.

Scope

This document will describe the range requirements to include location, size and dimensions, seed items, their sizes and locations, appropriate burying procedures, range survey procedures and appropriate quality control checks.

Objectives

The geophysical mapping range being built in the North Training Area (NTA) of Camp Guernsey, WY is an area seeded with industry standard objects (ISO) acting as surrogates for unexploded ordnance (UXO) in order to present a geophysical mapping challenge to R2C2 competitors. In building this range with a known ground truth (i.e., precise descriptions and locations of seeded ISOs), the R2C2 can evaluate the effectiveness of competitors' robotic solutions to geophysical mapping challenges.

General Range Locations

Figure A-1. Map of Wyoming Showing General Location of R2C2 Ranges.

The Geophysical Mapping (GM) Range

The range to be constructed has an area of approximately 2 acres, located in the North Training Area of Camp Guernsey, WY. Figure A-2 shows a Google Earth image of the

Geophysical Mapping Range to be constructed and also shows its proximity to the other ranges being constructed.

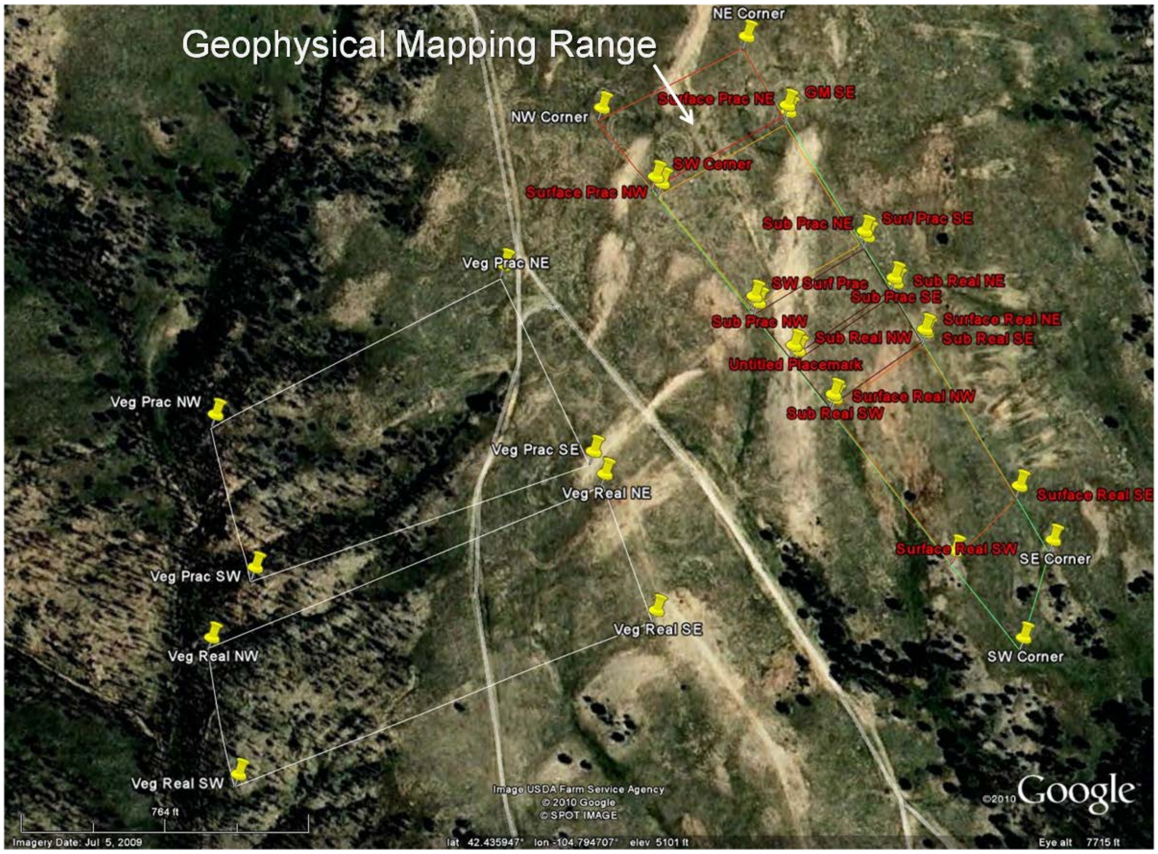


Figure A-2. Locations of R2C2 Ranges being constructed in Camp Guernsey NTA.

Location

The GM range is the northernmost range and is defined as a four sided polygon with corner locations defined in Table A-1.

Table A-1. Geophysical Mapping Range Corner Post Coordinates

Range Name	Location ID	MGRS Coordinates
Geophysical Mapping Range	NE Corner	13TEG1701598501
	NW Corner	13TEG1690098445
	SE Corner	13TEG1704898447
	SW Corner	13TEG1694398390

Range Preparation Process

This is an overview description of the range preparation process. A more detailed description of surveying and QA procedures appears at the end of this document. Range preparation begins with a precise survey of all four corner posts. Their approximate locations are given in Table A-1. Corner post locations will be established within the range in Table A-1, marked with stakes, and the stake locations precisely surveyed. Corner locations will then be recorded in a table with their location identifier, latitude (in decimal degrees), longitude (in decimal degrees), and elevation (in meters above the WGS84 datum.) A GPS-based system with Real-Time Kinematic (RTK) correction will be used to provide accuracy to within +/- 3 cm.

The next step in the preparation process is for the range to be mowed, or cleared of all vegetation taller than 8cm.

We will then randomly place obstacles on the range. The obstacles will be constructed of railroad ties.

The next step to prepare the range is to create a geophysical baseline map. We will use the UXO Trailer built by ARA's Northeast Division (NED) as the baseline mapping equipment.

Once the geophysical baseline has been produced, we will use it to plan the seeding of the range with small and medium industry standard objects (ISO).

The final step is to dig the seed locations, place the ISOs, survey and record their locations in latitude, longitude, and depth in centimeters, and bury the ISOs.

Equipment

The survey equipment consists of an Ashtech Magellan ProMark3 RTK GPS survey kit. Figure A-3 below shows the kit in use.

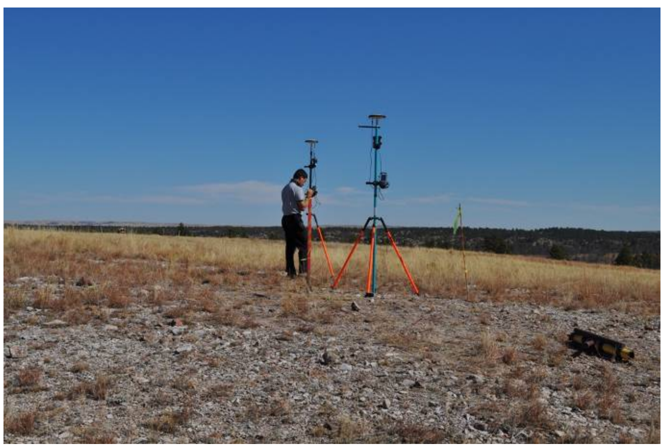


Figure A-3. Ashtech Magellan ProMark 3 RTK Surveying Equipment in Use.

The NED UXO Trailer is a towed trailer featuring a Minelab Single Transmit Multiple Receive (STMR) metal detection array. The detection array is a Time domain electromagnetic induction sensor. The trailer is shown in Figure A-4.

Figure A-4. The NED Basic UXO Trailer.

Corner Survey Procedures

We will use a crew trained in the use of the Ashtech Magellan ProMark 3 RTK system.

The project manager will establish the actual locations of the corner posts.

The survey team will place the corner posts at their predetermined locations and then survey their locations.

The surveying team will ensure that their measurements are precise up to +/- 3 cm in the x, y, and z dimensions by allowing enough time for the GPS receiver to resolve its location to a sufficient accuracy.

The survey team will record the precise locations of the corner posts.

The survey team will then reacquire each corner post location and verify the documented coordinates.

Mowing Process

We will use a brush cutter/ bush hog to cut down all of the vegetation on the range as low to the ground as possible.

Obstacle Placement Process

Obstacles will be constructed of railroad ties. Each obstacle will be constructed of 10 railroad ties – a bundle of 2 by 5. Obstacles will be placed at various locations (to be determined) on the range.

Geophysical Mapping Baseline Procedures

The geophysical mapping baseline will be completed on the GM range after the corners of the range have been surveyed, but before the seeding has been done.

ARA's NED will collect baseline geophysical data for the entire range and build a geophysical map showing the electromagnetic response of the range.

Baseline data will be collected at the appropriate speed and line spacing for the Minelab STMR array.

Data will be collected in a form appropriate for post-processing by tools such as Oasis Montaj.

Collected data will be analyzed for average electromagnetic response in millivolts and nanoTeslas.

Localized peaks will be identified for marking on the range as unacceptable seed locations.

Seeding Procedures

Using the analyzed baseline data, the project manager will determine, with recommendations by the project geophysicist, the approximate locations of each of the 63 medium and 63 small ISO being used as seeds.

All seed locations will be selected so that no other anomaly, either pre-existing or another planned seed, will be within 2 meters of a seed location. Since the mapping area is approximately 2 acres this means about 1,875 potential 2m x 2m locations exist from which we need only find 100 to 125 that are "clean."

All seed items will be either the small or medium ISO (see Figure A-5.) (Only localized sensor responses are needed to assess how well robotic systems measure where EM data are collected. Therefore, large ISOs are not needed.)

Figure A-5. Picture of ISOs required for the R2C2.

The ISOs are described in Table A-2.

Table A-2. ISO Descriptions and Specifications.

Item	Nominal Pipe Size	Outside Diameter	Length	Part Number[1]	ASTM Specification
Small ISO	1"	1.315" (33 mm)	4" (102 mm)	44615K466	A53/A773
Medium ISO	2"	2.375" (60 mm)	8" (204 mm)	44615K529	A53/A773
Large ISO	4"	4.500" (115 mm)	12" (306 mm)	44615K137	A53/A773

[1] Part number from the McMaster-Carr catalog.

All seeds will be buried perpendicular to the local ground surface (i.e. vertical with respect to the local topography). Coordinate accuracy will be +/-2cm in x, y and z, vertical orientation will be accurate to +/-5 degrees. These burial parameters will result in strong, single, monopole responses from horizontal loop EM systems such as the EM61 MK2.

All seeds will be placed in the ground at a depth of 5 to 7 times their diameter. All depth measurements will be to the center of the items. This may require that for each size of ISO, an offset representing the distance from the end of the ISO (the top, when buried vertically) to its center, is added to each survey measurement, if that measurement is taken at the top of each ISO.

Figure A-6. An ISO Being Surveyed in its Burial Location.

(Obstacles will be emplaced on the range. The R2C2 will identify how close competitors are expected to get to these obstacles. No ISOs will be seeded within the buffer surrounding these obstacles.)

The burial team will ensure that the ISOs are buried at the appropriate depth by double checking that the ISO for burial is the appropriate size and that the depth is 5 to 7 times the diameter of the ISO.

The burial team will survey the burial location (x,y, and z) and record it in the log

Description of Validation Trials (Surveying)

Survey Equipment Setup

Ad Hoc Monument

Repeated operation of the GPS system requires precise placement of the Base station. If the Base station is moved between samples, the measured points will be offset from existing points. To accurately place the Base station, we drove a pair of stakes into the ground to mark the position of the Base station. The point at the bottom of the Base station rod rested on top of the stake and pressed firmly against the other. This arrangement ensured that the GPS system was properly aligned above the same point every time it was used. The bubble level on Base station rod was used to ensure the rod was vertical, and the stakes ensured the horizontal and vertical positions were correct. This ad hoc monument proved very effective for positioning the base. Over several days we were able to consistently find staked out points within centimeter accuracy. For future surveying efforts, a more permanent monument is suggested. Though the stakes were effective, after a week of use, they were beginning to loosen, and may have become unstable with continued use. The position of the monument was selected to provide the best line of sight to all of the testing areas. It was on a slightly elevated area that was close to the center of the test ranges.

Figure A-7: Picture of Ad-Hoc Monument.

Base Setup

Our Promark 3 RTK Base station was setup with two main reference files “BSUBR” and “BSUBP” in the Fast Survey Program. These reference files serve to accurately relocate the GPS Base station with respect to the UTM system such that we may have +/- 1 meter accuracy with respect to the world but, with respect to the Rover Stations location relative to the Base station, we have centimeter accuracy.

We took 999 Points for each of the reference files to localize the GPS with respect to the world’s UTM coordinate system using WGS84 zone 13N. Our GPS elevation mask was set at 7 degrees above horizontal based on terrain around the Base station. We used the BSUBR file for all fields except the Subsurface Practice field where BSUBP was used.

Physical setup was as prescribed by our Geonav Vendor with kinematic bar type setup.

Figure A-8: Physical Setup for Base Station.

Rover Setup

For Our Promark 3 RTK station we used different files for each range's points but had similar settings as the Base station: WGS84 zone 13N, 7 degree elevation mask. Our RTK initialization was done as "on the fly" initialization after learning that the kinematic bar did not any more reliable results. We transcribed by hand all corner points in UTM from a Excel file provided to us into each of the field files. In addition we created an Outer Extents file which contained the extents of the non-vegetation removal fields.

Physical setup was as prescribed by our Geonav Vendor with kinematic bar type setup.

Figure A-9: Physical Rover Setup.

Field Setup

Corner Posts Placement

The GPS locations of the corners of the test ranges were provided to the surveying team. These coordinates were manually entered into the GPS system during system prep. At the field, the “stakeout point” function was used to locate the corner points. The Rover was moved to the corner post locations, and positioned roughly on the bipod. Then the Rover’s rod was plumbed using the attached bubble level. Fine adjustments were made to the position to get the Rover within 0.02 meters of the stakeout point in both Northing and Easting. A point was logged at each stakeout position. Several methods were tried to mark the corner posts, but the most effective method was to drive a 6” plastic stake into the ground to mark the exact position of the point indicated by the Rover. This stake was pounded in until it was flush with the ground so it would not be knocked over by ground operations. Then a 3 foot wooden stake was driven in next to the plastic stake to make the spot easier to identify visually. Camera posts were positioned 3 meters from the position of the marked corner positions.

Simulated UXO Placement

Subsurface:

The geophysical mapping and subsurface clearance test areas had numerous pieces of simulated unexploded ordinance (SUXO) buried at random locations around the field. These simulated pieces were ½”, 3” and 6” diameter steel pipe sections each marked with a 2 digit identifier number. These pieces were buried either using shovels or a small excavator. One team dug the holes and placed the SUXO’s in the holes. The pieces were placed at roughly 45 degrees from the vertical and pointed at various orientations from north. The surveying team then placed the tip of the GPS rod directly on top of the SUXO and plumbed the rod using the bubble level. The orientation of the SUXO was measured as the angle between the upper end of the pipe and magnetic north as shown on a compass. A data point was logged on each SUXO and the point description was edited to include the size, number, and orientation of the piece. After logging, the SUXOs were buried. After burying all of the pieces, the stakeout point function was used to locate each SUXO and a point was again logged. The elevation difference between the first point and the stakeout point provide the buried depth of the SUXO.

Figure A-10: Example of Sub Surface UXO Placement & GPS Measurement.

Surface:

The Surface clearance test areas had numerous pieces of simulated unexploded ordinance (SUXO) scattered on the surface of the test range. These pieces included sections of angle iron, ½” and 3” diameter pipe. These pieces were scattered manually around the fields. No GPS locations were determined for any of the surface debris.

Terrain Mapping

The surface contours of the geophysical mapping, surface clearance, and subsurface clearance areas were determined by logging a grid of GPS points over the surface of the test areas. The areas were all roughly rectangular. The stakeout line function of the GPS system was utilized to stakeout points along the longest side of the test range. The corner points of the test range were used to define this line, then the Rover was walked along this line and points were logged every 10 paces (roughly 10 meters). If significant contour change (e.g., ravines) happened within the 10 meter spacing, additional points were logged at the discretion of the surveyor. After logging all the points along the line, a 10 meter offset was added to the line and the process was repeated. When most of the test range had been mapped in this way, the opposite side of the range was mapped (using the remaining two corner points). If the sides of the test range were not parallel, additional points were logged to ensure a 10 meter grid spacing. If the surface contour will be used to determine changes in grade, it is a good best practice to log data points outside of the test range (offset 10 meters from the sides of the test range). This will help to define a smoother fitted surface during post processing. Logging points outside of the test range was only done for the “subsurface real” test range.

After mapping the surface contour, the Rover was used to mark the locations of notable obstacles in the test range. For the placed obstacles (rectangular stacks of railroad ties), GPS points were logged at the 4 corners of each stack at ground level. For natural obstacles (large rocks, trees, etc.) 4 points were logged at the outer extents of the obstacles at ground level. For every obstacle, the description of the points was modified to describe the obstacle.

Q&A

Geophysical Mapping

Disturbance Documentation Grid

For the geophysical mapping range, a grid was laid out to help characterize the ground disturbance caused by the competitor. The stakeout line function of the GPS system was utilized to stakeout points along the longest side of the test range. The corner points of the test range were used to define this line, then the Rover was walked along this line and points were logged every 20 meters as measured by a tape measure. The process was repeated on the opposite side of the test range. Each logged point was marked with a 3 foot wooden stake. The staked lines were then used to mark the grid. The offset function on the GPS was used to align the Rover 20 meters from the first side, then someone visually sighted between the two staked sides and the Rover to align the point. This process was repeated to generate the full grid. Each grid point was marked with a 3 foot wooden stake.

After marking the grid, the QA team examined each grid area for disturbances caused by the competitor. Each disturbance feature that was potentially out of spec was outlined with bright orange spray paint. For depressions or holes, a photo was taken of the hole with a measuring tape stuck in the hole vertically. Then a GPS point was logged at the deepest part of the depression and another was taken at the nearest undisturbed soil. For areas of positive surface deflection, a 5 pound weight was dropped on the mound from at least 1 ft. above the feature. This was repeated as necessary to push down loose soil and get an accurate measurement of the disturbance. Two photographs were taken after stamping, with a measuring tape in the image for scaling. One photograph was at roughly a 45 degree angle from the ground and the other was from ground level. Then a GPS point was logged on the highest part of the disturbance and a second point was logged at the nearest area of undisturbed soil. This process was to log the exact position and elevation change for each point of interest.

Subsurface Clearance

Disturbance of Dug Holes

For the subsurface real test range, QA was performed on holes left behind from digging up the SUXOs. Photos were taken of the hole and the mound of dirt created from digging. A tape measure was included in each photo for scaling. Three GPS points were logged for each hole. One point was logged at the deepest part of the hole. The rough dimensions of the hole as measured with the measuring tape were stored in the description of the point using the Rover. The second point was logged from the highest point of the mound of dirt left from digging. The rough dimensions of the mount as measured with the measuring tape were stored in the description of the point using the Rover. The final point was measured from the nearest section of undisturbed ground to give a baseline to compare the disturbance height.

R2C2 Competition

Field Manual

There are several intricacies about our GPS systems that were learned during the practice competition. These intricacies are documented here. This Field manual will help the user to conduct all GPS operations relevant to the R2C2 competition. Based on what the user needs to accomplish they can reference this manual for exact inputs and outputs needed to conduct GPS operations fast, reliably and accurately. Most importantly there is a nomenclature section that details out how all files, points, and reference stations should be labeled.

Survey Equipment Setup

Monument Placement & Construction

Monuments are used to mark the position of each Base station's physical location and thus, for each field created, a monument must be placed. It is important that monuments are permanent and immovable as they will be constantly used to accurately obtain reliable GPS positions of field extents, UXO positioning, and Q&A procedures. In the

Field Manual we will document a procedure which will assist in optimal monument placement as well as dictate guidelines for pouring a monument.

Figure A-11: Example Picture of a Surveying Monument (From Google Image Search.)

Physical Setup of GPS Equipment

Base Station Setup

In the Field Manual we will walk though how to setup the Base Station the first time on unstaked fields. It is important to note that the Base station's position accuracy will be about +/- 1 meter with respect to the world. Competitors will have to shift coordinate systems of boundaries or dig sites to be accurate in their coordinate space.

Rover Station Setup

In the Field Manual we will walk though a standard Rover Station setup assuming that the files have been created. The Setup described in this section of the Field Manual will allow the user to take new data points or stake out previously entered data points. Positioning of Rover is not important; this set up can be done while Rover station is in motion. For the ARC competition will be running multiple Rovers to maximize efficiency for GPS Surveying Operations.

File & Nomenclature System setup

We will perform as much Setup before the competition as is possible. This will encompass creating all GPS files, excel tools, and data export formats ahead of time to maximize competition efficiency. As part of this effort we will construct a detailed Nomenclature section that dictates out every file, surveying point, and Q&A documentation procedure as a main section in the Field Manual. By setting up virtually all files trees and nomenclature guidelines ahead of time our team can cross check everything ahead of time and ensure smooth competition operations.

Field Setup

General Field Setup

All of the fields will have “soft” corner markings such that if a competitors robot runs over the corner locations neither the corner nor the robot will be damaged. To solve this problem we will implement two types of corner markers; high-visibility markers and high-accuracy markers. High-visibility markers will be constructed of disposable material and will be destroyed without harm to the competitor should impact occur. The high accuracy markers will be sub surface magnetic nails such that competitor proposed concept of operations should not interact with this marker. Should impact of the high visibility marker occur our team will replace the marker quickly by localizing with the high-accuracy marker. The high-accuracy marker will also be available to competitors should they need to shift their reference planes.

Geophysical Mapping Field Setup

This range type contains buried UXOs, and obstacles that competitors must avoid. For the purposes of surveying operations the subsurface UXOs need to be GPS marked for scoring validation and later removal. Obstacles will have corner points GPS marked and delivered to the competitor. Additionally, a contour map will need to be taken before and after robotic testing to ensure heavy equipment does not disturb the overall grade of the land. The Field Manual will illustrate all operations necessary to create this field as well as document the correct export procedure to deliver competitor information (field corner locations, obstacle corner points, etc.)

Surface Clearance Field Setup

This range type contains surface UXOs for competitor retrieval and obstacles that competitors must avoid. Surface UXOs will be scattered randomly and their positions will not be noted. Just as in Geophysical Mapping, obstacles will have corner points GPS marked and delivered to the competitor. Again, a contour map will need to be taken before and after robotic testing to ensure heavy equipment does not disturb the overall grade of the land. The Field Manual will illustrate all operations necessary to create this field as well as document the correct export procedure to deliver competitor information (field corner locations, obstacle corner points, etc.)

Sub Surface Clearance Field Setup

This range solely has buried UXOs for customer retrieval. These Buried UXO positions will be GPS marked prior to and after burial. The competitor will be provided the surface GPS location. The subsurface location will be used for oversight team retrieval after the competition should they not be recovered by the competitor. The surface locations of the UXOs will also serve as a benchmark for Q&A criteria for disturbance scoring. The Field Manual will illustrate all operations necessary to create this field as well as document the correct export procedure to deliver competitor information (field corner locations, UXO surface locations, etc.)

Vegetation Removal Field Setup

This range type has no added features but contains vegetation to be removed. Large vegetation will have its position documented via GPS surveying by mapping opposite sides of the tree (or other) and interpolating a middle position which will be given to the competitors. Additionally, the oversight team will contour map the entire area for later Q&A evaluation as it pertains to debris and land grade variations. The Field Manual will illustrate all operations necessary to create this field as well as document the correct export procedure to deliver competitor information (field corner locations, large vegetation center points, etc.)

Q&A

Surface Damage Documentation

All ranges will be evaluated based on the latest version of the Rules and Metrics Document as it pertains to surface damage. The oversight team will place stakes in a grid pattern (grid density TBD based on specific range size) for damage evaluation. Q&A team will walk the grid and mark the largest suspect areas of surface damage in each grid unit. We will then take scaled photographs and measurements to obtain the degree of surface or subsurface deflection. After initial measurements the Q&A team will drop a 5-10lb (1ft. x 1ft.) object from a height of approximately two feet above all positive surface deflections. After the weight drop we will document all positive surface deflections. Negative surface deflections will be measured by placing an appropriately sized disk in the deepest part of the hole and measure negative surface deflection from the top of that disk. Specialty tools/jigs may be created for the purpose of standardizing deflection measurements.

Grade Change Documentation

For Surface Clearance and Vegetation Removal Ranges, grade changes must be documented. This documentation is performed by a before and after contour mapping of the topography. Contour mapping will be performed by establishing a major grid spacing based on area size to be mapped. GPS points will be taken approximately along this grid (+/- 1.5 meters). Where there is a high degree of vertical deflection or natural obstacles the grid will be refined appropriately to obtain topography characteristics. The before and after contour maps will be compared based via interpolated mesh projections and evaluated based on the Rules and Metrics Document.

Pile Cleanliness Documentation

For Surface and Subsurface Clearance Ranges, a pile of UXOs will be created. Each pile's state must be documented based on the Rules and Metrics Document.

Appendix C: Competition Rules and Metrics Document

Appendix C: Competition Rules and Metrics Document

Joint Ground Robotics Enterprise
ROBOTIC RANGE CLEARANCE COMPETITION (R2C2)

COMPETITION RULES AND METRICS

v. 6 AUG 2011

Document Change Summary

Section	Description	Date
Introduction - Determination of Cash Prize Competition Winner	Removed minimum performance requirement definition deadline.	13 JAN 2011
Introduction - Minimum Performance Requirements for Cash Prize Eligibility	Minimum Performance Requirements for Cash Prize Eligibility section added	13 JAN 2011
Introduction - Schedule	Changed Competitor In-Process Review schedule to “first two weeks of April 2011.”	13 JAN 2011
Rules – Operational Activities	Removed Exclusion Zone section and replaced with Standoff Capability Requirements	13 JAN 2011
Metrics – Metrics Categories	Added additional explanation of how points in metrics categories combine to create an event score	13 JAN 2011
Metrics – System Task Performance Metrics - Vegetation Clearance - Small Vegetation and Vegetation Residue Removal	Added “(Remaining trees will also count as remaining vegetation.)” to metric	13 JAN 2011
Metrics – System Task Performance Metrics - Surface Clearance - Surface Debris Removal	In A. c. (percent removed score), changed “weight” to “number”.	13 JAN 2011
Introduction - Minimum Performance Requirements for Cash Prize Eligibility	Changed language to read, “the team must participate in each event”	2 MAR 2011
Various	Changed language to consistently refer to “seeded metallic items.”	12 MAY 2011
Introduction – Rules Modifications and Adjudication	Changed competition schedule to reflect IPRs in April/May 2011 and actual competition from 1 August to 20 August 2011.	12 MAY 2011
Introduction – Rules Modifications and Adjudication	Added “Adjudication” to “Rules Modifications” section header.	12 MAY 2011
Introduction – Rules Modifications and Adjudication	Added statement, “The decisions and determinations of the R2C2 management and judges are final.”	12 MAY 2011
Metrics – System Task Performance Metrics - Sub-surface Clearance – Sub-surface Debris Removal	Added clarification to Sub-surface debris removal metrics section regarding requirement for visual identification of seeded metallic items in collection area with unaided eye.	12 MAY 2011
Metrics – Man Hours to Perform the Task	Added clarification language regarding the determination of a man hours baseline.	12 MAY 2011
Metrics – Geophysical Mapping – Sensor Coverage	Removed coverage penalty for less than 95% coverage.	6 AUG 2011

CONTENTS

Introduction

Purpose

The purpose of the Robotic Range Clearance Competition (R2C2) is to quickly tap into the innovation and ingenuity of the commercial robotic technology sector to improve the safety and effectiveness of any or all of the four tasks traditionally associated with range clearing operations:

1. Vegetation removal
2. Surface clearance
3. Geophysical mapping
4. Sub-surface clearance

Background

Range clearance operations as currently conducted are manpower intensive, time consuming, dangerous, and expensive. Initial data from robotic range clearance technology development efforts indicate the strong potential for significant reductions in the time and cost required to conduct range clearing operations. Experiments to date indicate the possibility of reducing range clearance times by two thirds and costs by one third if automated clearing equipment is used.

Additionally, there are no automated “commercial off the shelf” solutions available for the Department to procure. The traditional approach of establishing an R&D program that can be transitioned into a development and acquisition program is not possible within the desired quick turn-around timeframe as none of the uniformed services have programmed funding for this traditional approach. By exercising statutory authority under Section 2374a of title 10 United States Code as amended by Section 212 of the John Warner National Defense Authorization Act for Fiscal Year 2007 Public Law 109-364 to offer a cash prize for development robotic range clearing application, it may be possible to provide the desired capability in a significantly shorter amount of time.

Scope

The tasks associated with range clearance that likely have the greatest potential for applying ground robotics technology include automated vegetation clearance, automated surface debris clearance, automated geophysical mapping, and automated Sub-surface anomaly excavation. The competition will assess the ability of competitor systems to provide increased safety and operational effectiveness to range clearance operations. The competitor systems are expected to have applied robotics technology to all or some appropriate combination of the inherent range clearance tasks in a range clearance operation. Because the competition is focused on increasing safety and operational effectiveness via robotics automation as well as reducing time and cost, competitors are not expected to attempt to develop improved vegetation removal tools or geophysical detection and identification sensor technology.

Objective

The objective of this competition is to advance robotic technology used in range clearance operations in order to increase operational effectiveness while providing greater safety for range clearance team members.

General Competition Objectives

Operations should be as automated as practical. Full automation is desired but not required to compete in the competition. Unmanned tele-operation is the minimum acceptable system requirement to compete in the competition.

No downrange manual operations are authorized with the sole exception of deliberate system recovery operations.

The pre-existing grade shall not be changed more than +/- 15 cm.

Leave each site with no surface damage that would prevent a light truck from traversing the site.

In addition, systems will demonstrate the following category objectives:

Vegetation Removal Objectives

The competition is intended to demonstrate the following Vegetation Removal Objectives:

A. Remove all vegetation to a height no greater than 8 cm above surrounding grade. This will include trees up to 36 cm in diameter (measured at 122 cm height).

B. Vegetation residue must be mulched or removed from the site. Vegetation residue left on the site must be mulched to a height not greater than 15 cm in depth. Residue removed from the site must be placed in a designated area within 300 meters of the site.

Surface Clearance Objectives

The competition is intended to demonstrate the following Surface Clearance Objectives:

A. Remove all seeded metallic items from the surface of the contest site in the areas designated.

B. The site will be seeded with metallic items 20 mm in width or greater.

C. All seeded metallic items removed from the clearance site shall be placed in a designated collection area within 300 meters of the site.

Geophysical Mapping Objectives

The competition is intended to demonstrate the following Geophysical Mapping Objectives:

A. Navigate a digital geophysical mapping platform within the designated area to collect digital geophysical data so that seeded metallic objects can be detected and located to 30 cm or better positional accuracy.

B. Collect raw geophysical data with an objective noise level to be determined at the site.

C. Deploy a time domain electromagnetic induction metal detector and record its data over 100% of the designated area at a line spacing of 50 cm.

The geophysical mapping platform shall be operated at a consistent speed to be determined by the competitor.

Sub-surface Clearance Objectives

The competition is intended to demonstrate the following Sub-surface Clearance Objectives:

A. Remove all seeded metallic items identified in a supplied dig list from the designated area in the contest site. Seeded metallic item depths shall not exceed 1 meter.
B. The site will be seeded with metallic items 60 mm in width or greater.
C. All seeded metallic items removed from the clearance site shall be placed in a designated sub-surface clearance collection area within 300 meters of the site.

Competition Metrics

The metrics for the competition will be derived from the following areas:

A. System task performance
B. Level of human interaction
C. Man-hours to perform the task

Determination of Cash Prize Competition Winner

Competitors may choose to participate in all or some smaller combination of the 4 Events: (1) Vegetation Removal, (2) Surface Clearance, (3) Geophysical Mapping, and (4) Sub-surface Clearance.

The Ultimate Cash Prize will be awarded based on best performance against metrics, not one system against another. Competitors will score points based on their system's performance within each of the Events. The competitor that performs in all four categories and receives the highest score across all of the events will be declared the Overall Competition Winner. Additional cash prizes will be awarded to the best performance in each of the four events.

A Cash Prize of $1M will be awarded to the Overall Competition Winner having met competition objectives and participated in all four events. A Cash Prize of $250K will be awarded to the best performance having met competition objectives in each of the events. It will be possible for the Overall Winner of the $1M cash prize to also win the event cash prizes. The possible cash awards can range from one competitor winning the entire $2M (overall and best in each of the four events) to one competitor winning the Overall Cash Prize and four different competitors each winning a $250K Event Cash Prize. Therefore anywhere from one to five competitors could finish the competition with a cash prize. It is possible that no cash prize is awarded in one or more of the competition events if system performance does not meet the minimum requirements.

Minimum Performance Requirements for Cash Prize Eligibility

For each event a minimum score of 60 of 250 points must be achieved in the system task performance category and a minimum overall event score of 100 of 250 points must be achieved in order to be eligible for the event cash prize. For a team to be eligible for the Ultimate Cash Prize the team must participate in each event and have a minimum combined overall score of 600 of 1000 total possible points.

Rules Modifications and Adjudication

Robotic technology advancement is a key objective of the R2C2. Competitors are invited to communicate directly with R2C2 regarding any rule that restricts their ability to demonstrate technical achievement and innovative solutions.

The R2C2 has the authority to modify the rules at any time. Rules may be modified for many reasons, including accommodation of a promising technical approach that would have been prohibited by the rules.

R2C2 will communicate any modifications to the rules through the competitor SharePoint site and the Competition website.

Clarification questions fielded by the R2C2 shall be answered in the Competition Rules Frequently Asked Questions (FAQ). Questions that have been received but not yet answered will also be posted in the FAQ.

The R2C2 may revise the schedule at any time and interpret the rules in any manner to best meet R2C2's objectives. The decisions and determinations of the R2C2 management and judges are final. The R2C2's decisions are based on a number of factors such as fairness, safety, statutes, program goals, environmental protection, and efficient operations.

Schedule

Below is a notional schedule of competition activities.

Activity	Location	Date
Kick Off Event	Crystal City	22 October 2009
Industry Day	Tyndall AFB	10 Dec 2009
Signed Letters of Intent	Online	3 May 2010
Category Registration	Online	3 May 2010
Optional Competitor Testing	Camp Guernsey	1 Aug to 1 Nov 2010 and 1 May to 1 July 2011
Competitor In-Process Reviews	Competitor site	April/May 2011
Prize Competition Packets Issued	Online	90 days prior to Prize Competition
Prize Competition Packets Due	Online	45 days prior to Prize Competition
Prize Competition	Camp Guernsey	1 August through 20 August 2011

Eligibility & Participation

Participation Process

In order to participate and be prize eligible, interested parties must do the following:

1. Form a team (team is defined as one or more competitors)
    a. Team leader signs a Letter of Intent
    b. Receive access to team SharePoint
2. Choose competition categories
3. In-process Review (IPR)
    a. Host IPR meeting
4. Compete
    a. Submit Prize Competition Packet
    b. Participate in Prize Competition

Team Requirements

The R2C2 is a competition between competitor teams. Competitors will form teams on their own and said teams will meet the following requirements.

Team Leader

Competitor teams must have a team leader. The team leader must be an individual and must sign the Letter of Intent.

Team Members

Individuals may only be on one team.

Vendors

There are no vendor restrictions. Government Furnished Equipment (GFE) is limited to R2C2 approval.

Team Name

Teams must be given a name. R2C2 reserves the right to disapprove names. Names will be granted on a first come first served basis.

Letter of Intent

Letters of Intent (LOI) will be posted at www.roboticrangeclearance.com when available. The team lead for each competitor team must complete and turn in the LOI. The LOI establishes who the competitor teams are. The LOI is not a binding agreement that compels participation in the R2C2. Teams may withdraw from the competition at any time, in writing, without penalty.

Competitor SharePoint

Once a team's LOI is received a SharePoint account will be created. The SharePoint is the primary communication clearinghouse for the competition. Up to two individuals may be given access per team. The Competitor SharePoint is not intended for use as an internal team tool but for external team interaction with the competition oversight.

The Competitor SharePoint has two parts:

- An all competitor level that includes competition documents, the competition calendar, and discussion board.
- A team folder that can only be accessed by your team and the competition oversight.

Category Registration

Teams may choose to participate in all or some smaller combination of the 4 performance categories: (1) Vegetation Removal, (2) Surface Clearance, (3) Geophysical Mapping, and (4) Sub-surface Clearance. Once teams are given access to the SharePoint site they must inform R2C2 of the categories the team will be participating in.

This will allow R2C2 adequate time to resource, approve, and build the surrogate ranges for the prize competition.

Optional Competitor Testing

Any team that does not have access to adequate developmental test facilities may utilize Camp Guernsey with prior approval. Use of Camp Guernsey for optional competitor team testing will have no bearing on the outcome of the prize competition. Packets will be posted on the SharePoint with all required information due 45 days before your requested test period. Packets contain forms that must be filled out and returned to Camp Guernsey that will allow the oversight team to appropriately resource and schedule the testing. Testing space will be available from 1 Aug to 1 Nov 2010 and 1 May to 1 July 2011. No billeting is available in this period. A list of available Camp Guernsey resources will be posted on the SharePoint.

In-Process Review

Participation is required for entrance to the prize competition.

The team shall present a technical briefing to the R2C2 Competition representatives who will review technical approach, progress, schedule, and risks at a time to be scheduled between the R2C2 Oversight Team and each Competitor Team.

Rules

The rules are intended to promote the widest variety of technical solutions.

The competition is structured to represent active range clearance prior to new range construction on an Army facility.

Safety is the number one priority.

Operational Safety

During operation, no personnel shall be closer to a moving Unmanned Ground Vehicle (UGV) than the operator and personnel will comply with their team's approved safety plans at all times.

Safety Officer

Teams shall designate a safety officer for the duration of the competition. Safety shall be his/her sole responsibility while the UGV is operating. UXO technicians are not required.

Emergency Stop (E-Stop)

The system shall have an Emergency Stop (E-Stop). The system must halt within 15 meters and cease all equipment operations when the E-Stop is initiated.

Warning Devices

Each vehicle shall be equipped with a warning light that is activated according to the state of the E-Stop system.

Each vehicle shall display one or more flashing amber warning lights, the combination of which results in visibility 360 degrees azimuthally around the vehicle. The warning light(s) shall operate when the vehicle is in E-stop RUN mode. The vehicle may not commence movement until the warning light(s) has been in operation for 5 seconds. The warning light(s) shall comply with SAE Class 1 standards for warning lights and shall not produce light(s) than can be confused with those of public safety vehicles such as law enforcement, fire, or ambulance.

Loss of Communications Stop

The system shall automatically halt and cease operations if communications with the system are lost or interrupted for a maximum of 2 seconds and may travel no farther than 30 meters.

No Freewheel

The systems shall not be capable of motion when stopped or un-powered.

For example, systems that would roll downhill if shut off are considered freewheeling and are un-safe for competition.

Speed Limit

The Camp Guernsey North Training Area speed limit is 30 MPH. Systems must comply with regulated speed limits.

Applicable Safety Documents

DA-PAM 385-10 Army Safety

EN 385-1-1

Radiated Energy Safety Standards

- Competitors are directed to OSHA 29 CFR 1926.54 and OSHA Technical Manual (TED 1-0.15A), Section III - Chapter 6 (1999, January 20) for relevant laser safety standards.
- Competitors are directed to OSHA 29 CFR 1910.97 (Non-ionizing Radiation) and Department of Defense Instruction 6055.11 (1995, February 21) for relevant RF safety standards.
- Competitors are directed to OSHA 29 CFR 1910.95 (Occupational Noise Control) and OSHA Technical Manual (TED 1-0.15A), Section III - Chapter 5 (1999, January 20) for relevant acoustic safety standards.

Operational Activities

Event Times

R2C2 Range Manager will call the official start and stop times of each event. The total duration of each event will be a maximum of 8 hours. The start times will be coordinated with each team prior to the individual event and subject to change for any management or safety need as deemed necessary by the R2C2 Oversight Team.

The event may be paused for competition event officials and/or the competitors to take sustenance breaks. Any pauses required for sustenance breaks will not be counted against the event time.

Standoff Capability Requirements

Teams must have the capability to fully operate their systems at a range of 870 meters. This is intended to represent the surface danger zone of large munitions. In addition the command locations shall not have guaranteed direct line of sight to the operation sites.

No personnel on range

No team personnel may enter the range at any time without R2C2 Management Team and Range Safety Officer authorization. Violations will result in team member disqualification.

Area of Operation boundary

No system shall be more than 3 meters outside the perimeter of the area of operation (AO) or a penalty will be assessed. The AO boundaries will be defined in a SHAPE file provided to the competitor team.

Mapping data

All raw geophysical data is to be delivered to the R2C2 in the raw data format defined in Section 4 of Data Item Description (DID) MMRP-09-04.

This DID can be found at the following web site address:

http://www.hnd.usace.army.mil/oew/policy/dids/FY09_MMRP_DIDS/MMRP-09-004.pdf.

The data shall be provided by the competitor in two forms.

First the raw unfiltered geophysical data shall be provided after the conclusion of daily data gathering operations before departing the range. Next the competitor shall provide the raw data in a format where it has been merged with the navigation data. The raw geophysical data shall NOT be filtered in any manner.

Second, positioning data may be filtered and merged with positional data to produce what the competitor believes to be the best representation of where geophysical data measurements were actually recorded. All such filtering must be documented in the metadata file(s) accompanying the geophysical data delivery. The merged data must be delivered to the R2C2 Oversight Team within 48 hours of the completion of the geophysical data collection.

Metrics

General Scoring

Competitors may choose to participate in all or some smaller combination of the 4 Performance Areas: (1) Vegetation Clearance, (2) Surface Debris Clearance, (3) Geophysical Mapping, and (4) Sub-surface Debris Clearance. Metrics and scoring methods will be discussed for each of the performance areas.

The overall philosophy of the scoring is that for each event, teams will begin with the maximum points for each category and will lose points as solutions fail to achieve the objective requirements. Each event is worth a maximum of 250 points and will be evaluated with three categories of metrics (system performance, level of human interaction, and man-hours to perform.) The metric and scoring breakdowns for each of these categories and how they apply to each event are described below.

Event and Competition Scoring

Each event is valued equally in the overall competition score, with each event worth 250 points. A team's overall competition score will be determined by the sum of the individual event scores for a maximum total of 1000 points.

Scores in individual events will be accumulated from evaluation of metrics in three categories.

Metrics Categories

Each event has three categories of metrics.

A. System task performance

System task performance metrics will address the objectives related to system performance specific to each event. Higher levels of performance will result in higher scores.

B. Level of human interaction

Level of human interaction metrics will address competition objectives related to encouraging higher levels of autonomy. Lower levels of human interaction will result in higher scores while higher levels of human interaction will result in lower scores.

C. Man hours to perform the task

The Man-hours to perform the task metric will address the competition objective of reducing manpower required to perform the tasks. As man-hours to perform a task or event remain low, points deducted will be low (resulting in a higher score). As man-hours to perform a task increase, via either increased personnel or increased task duration, points deducted will increase (resulting in a lower score).

Each of these event categories is worth 250 points, but weighted according to the breakdown in the next section (Metrics Category Weights) so that the event score maximum is 250 points total.

Metrics Category Weights

Each metric category will have a different weight for each event score. The breakdown is as follows:

A. System task performance (50%)
B. Level of human interaction (40%)
C. Man hours to perform the task (10%)

System Task Performance is the most important factor in the evaluation. Level of Human Interaction is less important than System Task Performance. Man Hours to perform the task is less important than Level of Human Interaction. Metric weighting is consistent across events.

Penalties in Scope of the Entire Competition

These are penalties that are assessed at the event level, but are the same for each event.

A. Teams will be assessed a 50 point penalty each time a robot leaves the range perimeter or enters a no-go area on the range except when going to the pit area or disposal area.
B. Team members will be disqualified from the competition for entering the 870 meters exclusion zone during robotic clearance operations without authorization from the R2C2 Management Team and Range Safety Officer.

Surface Damage

A. The site will be divided into grid areas for assessment.
B. Any surface damage will be measured. Depths greater than 15 cm will be penalized.
C. Points will be deducted for any instance in a grid area.
D. Maximum is one penalty per grid area.

Surface Grade

A. A survey of a pre-determined set of points before and after operations will be conducted by R2C2. The survey points are notionally the corners of the range, where the gridlines would intersect the range boundary and where the gridlines would intersect on the range itself.
B. Points will be deducted if the absolute value of the difference between each measurement from the survey points is more than 15 cm.

Tie-breaking Procedures

A. Tie-breaking procedures are only invoked to determine an event or overall winner.
B. In the event of a points tie the team with the fastest time will be the winner.
C. In the event of a point and time tie then the solution with the greatest autonomy will be the winner.

System Task Performance Metrics

Vegetation Clearance

Vegetation Tree Removal (maximum 125 points)

A. Scoring will be determined by measuring tree stumps on the event range. Teams will begin the event with 250 points. Points will be deducted for each tree or stump remaining greater than 8 cm above the surrounding grade.
B. The vegetation removal score will be difference between 125 and the deductions.

Small Vegetation and Vegetation Residue Removal (maximum 125 points)

A. The site will be divided into grid areas.
B. Points will be deducted for each grid area where remaining vegetation or vegetation residue is greater than 15 cm above the surrounding grade. (Remaining trees will also count as remaining vegetation.)
C. The small vegetation and vegetation residue removal score will be difference between 125 and the deductions.

Geophysical Mapping

Delivery of Raw data

Raw data should be provided to the judges within 30 minutes of completing the geophysical mapping event. The merged data should be delivered to the R2C2 Oversight Team within 48 hours of the completion of the geophysical data collection. If the team does not deliver the merged data by the deadline, the score for the entire geophysical mapping event shall be zero.

Noise Level (70 Points)

A. Using Oasis Montaj's QC tools determine the average level of RMS noise in the raw data.
    a. Baseline noise will be determined by the R2C2 Competition Team.
B. Score will be determined by the following

Noise Range	Points Awarded
Low RMS noise level	Most
Moderate RMS noise level	Some
High RMS noise level	Least

C. Noise ranges to be determined.

Sensor Coverage (60 points)

A. Score will be determined by the percent of the range covered.
B. Score will be determined by the following:

Percentage of coverage multiplied by 60 points = Score

Anomaly Location Accuracy (60 points)

A. Determine anomaly peak response locations using Oasis Montaj's UX-Detect automatic anomaly detection algorithm on the submitted merged data.
B. Number detected scoring
   (# of Detections within 30cm of actual burial location / # seeded metallic items)* 60 = detection score.

Survey Speed (60 points)

A. Using Oasis Montaj, the point-to-point velocities will be calculated for all data collected.
B. Scoring will be based on percentage of the data collected at the specified design speed.
   a. Design speed will be determined by competitor team prior to event.
C. The scoring will be determined by the following table:

Design speed range	Points
98% to 100% within + or - 0.3MPH of design speed:	60 points
95% to 98% within + or - 0.3MPH of design speed:	40 points
75% to 95% within + or - 0.3MPH of design speed:	20 points
50% to 75% within + or - 0.3MPH of design speed:	5 points
less than 50% within + or - 0.3MPH of design speed:	0 points

Surface Clearance

Surface Debris Removal (250 points)

Site will be seeded with material representing surface debris. The objective is to remove all seeded metallic items and to place just the seeded metallic items removed from the site into a designated collection area.

A. Percent removed score
   a. After surface clearance operations are complete, the site will be Quality Control (QC) swept to determine remaining seeded metallic items.
   b. Percent removed score will be calculated as follows:
   c. (Number of seeded metallic items in collection area - Number of seeded metallic items present in QC pickup)/Number of total seeded metallic items * 125 points.
B. Pile cleanliness score
   a. Pile cleanliness score will be calculated as follows:
   b. Average pile percent clean * 125 points, where average pile percent clean is determined by sampling the collection pile and

determining the percent of the pile that is seeded metallic items as a function of the total material in the samples.

C. Surface debris removal score will be the sum of percent removed score and pile cleanliness score.

Sub-Surface Clearance

Sub-surface Debris Removal (250 points)

A. Teams begin the event with 250 points
B. Each competitor team will be given a set of dig coordinates.
C. 5 points will be deducted for each seeded metallic item not recovered and placed in the collection area.
D. Points will be deducted for each seeded metallic item placed in the collection area that is not visually recognizable in its placed condition by the unaided human eye.
E. Points will only be deducted once for each seeded metallic item not recovered or recognizable in the collection area.
F. No sub surface seeded metallic item intended for removal will be at a depth greater than 1 meter.

Level of Human Interaction

Human Interaction, for the purpose of the R2C2, is defined as: any time an operator or team member uses any human-machine interface device such as, but not limited to, joystick, keyboard, or voice recognition software to control any machinery engaged in a competition task.

A. Teams will begin each event with 250 points in this category.
B. Competition team members will be observed by a R2C2 judge and will be filmed for reference.
C. According to the professional judgment of a R2C2 robotics expert (judge), the Level of Human Interaction involved with the performance of the task of the total system will be determined according to the following table:

Percent Score	Description of Level of Human Interaction
100%	Near zero human interaction
75%	Minimal Interaction
50%	Moderate Interaction
25%	Frequent Interaction
0%	Continuous Interaction (completely tele-operated.)

   a. This judgment will account for number of operators and number of robotic systems.

D. Scores will be computed by the percent score * 250 as a function of the level of human interaction judged to have been achieved by the expert judge.
E. Complete tele-operated solutions will get zero points for this metric.

Man Hours to Perform the Task

A. Defined as Total time to perform the task multiplied by the number of people on site.
   a. The number of people on site will be defined as the number of people actively involved in the operation.
   b. Team observers or spectators will be allowed, but any observers/spectators will not be allowed to interact with the competition team during the event.

B. The team captain will notify the R2C2 Range Manager when the team is ready to start the task. This will count as the event start time for the purpose of measuring the "Man Hours to Perform the Task Category."

C. End time will be called when the competitor team captain says they have finished (and when the system has returned to the pit area) or when the time limit of the event is reached.

D. Active team members will be designated by the team prior to the competition event and each member will receive identification (referred to as a "pit pass") designating that status.

E. Any team member without a pit pass who is deemed by the competition to be engaged in assisting the team during the event will be added to the team roster and will be included in the man-hours calculation.

F. The robot must be in the pit area for the end of the exercise to be called prior to the expiration of the time limit.

G. Event durations will be capped.

H. "Phone a friend" does not count against man hours metric.

I. Safety officer does not count against man hours.

J. Score will be calculated as (man hours allotted (baseline) / man hours required) * 250 with a 250 point maximum. The baseline will be determined as the number of team members actively involved in operating the system(s) at the start of each event. This will include any spotters, observers, technical advisors, and similar personnel determined by the R2C2 to be actively involved with operating the system(s).

Appendix D: Judge Guides

Appendix D: Robotic Range Clearance Competition (R2C2) Judges Guide

Introduction

The purpose of this guide is to help prepare the Robotic Range Clearance Competition (R2C2) judges and officials for their duties at the competition event.

The objective of the competition is to advance robotic technology used in range clearance operations in order to increase operational effectiveness while providing greater safety for range clearance team members. There are four events that will be judged separately and then an overall prize based on the best qualifying overall score.

The four events that make up the competition are:

1. Vegetation removal
2. Surface clearance
3. Geophysical mapping
4. Sub-surface clearance

Organization

The judging duties are distributed across six official judges for the competition.

These are:
Chief Judge - Dr Jim Overholt – USA/TARDEC,
Safety Judge - Lucas Martinez – USAF/AFRL,
Autonomy Judge - Mike Bruch – USN/SPAWAR,
Geophysical mapping Judge - Andy Schwartz – USA/USACOE,
Task Judges - Walt Waltz USAF/AFRL and Plyer McManus USA/USACOE.

The duty of each judge is to oversee the events for your responsible areas and then to Adjudicate the scoring for that event. You will have data collection assistants and field referees to assist you. In addition we will be collecting video of as much as possible for you to review if needed.

The Chief Judge is responsible to supervise the judges, data collection assistants, and field referees, verify and validate the scoring of all events, and interpret the rules as applied to competition adjudication matters.

The Safety Judge is responsible to conduct and supervise all of the equipment safety tests, verify and validate the safety test methods, and observe all of the team events to judge any perceived safety violations or issues.

The Autonomy Judge is responsible to supervise the autonomy data collection assistants and observe all of the team events and related autonomy data to judge the level of autonomy of the robotic systems.

The Geophysical mapping Judge is responsible to supervise the geophysical mapping data collection assistants, verify the condition of the event site, observe all of the geophysical mapping events, collect the geophysical mapping data from the teams, and process/calculate the geophysical mapping data to judge the performance to the rules.

The Task Judges are responsible to supervise the data collection assistants, verify the condition of the event sites, observe all of the team events, inspect the condition of the sites and debris/collection areas post event, and to judge the task performance for each event.

Training

There will be judge training for the 1st three days on site for you to practice and get your assistants lined up prior to the event. We will have surrogate robotic systems and operators to perform each of the task events. The expectation is to conduct trial runs and have the judges do mock scoring to practice and work out any details.

Event Activities

For the actual events, the judges are expected to be on site at least one hour prior to the start of each event. The events will last up to nine (9) hours from the start. Due to the nature of the event and the available assistants, there should be ample time for the judges and officials to take breaks and have lunch. Meals and water will be provided at the competition site. At the completion of each event the judges will be responsible to collect all of the data for their event/area, inspect the event sites and collection piles, and then review and score their event. The scores will be submitted to the chief judge who will review the data and then release the judges/officials when he is satisfied with the score. The chief judge will maintain the scores and data in a safe location for record keeping post event.

Facilities

The judges will be staying at the Grey Rocks Ranch facility. There is a conference room at the ranch that can be used for deliberations and meetings to discuss the scoring after the events. At the competition site, there will be a work site trailer for the judges to use for their data collection and on-site needs.

Please refer to the R2C2 Rules and metrics that you have been provided for the scoring breakdowns and official rules, and the R2C2 October Validation Trials AAR and Recommended Rules changes draft final v. DEC 2010

Please refer any questions about your role or the competition event to Mr. Brian Skibba, AFRL (850) 819-6905.

Appendix E: Letter of Intent

SUBJECT: Competitor Letter of Intent to Participate in the Robotic Range Clearance Competition

1. Purpose. OUSD (AT&L)/PSA, LW&M is planning to conduct a Robotic Range Clearance Competition and to award $2M in prizes. This Competitor Letter of Intent (LOI) will act as an expression of intent to participate in the Robotic Range Clearance Competition. The Competitor team or organization agrees to have a mid-progress review and appear at the Competition site for the final Competition at a mutually agreed upon time, ready to perform. This LOI does not constitute or create, and shall not be deemed to constitute or create, any legally binding or enforceable obligation on the part of either party. OUSD (AT&L)/PSA, LW&M reserves the right to cancel the Competition at any time (including the cancellation of any cash prizes) if dictated by Department of Defense (DoD) priorities, availability of funding, lack of sufficient participation of competitors, or for any other reason determined to be in the interests of DoD.

2. Background. Based on the positive response to a previous Request for Information, the Office of Secretary of Defense (OSD), in collaboration with the US Army, is planning to conduct a Competition (with a cash prize for the winner(s)) to foster the ability to clear training ranges of debris and unexploded ordnance using robotic technologies. DoD intends for this Competition to result in viable systems that can be placed into service clearing ranges. To better plan and manage logistical requirements for this Competition, the Competition organizers request that companies or organizations that are planning on entering this Competition make a commitment by signing this LOI. The Competition organizers will publish Competition rules, scoring criteria, and any rule changes in a timely manner.

3. Competitor Understandings and Agreements. The points of understanding and agreement are listed below:

- The competitor teams or organizations agree to abide by the rules of the Competition and agree to accept the judges' rulings as final.
- The Competition will be held at Camp Guernsey, WY.
- Any Government Furnished Equipment (GFE) made available to competitors will be on a first come-first serve basis, subject to availability and military needs.
- If the competitor becomes unable or unwilling to take part in the Competition, the competitor shall notify the competition organizers immediately of its withdrawal. If the competitor withdraws from the Competition, it will not be allowed to re-enter the Competition and its position in the Competition will be forfeited.

4. Team Prime. Each team planning to participate in the Competition shall designate a Prime member. The Prime will be the point of contact with the competition organizers. The Prime will be the representative who signs this LOI for the team. The cash awards for the Competition will be awarded to the Prime. In the event that a member of the team is added or replaced, the Prime is responsible for obtaining approval via the competition organizers. Organizations can participate on more than one team, but they may ONLY be the Prime on one team. No individuals can participate on more than one team. All team members will be listed on Attachment A.

5. Effective date. This LOI will become effective when signed by the Prime member and will remain in effect until the final date of the Competition (planned for calendar year 2011). This LOI must be submitted to the competition organizers no later than 5:00PM (EDT) 03 May 2010.

Team Name	Signature
Date	Organization

Attachment A: Team Members

Team Name			
Company/Organization	**POC**	**Email**	**Phone**

Appendix F: Competitor Logistics Info & Technical Data Package

Appendix F: Competitor Logistics Info & Technical Data Package

Joint Ground Robotics Enterprise ROBOTIC RANGE CLEARANCE COMPETITION (R2C2)

COMPETITOR LOGISTICS INFORMATION AND TECHNICAL DATA PACKET

v. 22 July 2011

1 August through 15 August 2011

Document Change Summary

Section	Description	Date

Table of Contents

1. Introduction

The Office of Secretary of Defense (OSD) in collaboration with the US Air Force and US Army is conducting a Robotic Range Clearance Competition (R2C2) to foster the ability to clear training ranges of debris and unexploded ordnance (UXO) using robotic technologies. The purpose of R2C2 is to quickly tap into the innovation and ingenuity of the commercial robotic technology sector to improve the safety and effectiveness of the four tasks traditionally associated with range clearing operations: 1) Vegetation removal, 2) Surface clearance, 3) Geophysical mapping, and 4) Subsurface clearance.

This packet is intended to provide to competitor teams logistics information and range data for the competition.

2. General Information

The R2C2 events will be conducted on the northern training areas at Camp Guernsey, WY, approximately 25 miles from the main camp. The surrounding area is comprised of mixed grass and sagebrush upland plains with sections of lodge pole pines and cottonwoods. These competition sites are all contained within a 600–acre continuous area at an elevation of approximately 5000 ft. The sites are representative of military impact areas and training ranges that are in need of unexploded ordnance (UXO) clearance. Note: this area has no known history of UXO.

2.1. Schedule

The competition will be conducted from August 7-15, 2011 with a Media/Visitor day scheduled for Thursday August 11. R2C2 competitor practice and setup activities will be conducted August 1-5. Each competition event will be conducted over an 8 hour shift to represent 1 work day starting at 8am until 5pm local time. Depending on the day, up to two teams will be competing simultaneously in separate events. See technical data section for exact location of your ranges.

Table 1: Major Event Schedule.

Event	Location	Date	Time
Competitor Check In	JTEC Office	8/1-8/7/2011	Call to schedule
Practice Week	Competition Area	8/1-8/5/2011	0800-1700
Kickoff/Opening Reception	Building 011	8/7/2011	1700
Competition	Competition Area	8/8-8/13/2011	0800-1700
Media and Visitor Day	Competition Area	8/11/2011	0800-1430

2.2. Notional Daily Schedule

Time	Event
0400	Paddock unlocked.
0500	Check-in begins, anyone arriving after morning briefing checks in at Command and Control before coming into the Paddock.
0515	Morning safety briefing in the Mess Tent. Equipment can be moved to staging areas after the safety briefing.
0600	Ranges open for range walks. Breakfast available in the Mess Tent.
0800	Competition events begin.
1200	Lunch available in the Mess Tent.
1700	Ranges closed. Move all equipment back to Paddock
1730	Fueling begins.
1800	Briefing and announcements for the following day in the Mess Tent. Dinner available in the Mess Tent.
2000	Paddock locked for the night.

2.3. Contact Information

Camp Guernsey Point of Contact: Keith Reedy: (307) 331-3743

Competition Director: Brian Skibba: (850) 819-6905

Competition Logistics: Travis Bruegger: (937) 238-8288

Competition Operations: Dave Malek: (937) 684-6250

Medical Emergencies: 911

Fires/Other Emergencies/Urgent Matters Relating to Camp Guernsey (24 hrs):

Camp Guernsey Fire Desk: (307) 836-7810

In case of fire, **call 911** AND the **Fire Desk**

2.4. Requirements for Field Operations

Competitors must meet the following requirements before they will be allowed to operate on the competition ranges.

2.4.1. Safety Test

All vehicles used on competition ranges must pass a safety test before they will be allowed to operate any vehicles on the real or practice ranges. Safety tests can be completed any time during practice week. See the SAFETY GUIDANCE & REGULATIONS document for details.

2.4.2. Environmental/Cultural Briefing

All competitors must attend an environmental/cultural briefing before conducting any operations in the competition area. This is required for all individuals participating in the competition. The briefing will be held at the Competition Site early in the Practice Week. It is a one-time briefing and should last no more than one hour. When on-site, please see Command and Control (C&C) for more information.

2.4.3. Confirm Radio De-confliction- If necessary, during the competition

If any radio frequency conflicts are identified during practice week, appropriate measures will be implemented to mitigate the problem. When on-site, please contact Command and Control for more information or to report a conflict.

2.5. Other Advisories

While basic necessities will be provided, the competition will be held outside so please be prepared for weather conditions. Range elevations are around 5000 ft. mean sea level (MSL.) The effects of ultraviolet ray exposure from the sun are amplified at these altitudes. Typical early August days are hot and dry (highs in the 90s) with cool nights (lows in the 60s) and possible thunderstorms in the afternoons. Please dress accordingly. Wide brimmed hats, sunscreen, and insect repellant are highly recommended.

All participants should drink plenty of water to prevent dehydration. The R2C2 will provide drinking water onsite.

3. Housing Logistics

All competing teams will be staying in barracks in the Cantonment area at CampGuernsey during the competition. Teams are expected to arrive between August 1st and 5th during normal business hours. Please schedule the arrival of your personnel and equipment with R2C2 Staff prior to your arrival so someone can be available to greet you. R2C2 staff will provide you with room keys and a briefing when you arrive. To schedule your arrival, please contact Paula Frisbey at (307) 836-7839 or pfrisbey@ara.com.

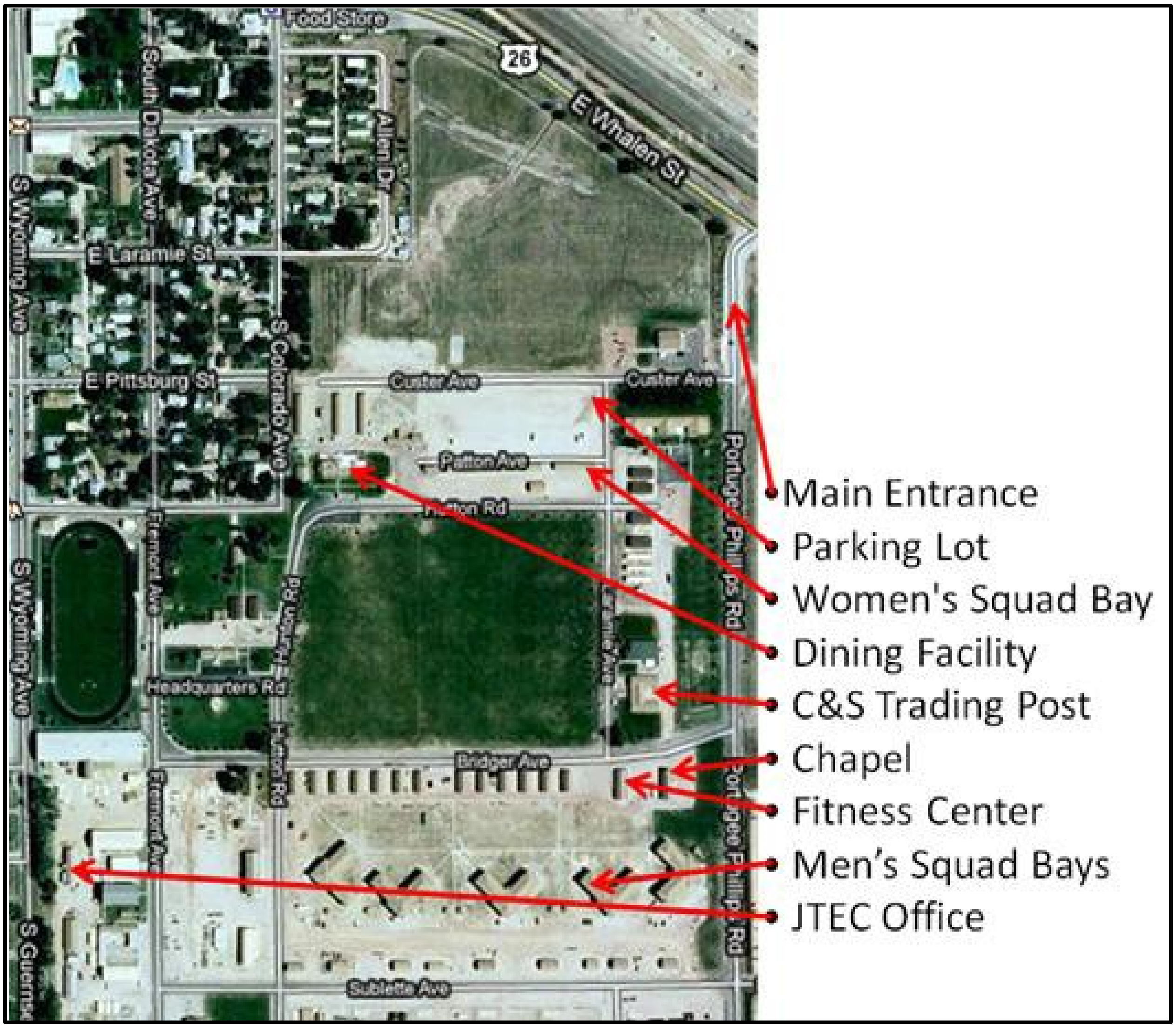


Figure 1: Map of Cantonment Area at Camp Guernsey

Access to the camp is through the front gate only. Guards at the gate will check ID's during entry, but no visit requests are required. Drivers of vehicles must be certified to operate the vehicles they are driving (e.g., if operating a vehicle that requires a commercial driver's license (CDL), the operator must be prepared to present a valid CDL when entering Camp Guernsey).

The Camp Guernsey front gate is open between 0500 and 2200 every day. For after- hours access to the Cantonment Area, you will need to push the intercom button at the front gate to request entry. Large vehicles can be parked temporarily at the parking lot marked on the map shown in Figure 1. However, all competition vehicles and trailers should be moved to the competition area as soon as possible after coordinating that movement with the R2C2 team (see section 2.3 for Points of Contact.)

All competitor teams will be housed in the camp barracks in 8 person squad bays. Men will be in building 501 and women in building 408. Cohabitation is not allowed on Camp Guernsey. You will have access to your rooms at any time after initial check in. Parking is available adjacent to the buildings.

Showers and coin operated laundry machines are available in the barracks. Internet access should be available in the barracks for a fee. You'll find more information in the squad bay or by connecting to the wireless router.

Please obey all posted speed limits, signs, and directions while on Camp Guernsey. Please note that the posted speed limit in the Cantonment area is 20 mph (10 mph when pedestrians are present). The speed limit in the North Training Area (site of the competition) is 30 mph.

3.1. Resources available in Camp Guernsey

Dining Facility – Meals are available in the mess hall for any participants who are not at the competition area. Anyone using the dining facility will sign in at the mess hall sign in table for each meal. Details on this procedure will be provided at check in.

C&S Trading Post – Convenience store. **Chapel** – Check schedule for religious services. **Fitness Center** – Open 24 hours.
Barracks – Housing for all competitors.

Wi-Fi – Wireless internet access is often available in the barracks for a fee. Daily, weekly, and monthly rates are available

3.2. Resources available in and near the town of Guernsey

3.2.1. Hospital/Pharmacy

Register Cliff Pharmacy:
437 W Whalen Ave; Guernsey, WY 82214 (307) 836-9275

Guernsey Medical Center:
1 East Whalen St., Guernsey, WY (307) 836-2422

Platte County Memorial Hospital:
201 14th St., Wheatland, WY 82201 (307) 322-3636

3.2.2. Gas Stations

Johnston's Corner:
550 W Whalen St., Guernsey, WY (307) 836-3155

Shell:
200 E Whalen St., Guernsey, WY

3.2.3. Hardware

Howshar Appliance & Hardware:
18 South Wyoming Avenue, Guernsey, WY 82214 (307) 836-2611

3.2.4. Food

Nana 's Kitchen – Quality Sit Down restaurant with ―home cooking‖;
37 North Wyoming, Guernsey, WY 82214 (307) 836-2010

Craz y Ton y's – Bar and Grill, good low cost grill food, smoky bar atmosphere; Highway 26
Guernsey, WY 82214
(307) 836-2317

The Riverview Restaurant – Diner Food
800 West Laramie, Guernsey, WY 82214 (307) 836-2300

The Lunch Box – (Lunch only)
Just outside the main gate of camp Guernsey

B&F Foods – (Grocery) Open 0700 – 2000 Daily
452 Whalen St., Guernsey, WY 82214 (307) 836-2266

Johnston's Corner –Gas Station Restaurant: Pizza, Fired Chicken, Subs
550 W Whalen St., Guernsey, WY 82214 (307) 836-3155

*Please note that the speed limit in the town of Guernsey is 30 mph. The speed limit drops suddenly when entering town on Highway 26 and the speed limits are strictly enforced in Guernsey.

4. Competition Logistics

The competition will be held in the North Training Area between 0800 and 1700 according to the schedule. Directions to the competition area from the Camp Guernsey Cantonment area (billeting area for teams) are available in the included document–Directions from Camp Guernsey Front Gate to Competition Site.pdf‖. The route to the competition area and back to Camp Guernsey's Cantonment Area will be clearly marked with signs for your convenience.

The Paddock will be unlocked at 0400 each morning and participants must sign in at the Command and Control (C&C) trailer upon arrival. Anyone leaving the competition area must sign out at C&C before leaving the Paddock.

There will be a morning safety briefing every competition day at 0515. The briefing will review all pertinent safety procedures and cover all activities that are scheduled for that day and any changes to the schedule or procedures. Any team participating in competition activities must have a representative present during the safety briefing. Everyone in the Paddock at 0515 is expected to attend the briefing and anyone entering the Paddock after the briefing is expected to review the briefing notices posted at the C&C trailer.

All access to competition ranges will be strictly controlled by C&C. Any movement of personnel or equipment to the ranges or staging areas must be coordinated with R2C2 C&C. All competitors will be escorted to and from the ranges by R2C2 staff.

All competitors will be allotted a space in the Paddock as shown in Figure 2. Competition vehicles and all other equipment should be stored within the allotted space. Non-competition vehicles should be parked in the parking area outside of the fenced Paddock.

The Paddock is fenced and will be monitored by security throughout the competition daily from 1900 at night to 0700 the next morning.

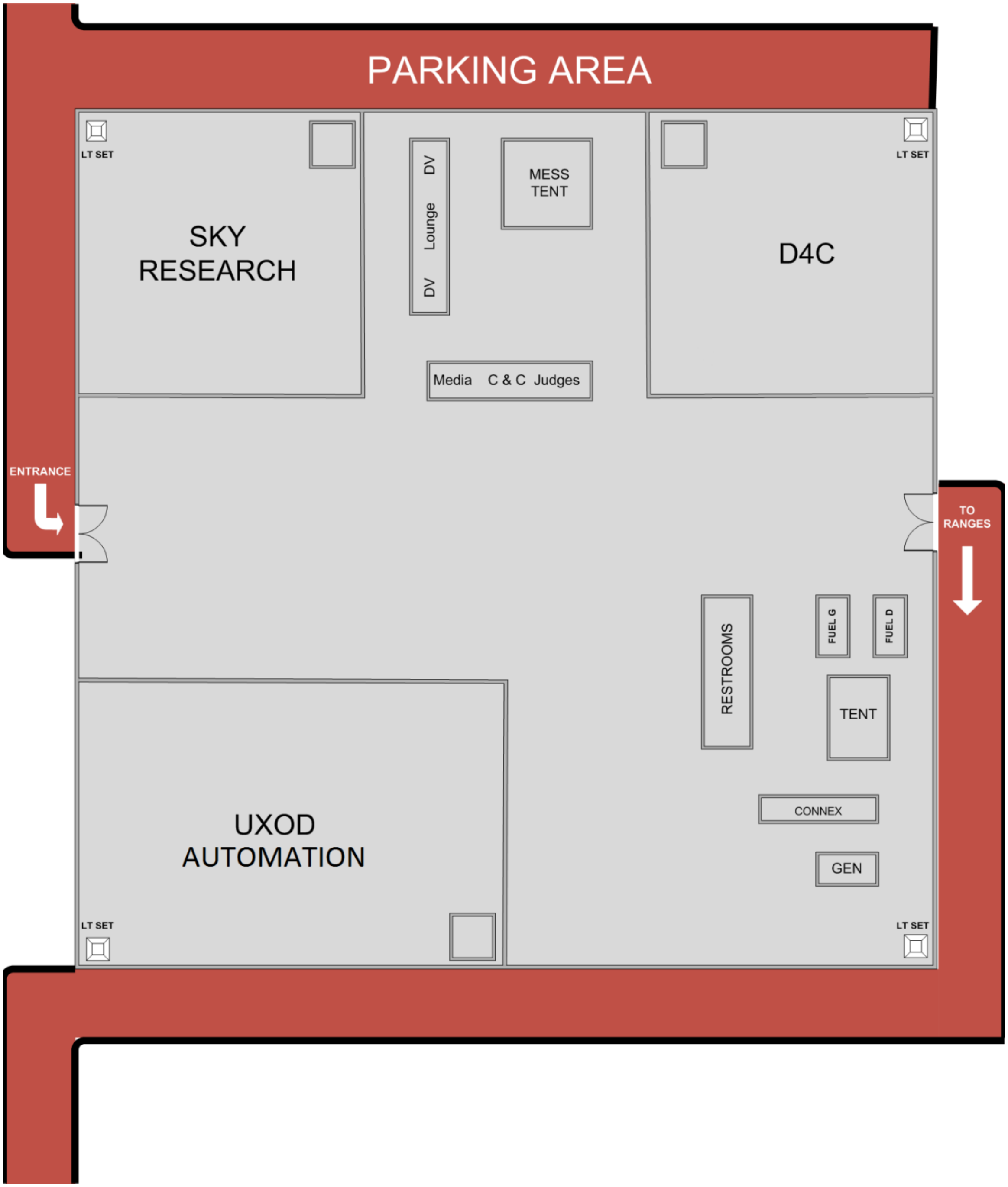


Figure 2: Paddock Area

4.1. Resources available at the competition field

Fueling Station—Fuel will be provided for all competition vehicles.

Restrooms— A restroom trailer will be available in the Paddock area.

Electricity—120VAC is available to competitors inside the Paddock from generators that operate the flood lights (labeled ―LT SET‖ on the map in Figure 2.)

Tent—Each team will be provided with a 15'X15' walled tent in the Paddock.

Meals—Breakfast, Lunch and Dinner will be available in the mess tent **(See Schedule, Section 2.1)**.

Snacks – Snack foods and bottled water will be available at all times in the mess tent.

Mobile phone coverage—Phones operating on the Verizon Network are known to work in most of the competition area, including 3G. Your coverage may vary depending on location.

Internet—No internet connection will be provided to teams by the R2C2, but you may be able to access data services through your cell phone service provider (at your cost).

4.2. Field Data

Each competitor has been assigned a competition range for each event. These are referred to as the ―Real‖ ranges. Competitors shall not operate any equipment on the Real ranges except during their scored events. Each team has also been assigned a practice range for each event that they will attempt. Teams are free to operate any equipment on their practice ranges in preparation for the competition events. The practice ranges approximate the conditions on the real ranges, but some variations should be expected.

Every range is defined by four corner points (Northwest, Northeast, Southeast, and Southwest). All of the corner points and additional data describe below will be provided to the Teams in Shapefile file format. Shapefiles will include 2 sets of 3 files with the extensions: .shp, .shx, and .dbf. The set of three files with the string ―_15‖ in the file name define the boundary lines, while the files with the string ―_11‖ contain the points. All of the files are necessary to fully define the competition range data.

GPS coordinates are given in Universal Transverse Mercator (UTM) system, zone 13N. All files will be named after their respective ranges as detailed below.
Character 1: R: Real
P: Practice
Character 2: #: Specifies range number
Character 3-5: GEO: Geophysical Mapping SUB: Subsurface Clearance SUR: Surface Clearance VEG: Vegetation Removal
Character 6-9: _##: numerical identifier added automatically

Example: R2VEG_15: Real Vegetation Removal range 2

4.2.1. Data Nomenclature

Localization Points: Three localization points will be provided for each range internal to the SHP file system. Additionally a concrete monument has been planted at each localization point to allow competitors to calibrate their GPS readings to the values measured by the R2C2 team. Localization points are named with a three character identifier and one digit identifier number.

Character 1-3: LOC: Specifies Localization Point
Character 4: #: Specifies point number

Example: LOC2 is localization point 2

Range Corner Points: The competition ranges are defined by 3 sets of 4 points. Range Corner Points define the scored area and shall be named after their two character cardinal direction that is most applicable as detailed below. Offset Corner Points
indicate the corners of the 30 meter offset from the range in which competitor vehicles are allowed to operate. Extended Offset Corner Points indicate the 33 meter boundary which competitor vehicles are not permitted to cross (excluding entry sides as dictated by the Rules document).

Character 1: Z: Specifies Range Corner Points
F: Specifies Offset Corner Point
E: Specifies Extended Offset Corner Point
Character 2-3: Two character after the most applicable cardinal direction

Example: ZNW is the northwest corner of the range

Obstacle and Obstruction Points: These points consist of 4 points that bound an obstruction which vehicles should avoid. These points are named with an alpha identifier, a number and a two-character cardinal direction identifier. Obstacles are stacks of wooden railroad ties intentionally added to ranges. Obstructions are any other object or terrain which the competitor vehicles should avoid.

Character 1-3: OBS: Specifies Obstacles
OBT: Specifies and Obstruction
Character 4-5: ##: Specifies point number
Character 6-7: Two characters representing the most applicable cardinal direction

Example: OBS2NE is the northeast corner of obstacle 2

Dump Area Points: These points consist of 4 points that bound the dump area (used for the Surface Clearance, Sub surface Clearance, and Vegetation Removal Events.) Dump area points are named with an alpha identifier and a two-character cardinal direction identifier. For the Subsurface and Surface Clearance ranges, Seed Items must be deposited in the Dump Area for scoring. For the Vegetation Clearance ranges, the dump area is provided as a suggested drop area for removed vegetation if needed. See the Rules and Metrics Document for additional details.

Character 1: D: Dump Site
Character 2-3: Two characters representing the most applicable cardinal direction

Example: DNE is northeast corner of The Dump Site

4.3. Provided Competition Data

This section describes the data for each range type. This will cover information enclosed in the SHP file system as well as additional types of files included in each competitor's custom data packet.

4.3.1. Geophysical Mapping

The Geophysical mapping range is a relatively flat field with buried metallic seed items. Competitors are expected to detect and locate all seed items in the range.

4.3.1.1. Geophysical Real Range Details

- The Real range SHP file system will include the following point types:
    - Localization Points
    - Range Corner Points
    - Offset corner points
    - Extended Corner Points
    - Obstacle Points
- The Real range is approximately two acres.
- The Real range is roughly square.
- The Real range contains two obstacles.

4.3.1.2. Geophysical Practice Range Details

- The Practice range SHP file system will include the following point types:
    - Localization Points
    - Range Corner Points
    - Obstacle Points
- The Practice ranges are roughly one acre.
- The Practice ranges are roughly square.
- The Practice ranges contain one obstacle.
- The Practice range files only contain corner points, localization points and obstacle points.
- Competitors will be provided 5 small and 5 medium Seed Items to seed their practice ranges as necessary to validate their systems.
- No seed items have been buried in the practice ranges. Teams should bring digging equipment if they wish to bury seed items on their practice range.

4.3.2. 4 Subsurface Clearance

All teams competing in the Subsurface Clearance event receive a SHP file system as well as a ―Dig List‖ pertaining to a specific assigned Real range. This ―Dig List‖ is a Microsoft Excel 2007 file and contains information about Seed Item size, depth and horizontal location. Seed Item sizes will be listed as either Medium or Large, corresponding to the Medium and Large Industry Standard Objects (ISO) being used in this event. Seed Item Depths (measured to the center of mass of the Seed Item) will be given in the following ranges: 0-0.3 m, 0.2-0.5 m, 0.4-0.7 m, and 0.6-1.0 m. No Seed Items will be buried deeper than
1 meter.

Location is given in Northing and Easting accompanied by the Horizontal Error margin (for both Northing and Easting), using the UTM zone 13N state plane as a reference. Collected Seed Items should be deposited in the Dump Area. Refer to the previously distributed ―SEEDED METALLIC ITEMS DESCRIPTION v. 8 FEB 2011‖ document for descriptions of the Seed Items.

4.3.2.1. Subsurface Real Range Details

- The Real range SHP file system include the following point types:
    - Localization Points
    - Range Corner Points
    - Offset corner points
    - Extended Corner Points
    - Dump area Points
- The Real range with have an associated ―Dig List‖ Microsoft Excel 2007 file.
- The Real range is approximately two acres.
- The Real range is roughly square.

4.3.2.2. Subsurface Practice Range Details

- The Practice range SHP file system include the following point types:
    - Localization Points
    - Range Corner Points
    - The Practice ranges are roughly one acre.
    - The Practice ranges are roughly square.
    - Competitors will be provided 5 Large and 5 Medium Seed Items to seed their Practice ranges as necessary to validate their systems.
- No seed items have been buried in the Practice ranges. Teams should bring digging equipment if they wish to bury seed items on their practice range.

4.3.3. Surface Clearance

All teams competing in the Surface Clearance event received a SHP file system only. The Real and Practice ranges will be seeded with various sizes of Seed Items. Collected Seed Items should be deposited in the Dump Area.

4.3.3.1. Surface Real Range Details

- The Real range SHP file system include the following point types:
    - Localization Points
    - Range Corner Point
    - Offset corner points
    - Extended Corner Points
    - Obstacle Corner Points
    - Dump area Points
- The Real range is 5 acres.
- The Real range is roughly square.
- The Real range contains 2 obstacles.
- The Real range will be seeded with various sizes of Seed Items.

4.3.3.2. Surface Practice Range Details

- The Practice range SHP file system include the following point types:
    - Localization Points
    - Range Corner Points
- The Practice ranges are roughly one acre.
- The Practice ranges are roughly square.
- The Practice range will be seeded with 10 each of small, medium, plate, and angle Seed Items.

4.3.4. Vegetation Clearance

All teams competing in the Vegetation Clearance event received a SHP file system only. Each vegetation clearance range has areas that have been deemed impassible for large equipment. These areas have been labeled as obstructions internal to the SHP file system, per the nomenclature section (4.2.1). Additionally the obstructed areas are marked with high visibility fence. Competitors should not cross into obstructions and competitors are not responsible for any vegetation removal in the obstructed areas. A large dump area has been designated outside of the vegetation clearance ranges. The dump area is available if needed. See the Rules and Metrics document for additional information.

4.3.4.1. Vegetation Real Range Details

- The Real range SHP file system will include the following point types:
  - Localization Points
  - Range Corner Points
  - Offset Corner points
  - Extended Corner Points
  - Dump area Points
  - Obstructions Points
- The Real range is approximately 3 acres
- The Real range is not square.
- The eastern half of the Real range contains all of the trees for cutting but the entire area must be cleared per the contest rules.

4.3.4.2. Vegetation Practice Range Details

- The Practice range SHP file system will include the following point types:
  - Localization Points
  - Range Corner Points
- The Practice ranges are roughly one acre.
- The Practice ranges are not square.

Appendix G: Safety Evaluation Form

Team Name:__________________________Team XYZ Team Lead Name:______________________________

Safety Review Officer:__________________________ Date:______________________________________

Safety Feature Measure:	**3.1.2** E-Stop
Requirement: The system shall have an Emergency Stop (E-Stop). The system must halt within 15 meters and cease all equipment operations when the E-Stop is initiated.	
Evaluation Method: The competitor shall successfully demonstrate the use of a remote activated E-stop. The E-stop will be demonstrated while system is both at idle and mobile during autonomous and manual tele-operation. The E-stop will be tested at a range of 800M. The system shall be operating at the maximum intended operating speed when the E-stop initiated. A laser measurement system will be used to measure the distance travelled.	
Safety Feature Measure:	**3.1.3** Warning Devices
Requirement: Each vehicle shall be equipped with a warning light that is activated according to the state of the E-Stop system. Each vehicle shall display one or more flashing amber warning lights, the combination of which results in visibility 360 degrees azimuthally around the vehicle. The warning light(s) shall operate when the vehicle is not in an E-stop state i.e. RUN mode. The vehicle may not commence movement until the warning light(s) has been in operation for 5 seconds. The warning light(s) shall comply with SAE Class 1 standards for warning lights and shall not produce light(s) than can be confused with those of public safety vehicles such as law enforcement, fire, or ambulance.	
Evaluation Method: The competitor will produce documentation showing that the warning lights in use meet SAE Class 1 standards. The warnings lights will be physically observed to operate when the vehicle is in the E-stop RUN mode and to ensure 360 degree visibility around each system. The vehicle will be videotaped and timed from system initiation to measure the time between warning light operation and system movement.	

Safety Feature Measure:	**3.1.4** Lost Communication
Requirement: The system shall automatically halt and cease operations if communications with the system are lost or interrupted for a maximum of 2 seconds and may travel no farther than 30 meters.	
Evaluation Method: An automated system will be used to cut power to the communication system and after 2 seconds measure distance traveled using a laser range finder. A tripod with a camera and the laser range finder will be placed 10 meters behind the vehicle at the start of the test, after which the robot will be run at its maximum forward operating speed when communication power is cut. Each team shall provide two wires that, when connected, supply power to their communication system or have their communication system powered by a single standard wall outlet plug, so that power in either the connection or wall plug can be cut by the system.	
Safety Feature Measure:	**3.1.5** No Freewheel
Requirement: The systems shall not be capable of motion when stopped or un-powered. For example, systems that would roll downhill if shut off are considered freewheeling and are un-safe for competition.	
Evaluation Method: This will be demonstrated by placing the robotic system 5 meters up the base of an incline with a slope of between 10 and 12 degrees and the direction of travel down the incline**.** The system will be placed on the incline in a powered state and the E-stop will be initiated. The system will be observed for a period of 30 seconds to confirm that no movement other than "settling" shall occur. Brake settling of up to 1/4 the system length will be allowed. The team will also provide a description of the system design to show that a power loss will not cause a free wheel situation.	

Vehicle Name: XYZ #1			
Safety Feature Measure:	**3.1.2** E-Stop	**Evaluation Status:**	Pass | Fail
Comments:			
Safety Feature Measure:	**3.1.3** Warning Devices	**Evaluation Status:**	Pass | Fail
Comments:			
Safety Feature Measure:	**3.1.4** Lost Communication	**Evaluation Status:**	Pass | Fail
Comments:			
Safety Feature Measure:	**3.1.5** No Freewheel	**Evaluation Status:**	Pass | Fail
Comments:			

Team Lead Signature:____________________________________ DATE:____________________
Team XYZ

APPROVED BY:____________________________________ DATE:____________________
R2C2 Safety Review Officer

Appendix H: Geophysical Mapping Challenge

LIST OF APPENDIX H FIGURES

LIST OF APPENDIX H TABLES

H.1. GEOPHYSICAL MAPPING CHALLENGE

H.1.1. Introduction

The geophysical mapping challenge is intended to demonstrate the following geophysical mapping objectives:

- Navigate a digital geophysical mapping platform within the designated area to collect digital geophysical data so that buried metallic objects can be detected and located to 30 cm or better positional accuracy.
- Collect raw geophysical data with an objective noise level to be determined at the site.
- Deploy a time domain electromagnetic induction metal detector and record its data over 100% of the designated area at a line spacing of 50 cm.

The geophysical mapping range was constructed over an area of 6,455.6 square meters. Two obstacles were placed within the area reducing the required coverage area to approximately 6,405 square meters. One hundred and twenty-five pipe sections were buried randomly throughout area. All pipe sections were buried in a vertical orientation, which produces a single mono-pole anomaly in horizontal loop electromagnetic induction metal detectors.

Figure H-1 shows the layout of the geophysical mapping challenge range area.

This document is arranged in the following order: Section H-2 presents the geophysical mapping metrics provided to the competitors by R2C2 in the Competition Rules and Metrics document and modifications to the geophysical metrics made prior to the start of the competition start. Section H-3 presents the analysis of the geophysical data performed by R2C2. Section H-4 presents the scoring of the geophysical data.

H.2. GEOPHYSICAL MAPPING METRICS

R2C2 Competition Rules and Metrics ; Geophysical Mapping Metrics
The following information is copied from the R2C2 Competition Rules and Metrics, Version 10 , July 2011.

H.2.1. Delivery of Raw data

Raw data should be provided to the judges within 30 minutes of completing the geophysical mapping event. The merged data should be delivered to the R2C2 Oversight Team within 48 hours of the completion of the geophysical data collection. If the team does not deliver the merged data by the deadline, the score for the entire geophysical mapping event shall be zero.

H.2.2. Noise Level (70 Points)

Using Oasis Montaj's QC tools determine the average level of RMS noise in the raw data.
Baseline noise will be determined by the R2C2 Competition Team.
Score will be determined as shown in Table H-1

Table H-1. Noise Level Scoring

Noise Range	Points Awarded
Low RMS noise level	Most
Moderate RMS noise level	Some
High RMS noise level	Least

H.2.3. Sensor Coverage (60 points)

Score will be determined by the percent of the range covered.
Score will be determined by the following
Percentage of coverage multiplied by 60 points = Score
Less than 95% coverage results in no points.

H.2.4. Anomaly Location Accuracy (60 points)

Determine anomaly peak response locations using Oasis Montaj's UX-Detect automatic anomaly detection algorithm on the submitted merged data.
Number detected scoring
(# of Detections within 30cm of actual burial location / # seeded)* 60 = detection score

H.2.5. Survey Speed (60 points)

Using Oasis Montaj, the point-to-point velocities will be calculated for all data collected.
Scoring will be based on percentage of the data collected at the specified design speed.
Design speed will be determined by competitor team prior to event.
The scoring will be determined by the following table:

Table H-2. Survey Speed Scoring Metrics

Design speed range	Points
98% to 100% within + or - 0.3MPH of design speed	60 points
95% to 98% within + or - 0.3MPH of design speed:	40 points
75% to 95% within + or - 0.3MPH of design speed:	20 points
50% to 75% within + or - 0.3MPH of design speed:	5 points
less than 50% within + or - 0.3MPH of design speed:	0 points

H.2.6. Revisions to The Geophysical Metrics Prior to Competition Start

H.2.6.1. Noise Level (70 Points)

No changes

H.2.6.2. Sensor Coverage (60 points)

The scoring was revised to eliminate a zero score in the event less than 95% of the area was covered.
All teams were informed the method of calculating coverage score would be following the method described in Attachment A to this document.

All teams were informed they would not be penalized for missed coverage around obstacles attributed to the width of their sensor platforms. They were informed polygons would be drawn around the obstacles to account for their platform width and these polygons would be excluded from their coverage scoring.
The area to be mapped was reduced by 20.5%. Attachment B presents the information communicated and provided to the competitor teams prior to the competition start.

H.2.6.3. Anomaly Location Accuracy (60 points)

No changes

H.2.6.4. Survey Speed (60 points)

No changes

H.3. GEOPHYSICAL DATA ANALYSIS

H.3.1. Noise Level

The purpose of the noise score was to encourage innovation in mitigating noise sources from team's robots as well as the deployment form factors teams selected to deploy their sensor packages. Sensor noise due to geology or other sources not attributed to the robot or the deployment form factor were not considered in this scoring. All final data was compared visually and via simple statistical analysis to comfirm competitor's processing of the final dataset(s) did not alter the noise level.

Noise in electromagnetic induction (EMI) metal detectors used to detect munitions is expected to have a normal distribution about a mean background of zero response. Noise levels were assessed on dynamic geophysical mapping data collected in the yellow polygon shown in Figure H-1, which is an area where a zero mean background response is expected because no metallic items exist in this polygon. All data collected by each competitor within this polygon was analyzed for the following statistical parameters:

- Standard deviation
- Range of values between the five percentile and the ninety-five percentile
- Goodness of fit of histogram of values to a normal distribution of background measurements

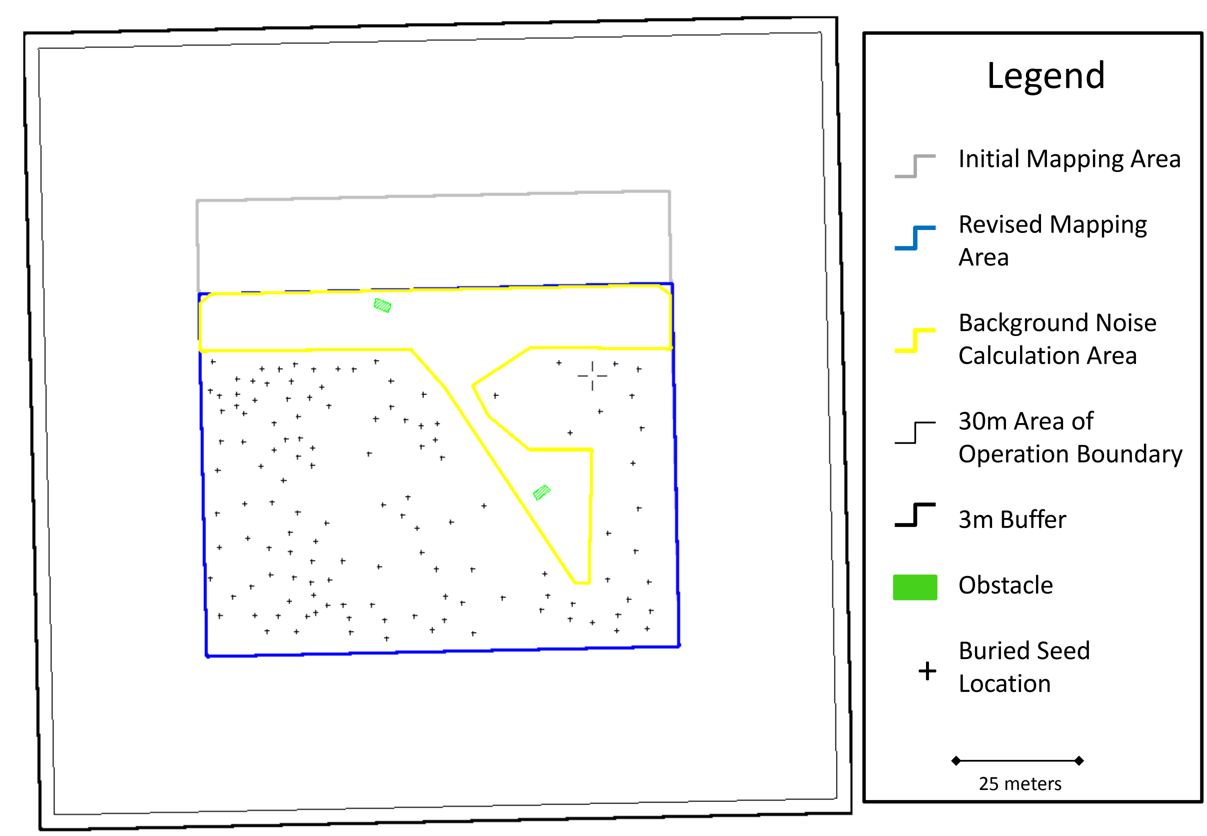


Figure H-1. Geophysical Mapping Challenge Range Area

The first two statistics were measured quantitatively. The last, goodness of fit, was assessed qualitatively.

To arrive at a score, competitor's statistics were compared to baseline statistics calculated from data collected by R2C2 using a man-portable EM61-MK2 in the background area. The R2C2 data collection represented current state of the art in EMI metal detecting for munitions. Scores were generated based on the percent difference of the two quantitative statistics compared to the R2C2-collected EM61-MK2 baseline statistics. Assessing the goodness of fit of values to a normal distribution of background measurements was an informal approach to assess normality, and was used to corroborate the quantitative statistics results.

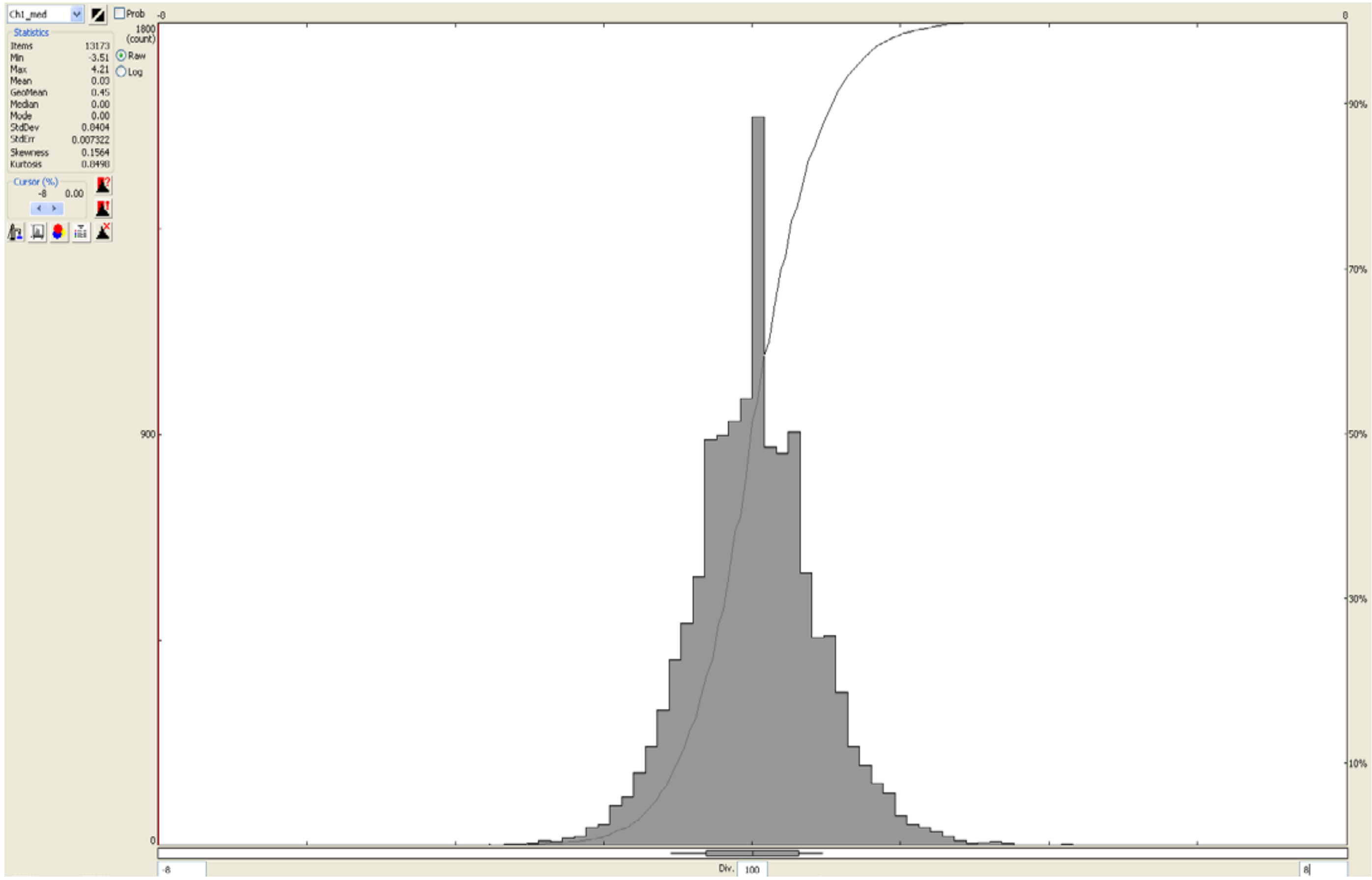
All three competitor's performance in minimizing noise exceeded the R2C2 baseline performance. Table H-1 presents the noise statistics results.

Team D4C and Team Sky Research each used one or more EM61-MK2 sensors manufactured by Geonics, Ltd. Team UXOD used a Dynamic Nano TEM (DNT) sensor manufactured by Zonge International. The EM61-MK2 and DNT do not have the same operating characteristics and do not measure the same time windows in the time-domain EMI response. However, channel one of the EM61-MK2 is centered at approximately 266 microseconds after transmitter turn-off and channel 30 of the DNT is centered at approximately 229 microseconds after turn-off. As this competition is about robotics and the purpose of the noise score is to assess mitigation of robot and deployment form-factor noise sources, the methods of assessing each team's noise characteristics described above and summarized in Table H-3 are appropriate for these purposes. They address the question: "Does the robot or its sensor deployment form-factor introduce noise in the geophysical instrument measurements?" Note: these statistics are not appropriate for assessing geophysical detection performance. For illustrative purposes only, Table H-3 also shows data from Team Sky Research's sensor #3 which shows noise attributed to the deployment form factor. Figure H-2–Figure H-6 show the histogram distribution of background measurements for the data tabulated in Table H-3.

Team Sky Research submitted five sensor datasets. The center sensor dataset was assessed for noise characteristics after it had been used for other scoring purposes. Since its noise characteristics were poor, all other sensor datasets were assessed for noise performance. Sensor 1 had the best noise characteristics. Sensor 1 and Sensor 3 noise characteristics are presented in Table H-1.

Table H-3. Summary Statistics of Dynamic Sensor Measurements in Background Area

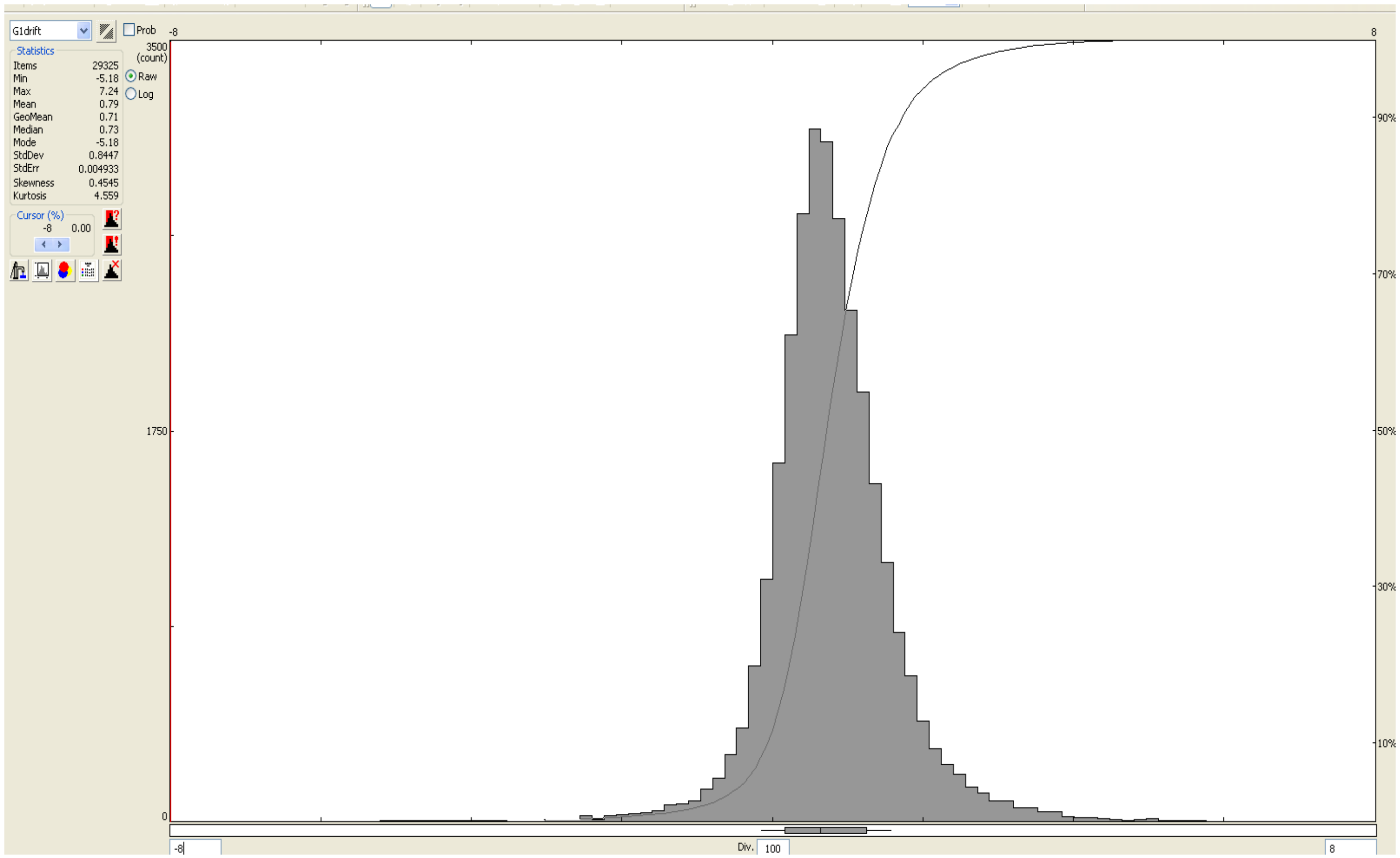
	R2C2 Baseline (EM61-MK2)	Team D4C		Team Sky Research (Sensor #1)(best noise statistics)		Team Sky Research (Sensor #3)(center sensor)		Team UXOD	
		Value	Percent Difference	Value	Percent Difference	Value	Percent Difference	Value	Percent Difference
Standard Deviation (mV)	0.84	0.84	0%	.82	-2%	1.6	+90%	.31	-63%
95 percentile value (mV)	1.4	2.2	n/a	2.0	n/a	3.9	n/a	.5	n/a
5 percentile value (mV)	-1.3	-.37	n/a	-.55	n/a	-1.4	n/a	-.96	n/a
Range 5% ile to 95% ile (mV)	2.7	2.57	-5%	2.55	-6%	5.3	+96%	1.46	-46%
Histogram representation corroborates normal distribution of noise?	Yes	Yes		Yes		No		Yes	
Notes:1) R2C2, Team D4C and Team Sky Research data calculated from channel 1 (center at approximately 266 microseconds) of EM61 MK2 data. Team UXOD data calculated from channel 30 of Dynamic Nano-TEM data (center at approximately 229 microseconds.)									



R2C2 Baseline

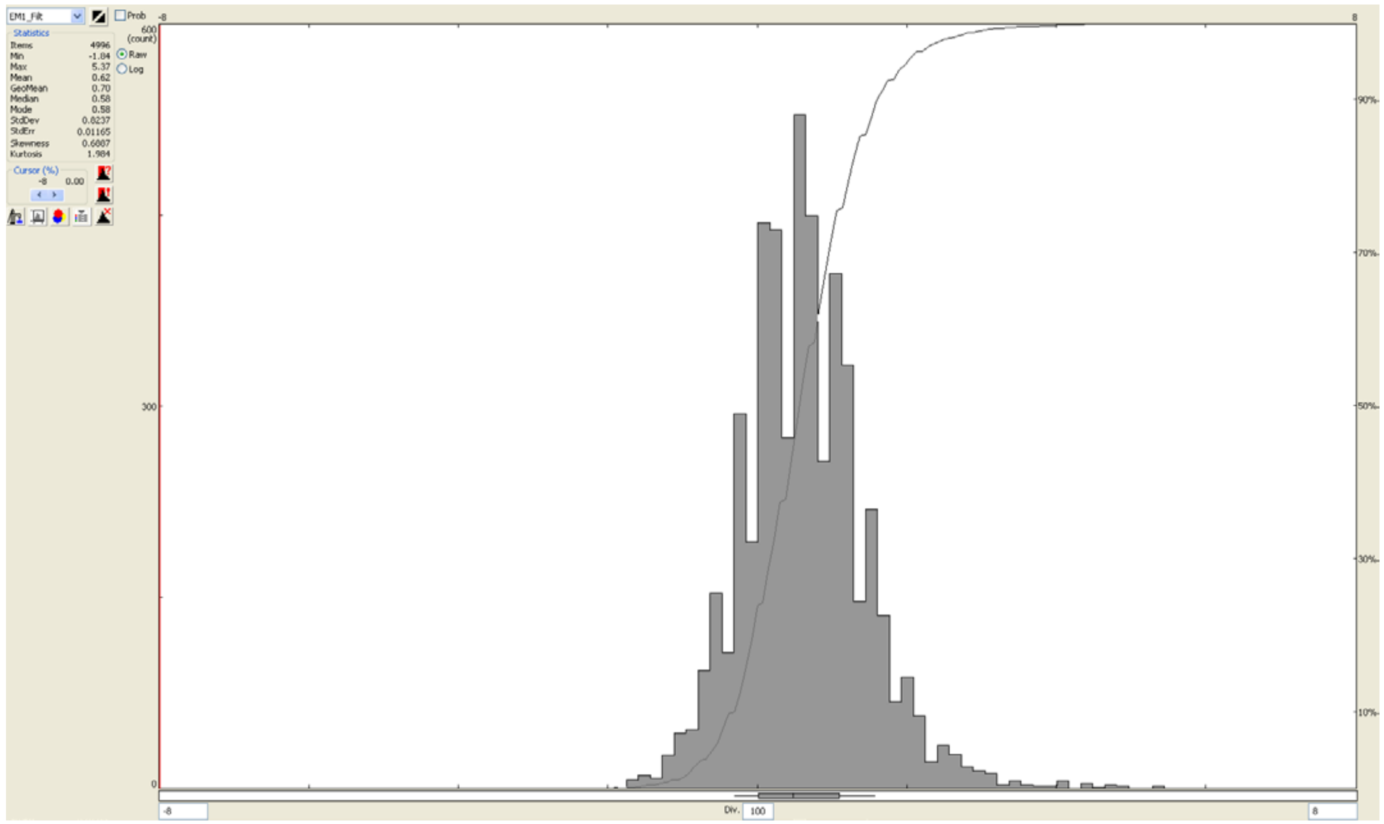
Figure H-2. R2C2 Baseline Histogram of EM61 Data

Histogram showing background measurement distribution of EM61-MK2 data collected by R2C2 and used as the baseline for noise scoring. Figure H-2 shows the data has a normal distribution as expected for this type of electromagnetic induction instrument



Team D4C

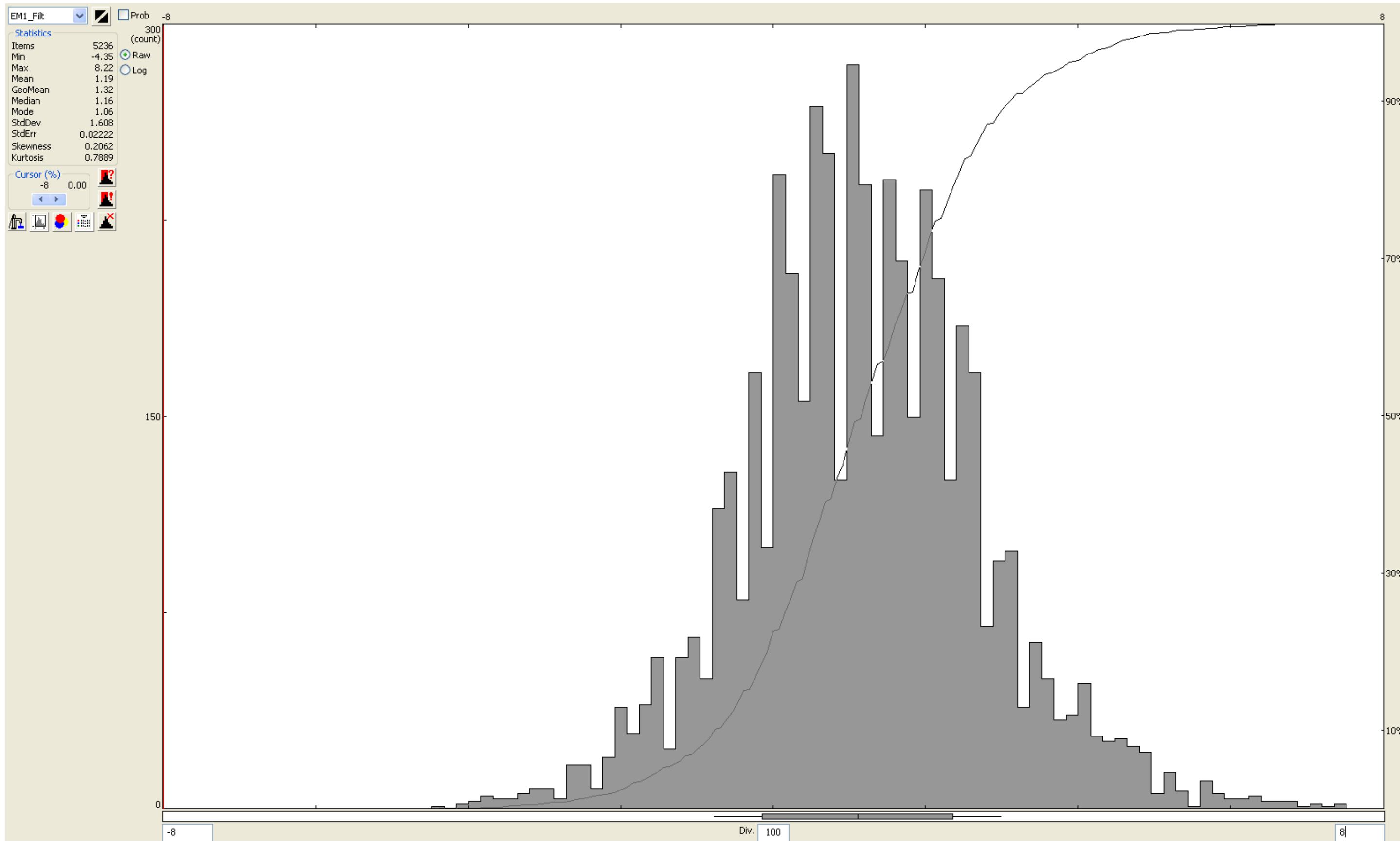
Figure H-3. .Histogram of EM64-MK2 Data Collected by Team D4C
Histogram showing background measurement distribution of EM61-MK2 data collected by Team D4C and used for noise scoring. Figure H-3 shows the data has a normal distribution as expected for this type of electromagnetic induction instrument



Team Sky Research
Sensor #1

Figure H-4. Histogram of EM61-MK2 Data Collected by Team Sky Research

Histogram showing background measurement distribution of EM61-MK2 data collected by Team Sky Research from sensor #1 and used for noise scoring. Figure H-4 shows the data has a predominant normal distribution for this type of electromagnetic induction instrument, though some platform or robot induced noise is visible by the saw-tooth nature of the histogram plot and an increase in instances of values in the 2 to 3 mV range.



Team Sky Research
Sensor #3

Figure H-5. Histogram of EM61MK2 Data Collected by Team Sky Research

Histogram showing background measurement distribution of EM61-MK2 data collected by Team Sky Research from sensor #3. Figure H-5 shows the data has a mixture of two normal distributions and platform or robot induced noise is clearly visible by the saw-tooth nature of the histogram plot and an marked increase in instances of values in the 3 to 5 mV range.

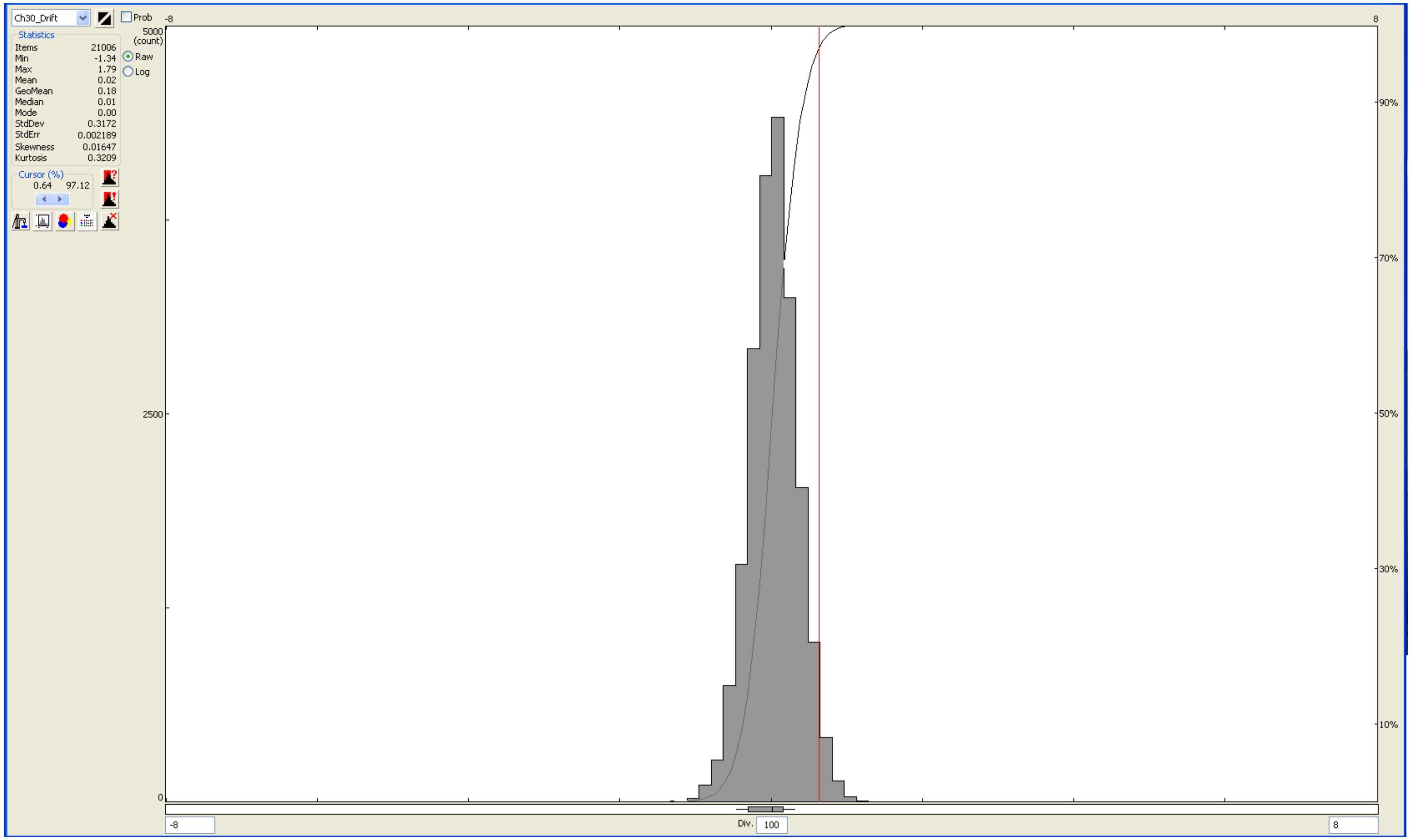
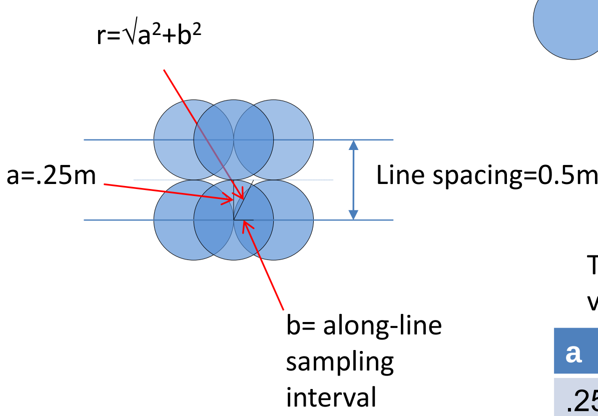


Figure H-6. Histogram of EM61-MK2 Data Collected by Team UXOD

Histogram showing background measurement distribution of EM61-MK2 data collected by Team UXOD and used for noise scoring. Figure H-6 shows the data has a normal distribution as expected for this type of electromagnetic induction instrument.

H.3.2. Sensor Coverage

Sensor coverage was assessed using the Geosoft “UCEFOOTPRINTCOV” processing routine. This routine calculates percent coverage using a user-defined circular sensor footprint. This routine does not automatically compensate for along-track sampling gaps. Therefore the average along-line sampling gaps were calculated for each design speed used by each team. Each average along-line spacing was then used to calculate the circular footprint needed to account for proper line spacing assessments. The line spacing requirement was 0.5 m. Figure H-7 illustrates this scenario and presents the information used to select appropriate footprint values for each design speed used by competitors. Table H-4 presents the design speeds used by each competitor, the footprint diameter used to assess meeting the 0.5 m coverage, and the coverage percentage calculated using the Geosoft routine. Figure H-8–Figure H-10 show the Geosoft generated maps illustrating the coverages achieved.



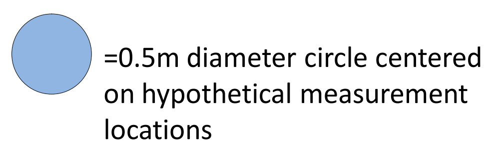


Table of footprint values to use for various along-line sampling intervals

a	b	r	D
.25	.25	0.354	0.707
.25	.2	0.320	0.640
.25	.11	0.270	0.546
.25	.1	0.269	0.539
.25	.09	0.266	0.531
.25	.08	0.262	0.525
.25	.06	0.257	0.514

Figure H-7. Input Calculation for Geosoft “UCEFOOTPRINTCOV”

Table H-4. Results of Coverage Assessments

Team	Design Speed	Average along-line sample spacing	Adjusted Footprint Diameter for Coverage Calculation	Calculated Coverage
Team D4C	1 m/sec	0.09 m	0.531 m	3,740.59 m^2 = 58.4%
	1.2 m/sec	0.09 m	0.531 m	
Team Sky Research	1.3 m/sec	0.11 m	0.546 m	Sensor #1: 2,565.6 m^2 = 40.1%
	1.25 m/sec	0.09 m	0.531 m	
	0.97 m/sec	0.08 m	0.525 m	
Team UXOD	1.34 m/sec	0.09 m	0.531 m	83.9%

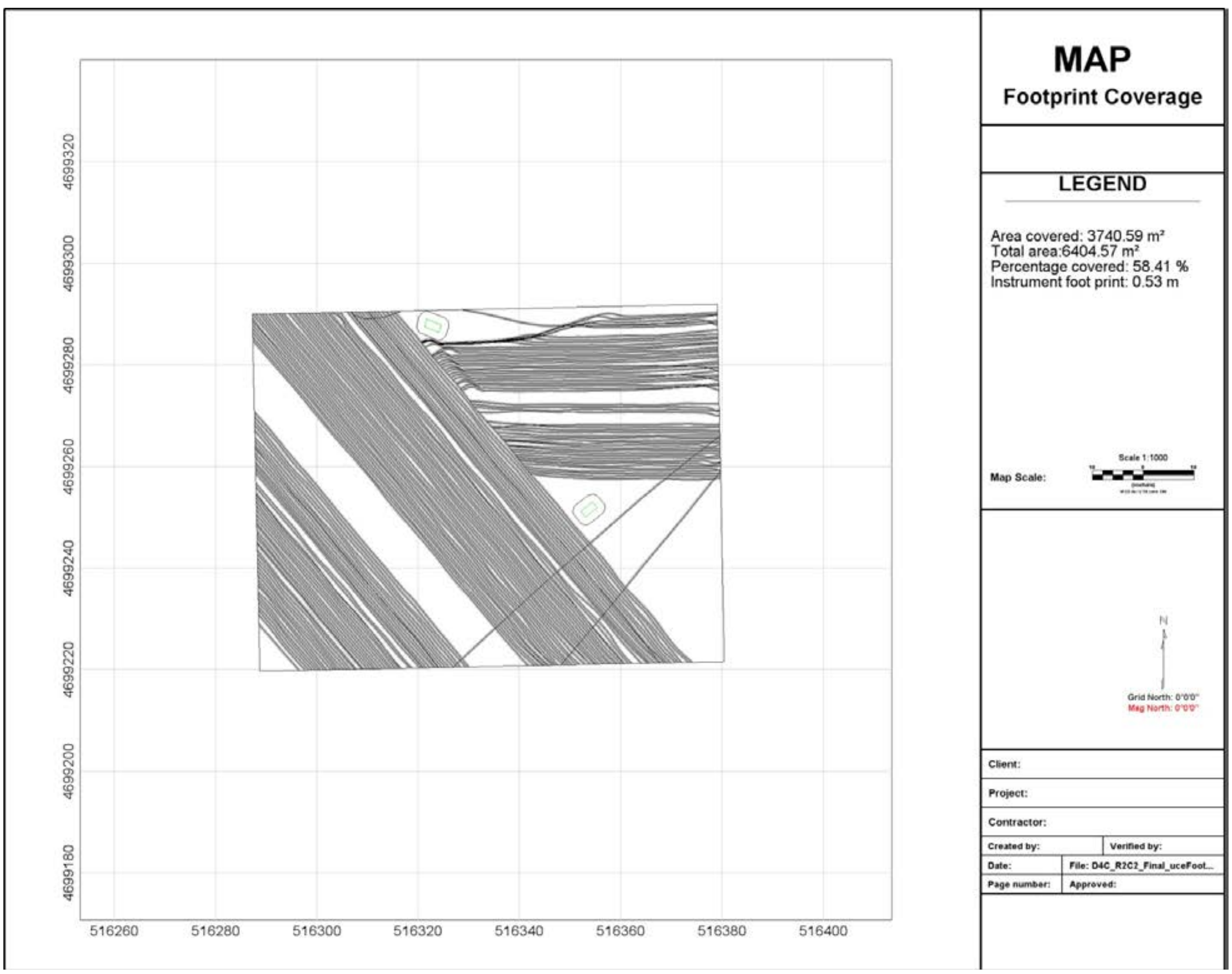


Figure H-8. Coverage Calculation Map for Team D4C

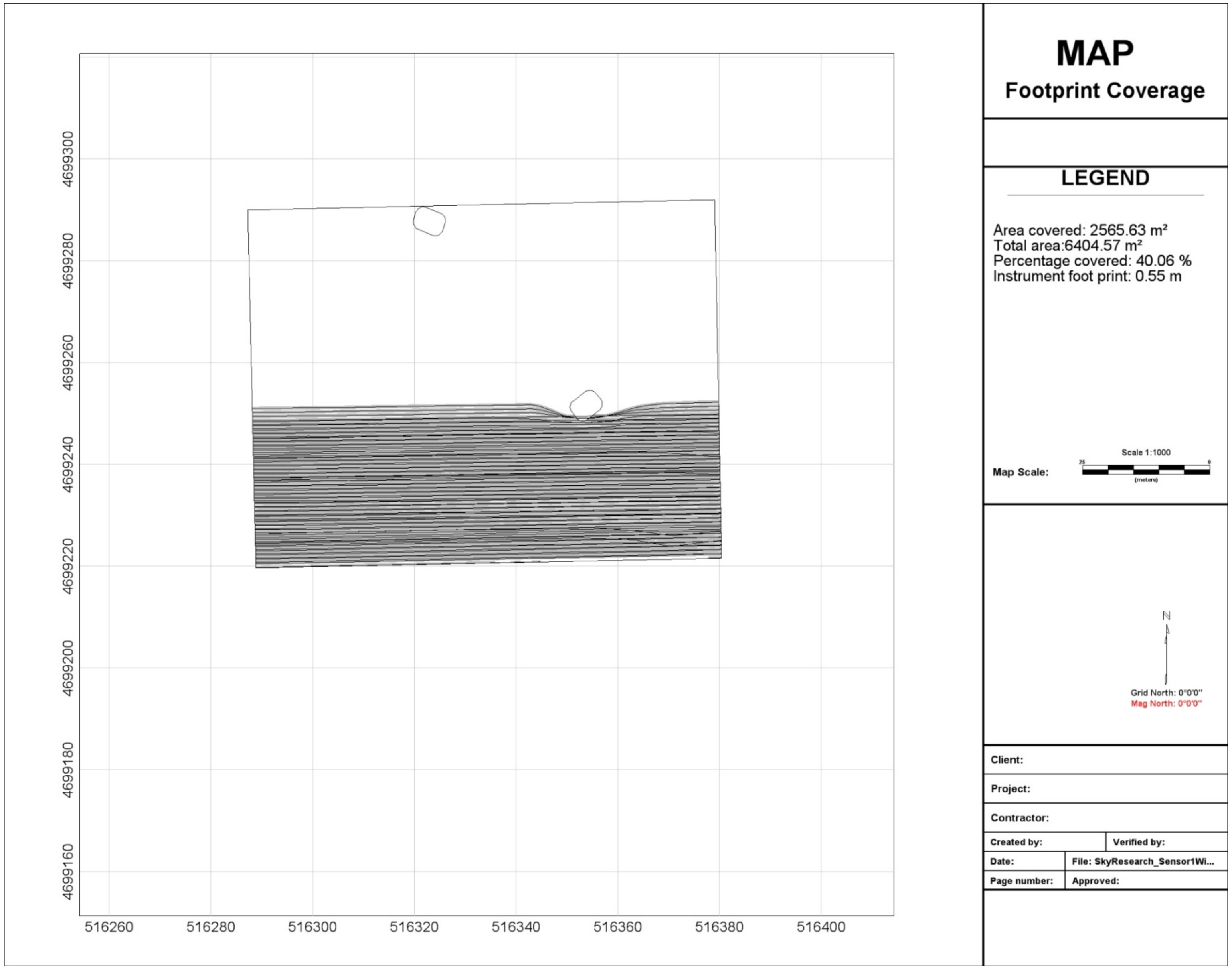


Figure H-9. Coverage Calculation Map for Team Sky Research

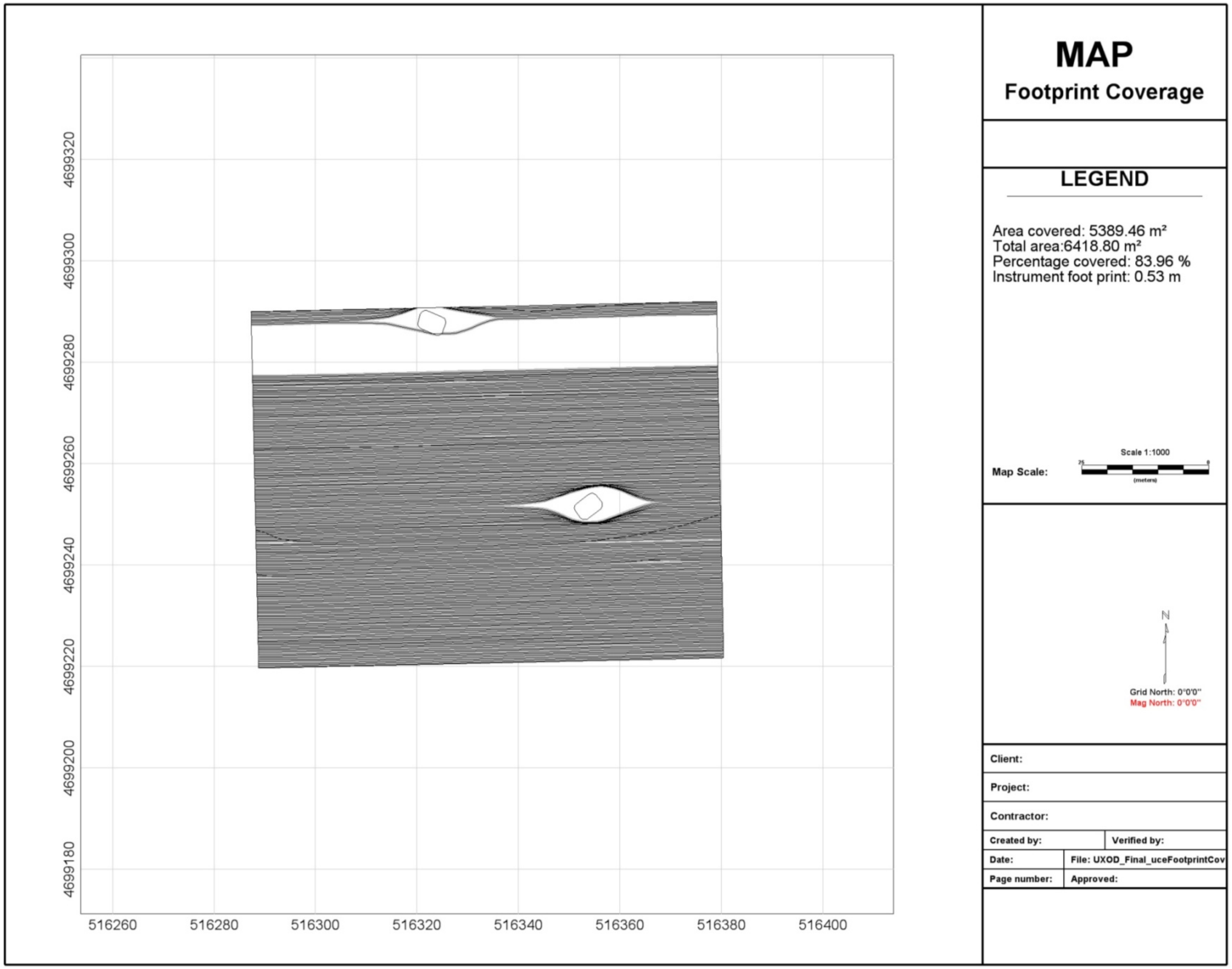


Figure H-10. Coverage Calculation Map for Team UXOD

H.3.3. Anomaly Location Accuracy

One hundred twenty-five pipe sections were buried throughout the geophysical mapping area. All were placed in a vertical orientation so that simple, single-pole anomalies would be produced in horizontal look EMI sensor data. All seeded pieces of pipe were placed at depths that produce large, clearly detected anomalies in all digital geophysical mapping systems used in the munitions response industry. Scoring was performed only against the 125 seeded pipe sections. Any existing metallic items present within the geophysical mapping area were not included in the scoring.

Anomaly location accuracy was calculated using the UCEPROVE Geosoft routine. This routine compares ground truth locations to detected anomaly locations and assesses how far the two are from each other. Anomalies were selected from processed final data delivered by each competitor. No adjustments were made to any measurement locations delivered by the competitors. Table H-5 summarizes the number of anomalies detected by each team and the number found within the 30cm requirement. All anomalies detected by Team UXOD (125 total) and Team Sky Research (58 total) were detected within the 30 cm requirement. Team D4C detected 97 anomalies of which 92 were detected within the 30 cm requirement. The five detected but not within the 30cm requirement were beyond the 30 cm requirement. A qualitative analysis of Team D4C data suggests the five anomalies detected outside the 30 cm requirement are due to gaps in coverage--portions of the mapping work where survey lines did not meet the 50 cm line coverage metric. Figure H-11–Figure H-13 show the Geosoft generated maps illustrating the anomaly location accuracy analysis results.

Table H-5. Results of Anomaly Location Accuracy Assessments

Team:	Team D4C	Team Sky Research	Team UXOD
Total number of seed items detected	97	69	125
Number of seed items detected within 30cm	92	69	125
Percent of all possible seed items detected within 30cm	73.6%	55.2%	100%

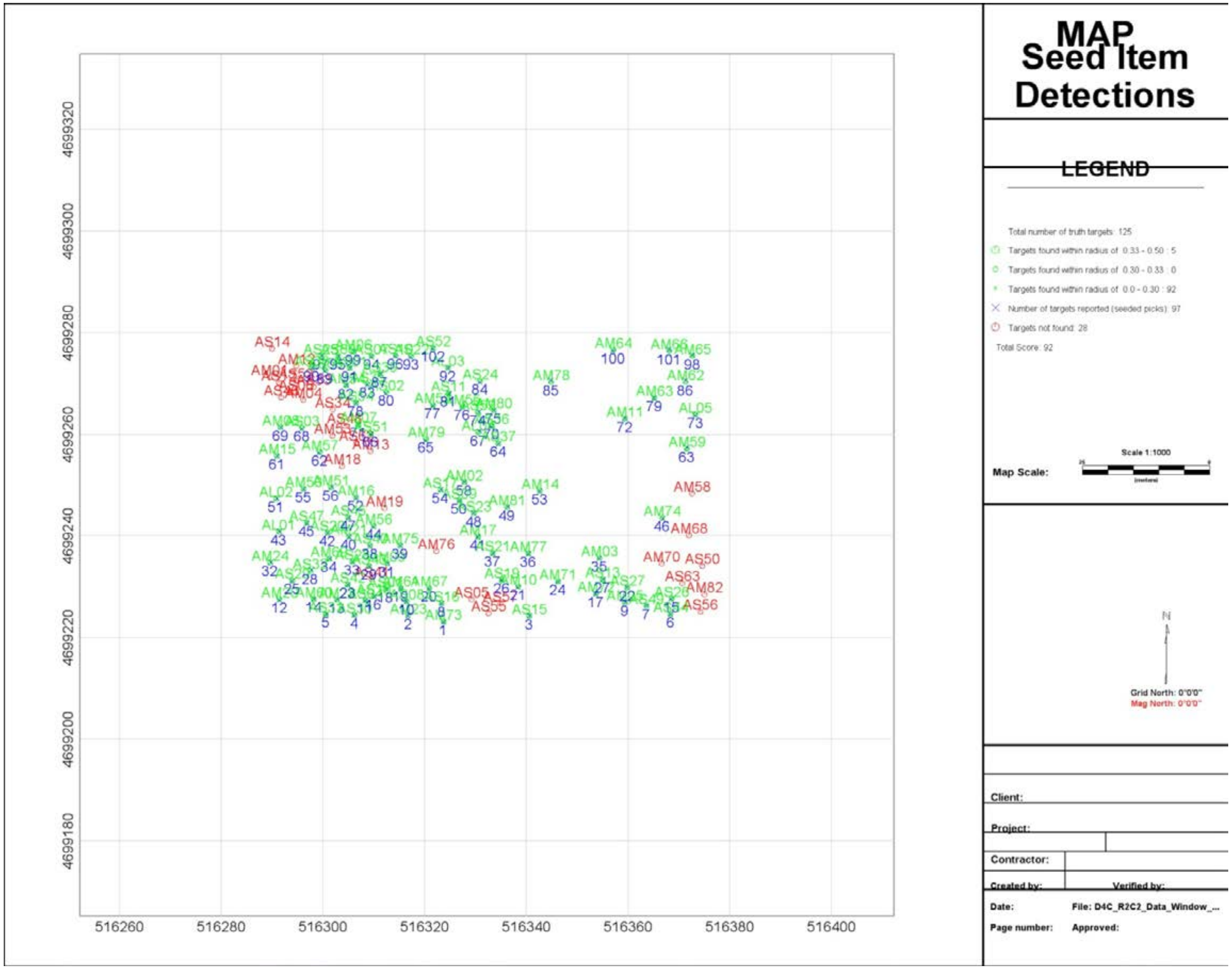


Figure H-11. Anomaly Location Accuracy Analysis for Team D4C

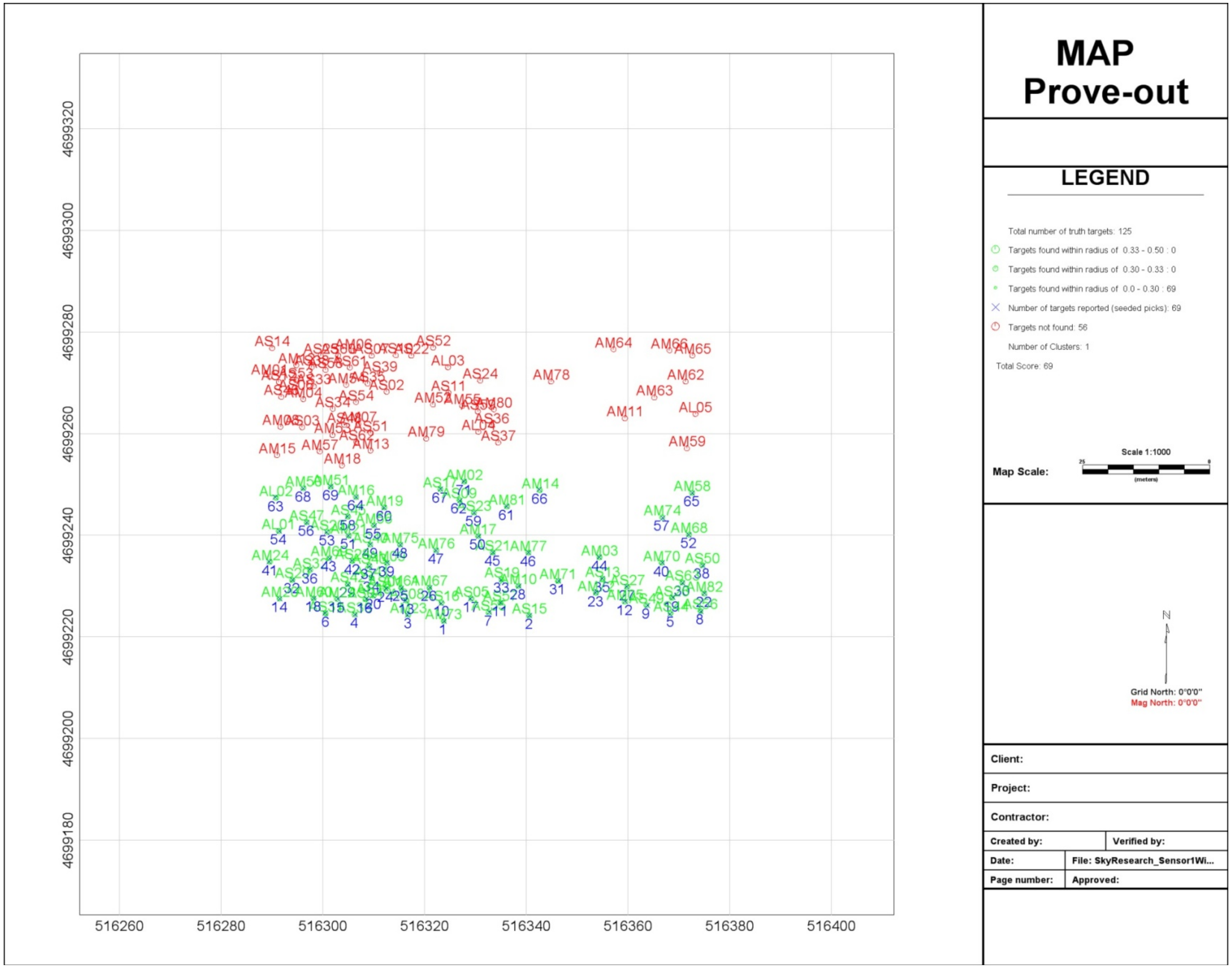


Figure H-12. Anomaly Location Accuracy analysis for Team Sky Research

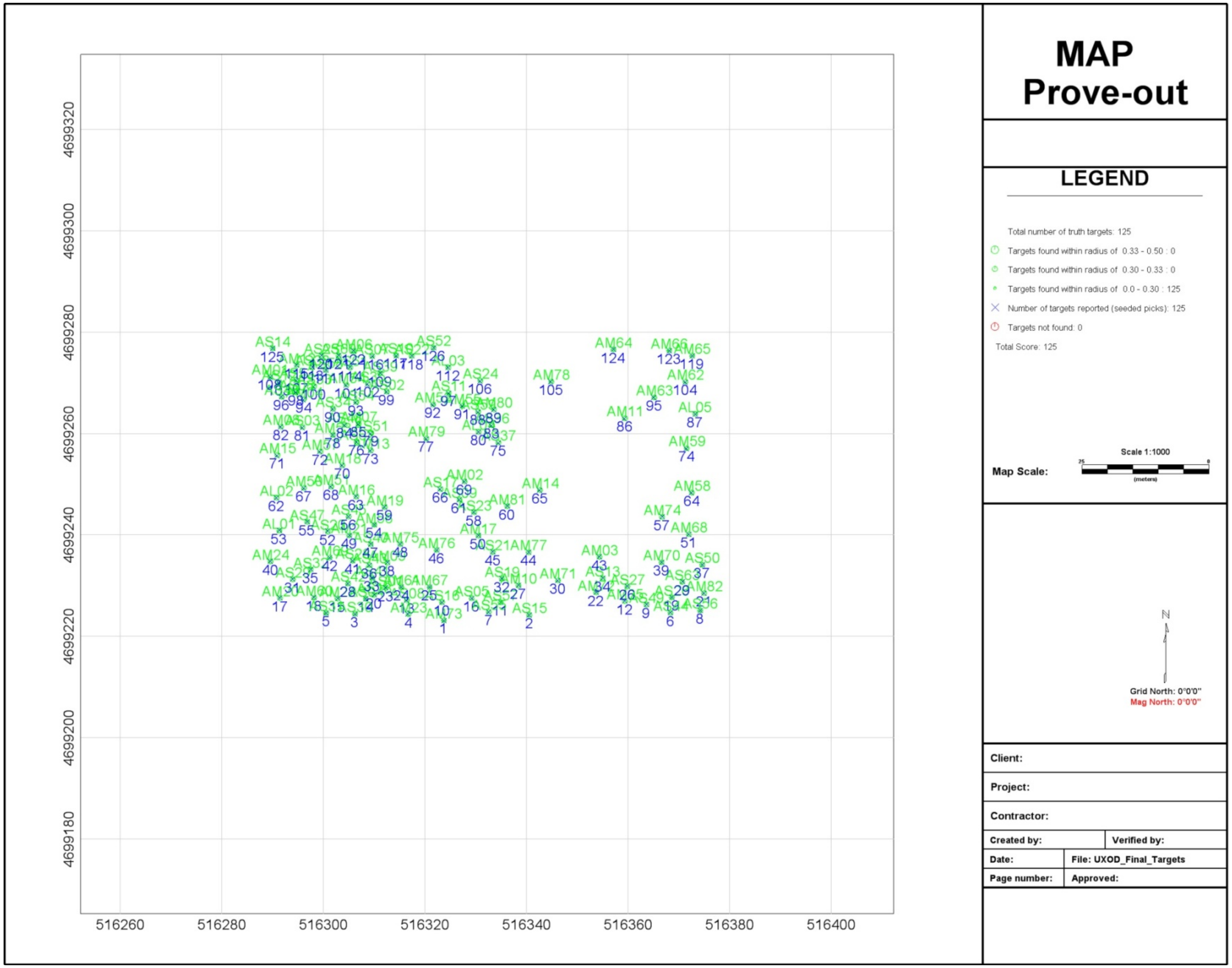


Figure H-13. Anomaly Location Accuracy Analysis for Team D4C

H.3.4. Survey Speed

Survey speed was calculated using the UCEVELOCITY routine in Geosoft. This routine calculates the point-to-point distances between adjacent measurement locations and then calculates the velocity between those points based on the time taken to traverse that distance. No adjustments were made to any measurement locations delivered by the competitors. Table H-6 summarizes the percent of the mapping performed within the team-selected design survey speeds. Team D4C selected two design speeds during their mapping event. Team Sky Research selected three design speeds and Team UXOD selected one. Figure H-14 and Figure H-15 show the survey speed analysis for Team D4C. Figure H-16–Figure H-18 show the survey speed analysis for Team Sky Research. Figure H-19 shows the survey speed analysis for Team UXOD.

Table H-6. Results of Survey Speed Assessments

Team:	Team D4C	Team Sky Research	Team UXOD
Survey Design Speed and Percent Mapping Performed at Design Speed ±0.1341 m/sec (±0.3MPH)	1 m/sec: 91.34% 1.2 m/sec: 75.59%	1.3 m/sec: 80.93% 1.25 m/sec: 89.04% 0.97 m/sec: 87.99%	1.34 m/sec: 58.81%
Composite Percentage	Greater than 75.59% and less than 91.34%	Greater than 80.93% and less than 89.04%	58.81%

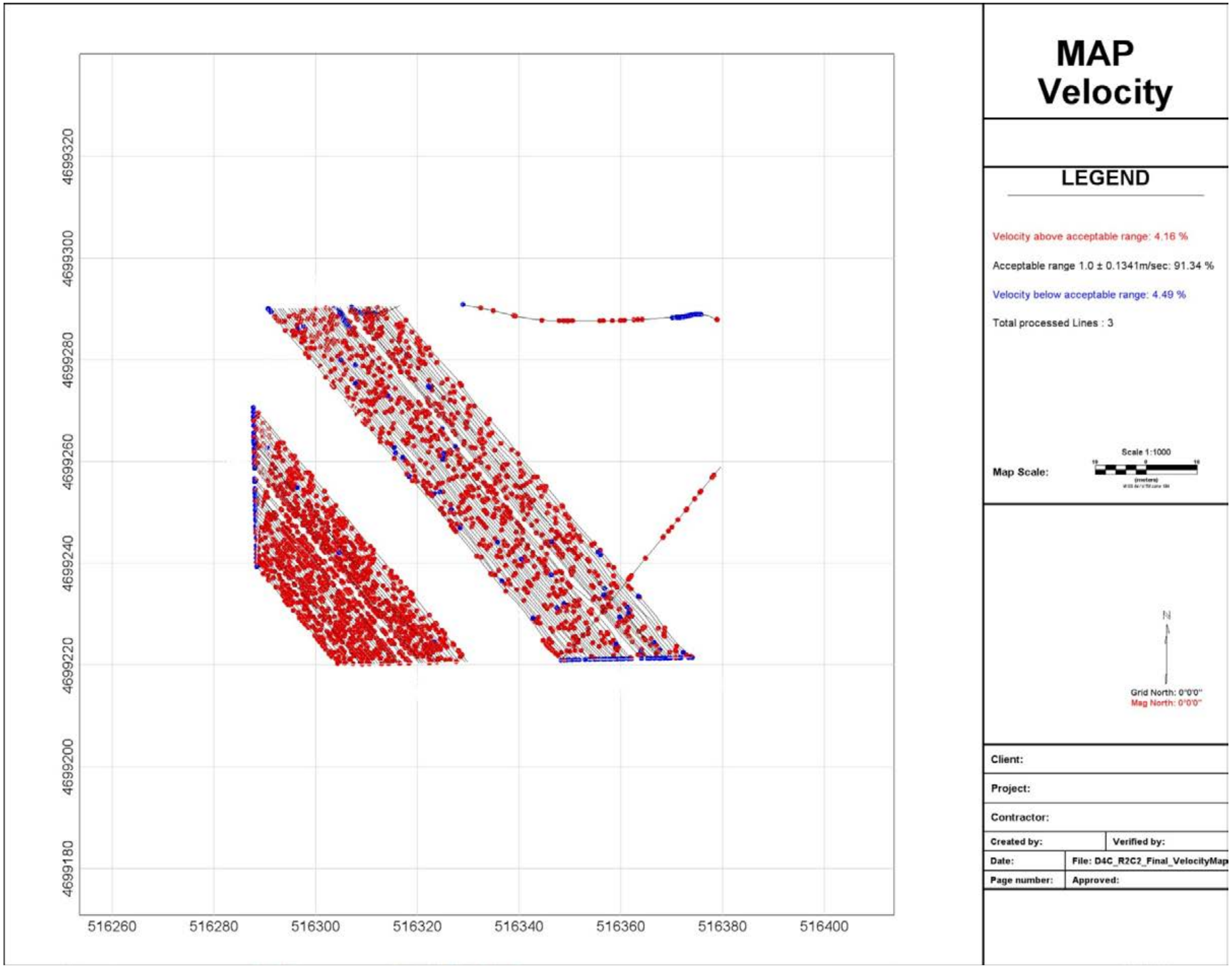


Figure H-14. Survey Speed Analysis for Team D4C at Design Speed of 1 m/s

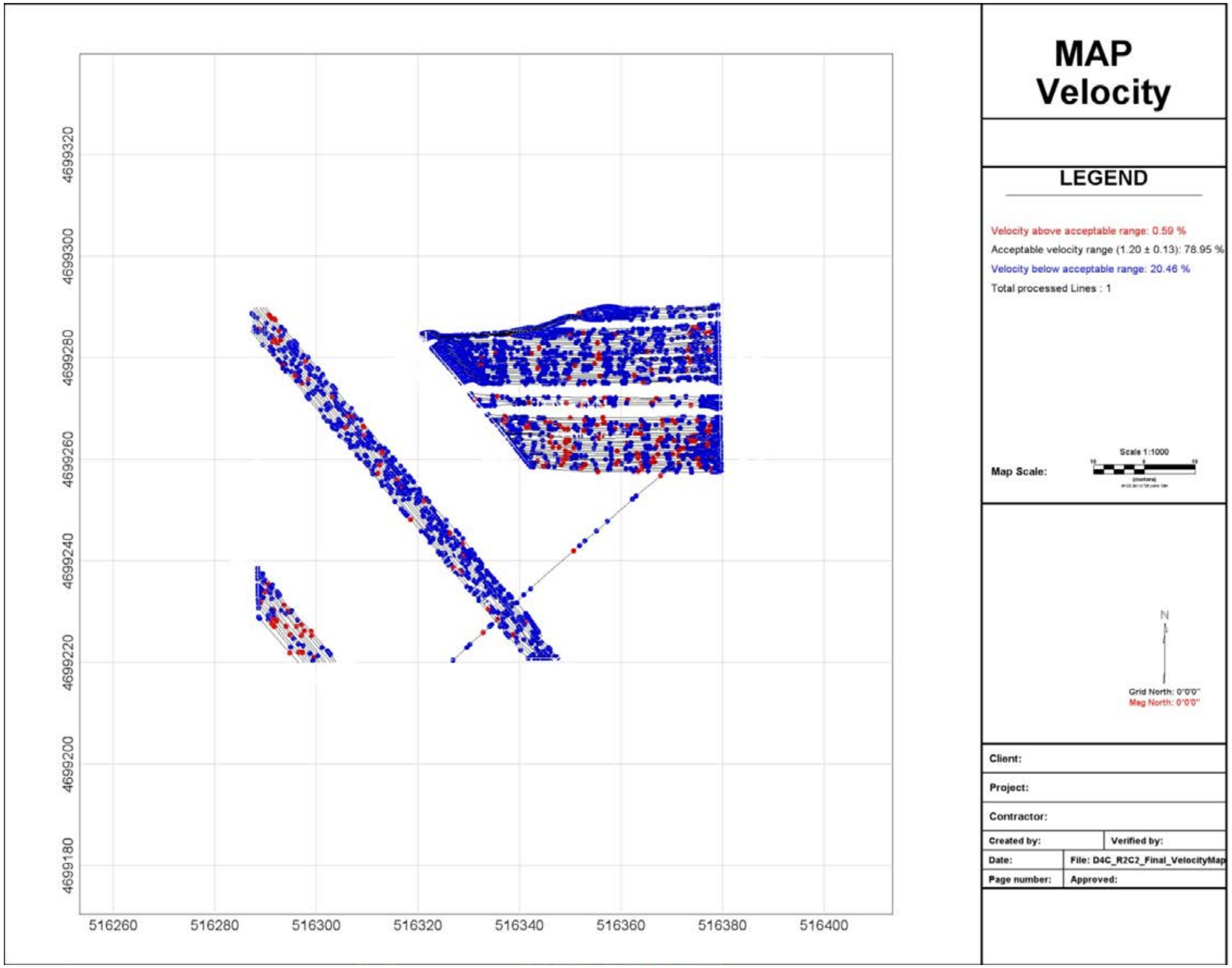


Figure H-15. Survey Speed Analysis for Team D4C at Design Speed of 1.2 m/s

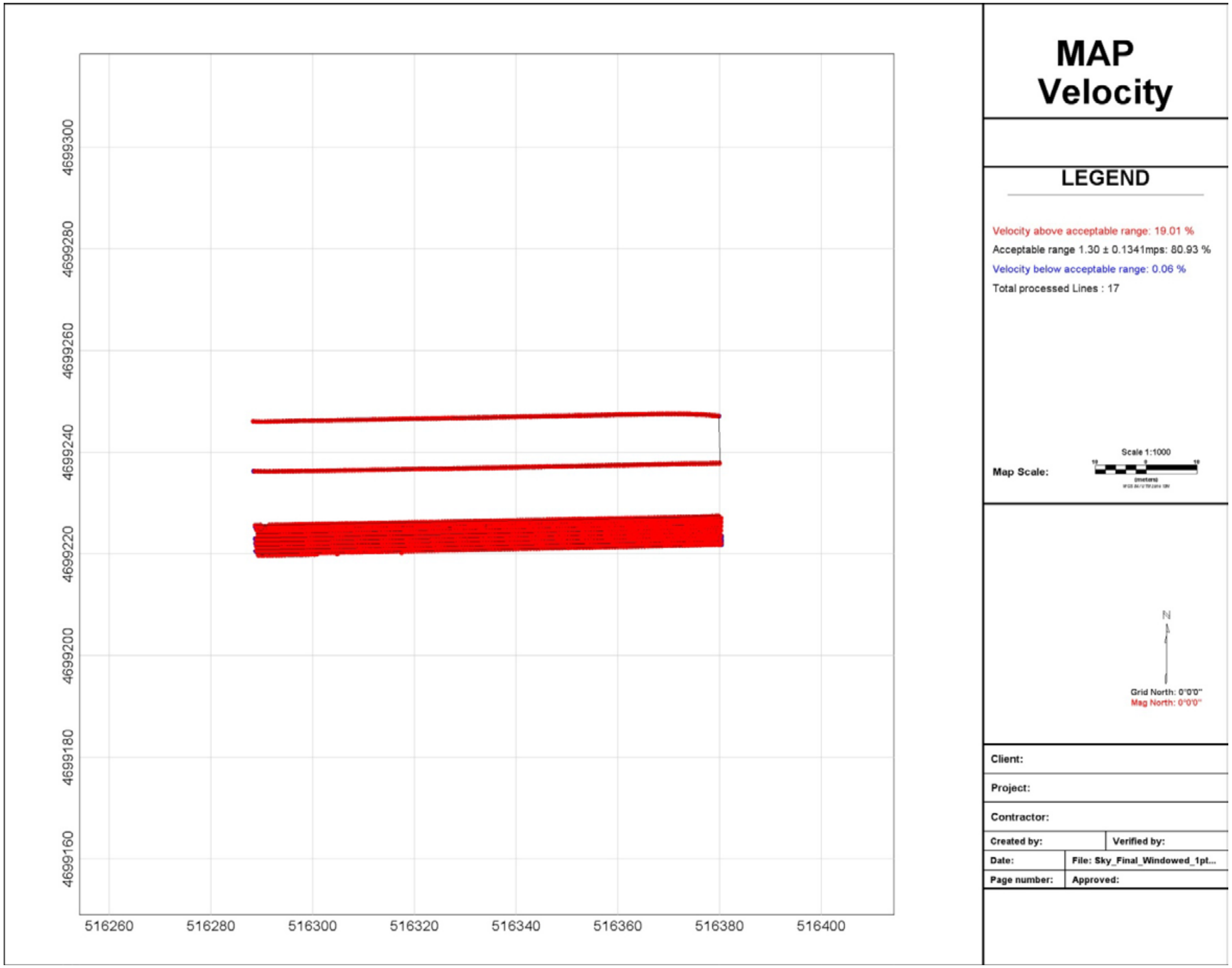


Figure H-16. Survey Speed Analysis for Team Sky Research at Design Speed of 1.3 m/s

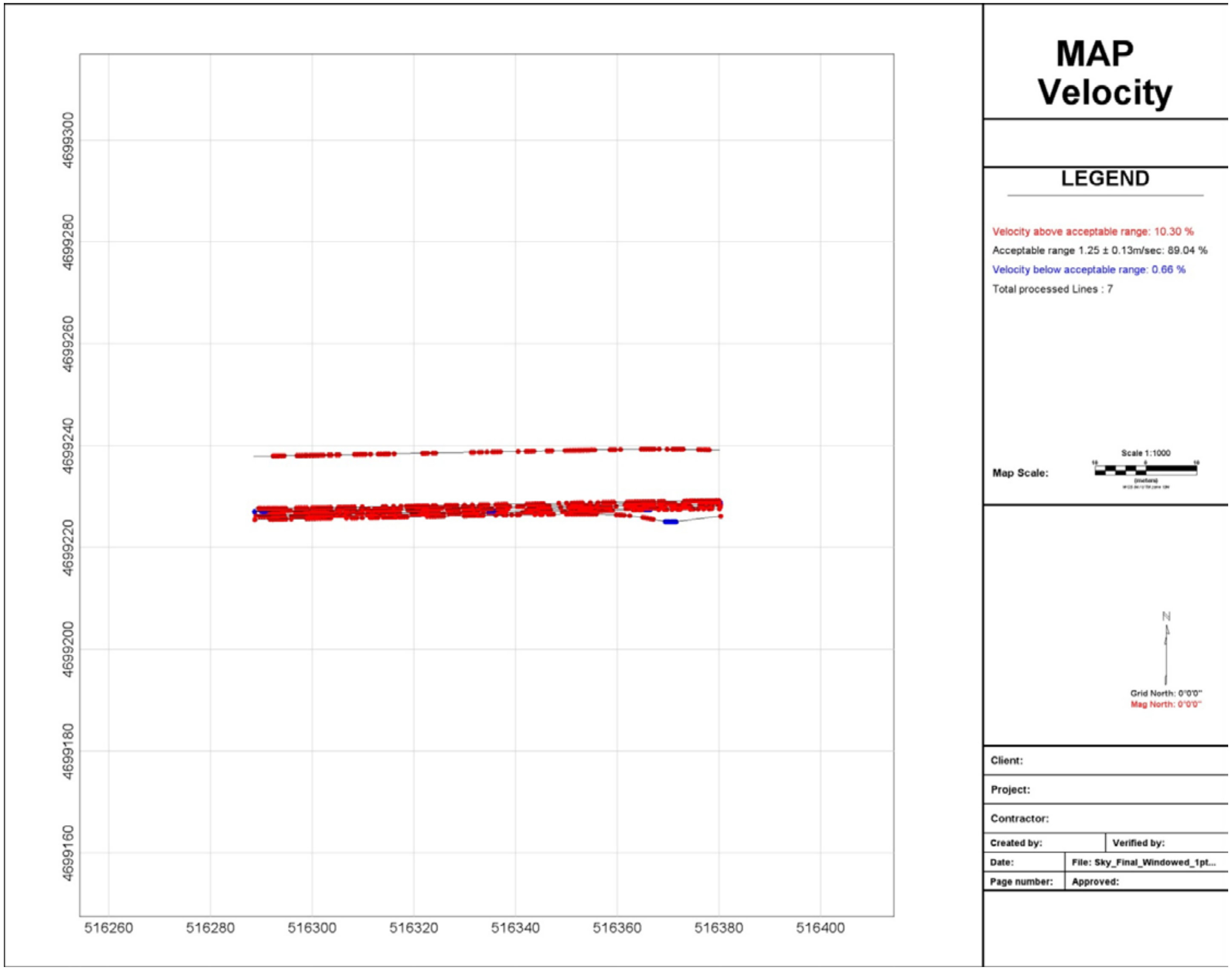


Figure H-17. Survey speed analysis for Team Sky Research at design speed of 1.25m/s

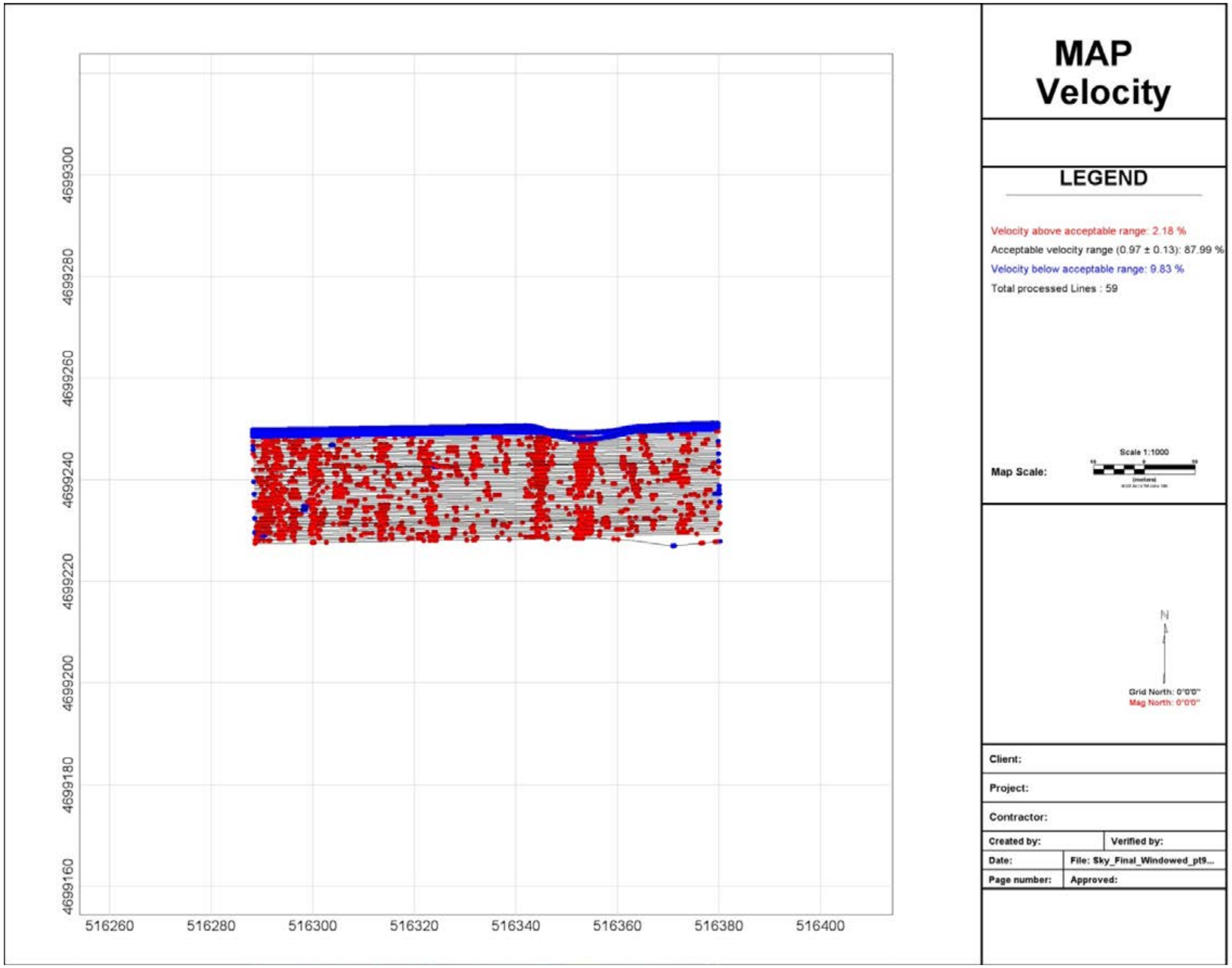


Figure H-18. Survey Speed Analysis for Team Sky Research at Design Speed of 1.3 m/s

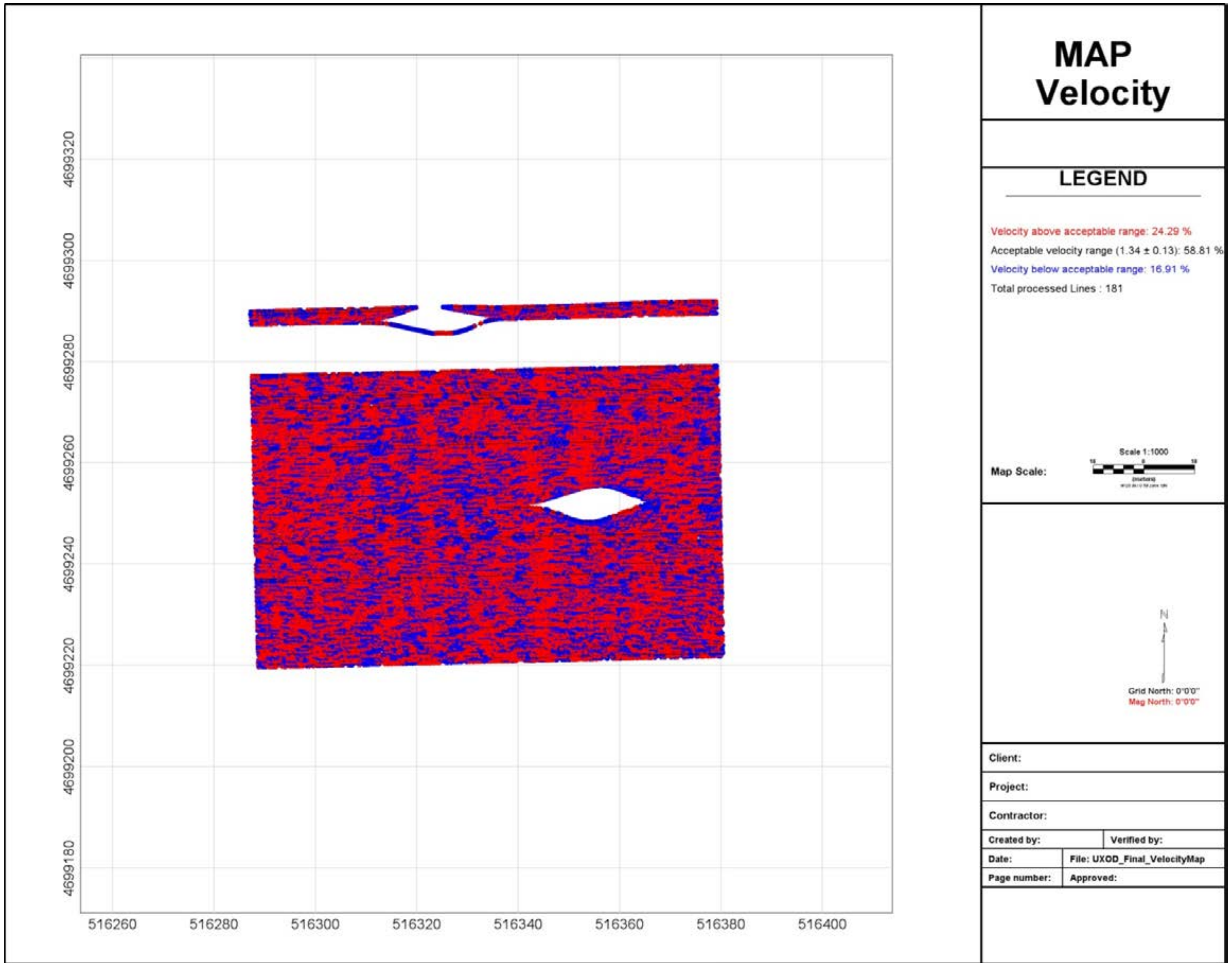


Figure H-19. Survey Speed Analysis for Team UXOD at Design Speed of 1.34 m/s

H.4. SCORING

The scoring was performed as described in Appendix C.

The geophysical mapping objectives included the intent to deploy a time domain electromagnetic induction metal detector and record its data over 100% of the designated area at a line spacing of 50 cm. All competitors brought geophysical mapping solutions that could deploy more than one sensor simultaneously. On 4 August the R2C2 verified with each team the intent was score the dataset from a single sensor. On August 4, while delivering the Q&A document (Attachment A), and again on August 6, during an all-teams briefing called by the R2C2, all teams were informed they could deploy more than one sensor if they desired and either themselves select which sensor's dataset they would submit for scoring, or they could submit all sensor datasets and the R2C2 would score each individually and use the dataset that produced the highest score for the geophysical mapping challenge task performance score. Team D4C and Team UXOD each submitted a single dataset for scoring. Team Sky Research submitted two final datasets, one for the center sensor of their five-sensor system, and one containing all five sensor's data. Team Sky Research did not specify which dataset they wanted scored. The R2C2 decided to process each sensor's data and used the sensor that produced the highest score. Sensor #1 scored the highest after summing the individual task performance scores in the four scoring categories, and is the sensor used for the Team Sky Research score reporting below.

Table H-7 presents the geophysical task performance scoring for each team.

Table H-7. Geophysical Mapping Task Performance Scores

		R2C2 Baseline	D4C	%diff	Sky Sensor 1	%diff	UXOD_Ch 30	%diff
Noise (units are mV)	StdDev	0.84	0.84	0.00%	0.82	-2.38%	0.31	-63.10%
	95%ile	1.4	2.2		2		0.5	
	5%ile	-1.3	-0.37		-0.55		-0.96	
	Range	2.7	2.57	-4.81%	2.55	-5.56%	1.46	-45.93%
			ave:	-2.41%	ave:	-3.97%		-54.51%
	Score (max. 70)		70		70		70	
Coverage	Percent Coverage		58.400%		40.100%		83.960%	
	Round-up plus 5		64%		46%		89%	
	percent of 60 points		38.4		27.6		53.4	
	Score (max. 60)		39		28		54	
Anomaly Detections	Total Detected		92		69		125	
	Percent Detected		73.6%		55.2%		100.0%	
	Score as percent of 60 points based on percent detected within requirement		44.16		33.12		60	
Speed	Percent within tolerance		84.7%		84.0%		58.8%	
	Score (max. 60)		20		20		5	
Total			173.16		151.12		189	

H.4.1. Noise Level

The purpose of the noise level score was to assess noise introduced to the geophysical data due to the robot or the deployment form-factor designed into the robotic geophysical mapping solution. Noise attributed to other sources such as geology or geophysical system electronics were not a factor in this scoring. Note: no sources of noise were observed that were attributed to geology or geophysical system electronics. Noise level scoring used a process that calculated the percent difference between various statistics describing team collected data and statistics describing data collected by R2C2. The average percent difference was then subtracted from 100 and the difference multiplied by 70 (the maximum points allotted to noise scoring.) Negative percent differences indicate the team's sensor noise was less than the R2C2 baseline noise. All teams had negative percent differences illustrating all used deployment platforms on their robots that minimized noise attributed to the robot or the deployment platform. Accordingly all three teams were allotted the full 70 points for their noise score.

H.4.2. Sensor Coverage

Sensor coverage was calculated as the percent of the area covered multiplied 60, the maximum points allotted to senor coverage scoring. The raw percent covered calculated was adjusted upward by 5% for each team. This was done to because of small random variations typical of GPS systems deployed in dynamic modes over rough terrain. These small random GSP variations do not accurately reflect the coverage achieved by the geophysical sensors. The five percent adjustment provides for coverage assessments that more accurately reflect the true coverage achieved by the geophysical sensor.

H.4.3. Anomaly Location Accuracy

Anomaly location accuracy was scored as the percent of anomalies detected within the 30 cm requirement multiplied by 60, the maximum points allotted to anomaly location accuracy scoring.

H.4.4. Survey Speed

Survey speed was scored according to the table presented in Section H.3.4 above. The average speeds tabulated in Table H-6 were used to assess the survey speed score.

H.5. SUMMARY

This report presents the metrics and scoring of the task performance portion of the Robotic Range Clearance Competition's geophysical mapping challenge. Geophysical data from the three competitors were analyzed following the methods outlined in the final R2C2 Rules and Metrics document (Appendix C). All data analysis was performed in the same manner for each of the three competitor's data. All scores were determined using the processes described in Appendix C. Table H-7 presents the geophysical mapping task performance scores for each of the three competitors.

H.6. ATTACHMENT A

Copy of Coverage Calculation and Scoring Method Provided to Competitor Teams Prior to Competition Start.

August 6, 2011

Robotic Range Clearance Competition

Geophysical Mapping Challenge

Q: Regarding coverage calculation for a 0.5m design specification, how are small deviations from the design handled in the scoring?

A: The coverage scoring is modified in response to this question. Score will be determined by the following:

A. Score will be determined by the percent of the range covered at the 50cm design line spacing. All coverage calculations will exclude areas under obstacles.

B. Score will be determined using the following formula:

   a. The Geosoft “UCEFOOTPRINTCOV” GX will be used to calculate percent coverage using a 0.5m footprint input value. The percent coverage will be rounded up to the next integer value.

   b. Integer values greater than 94% will be considered to fully meet the coverage requirement and the final coverage score will be 60.

   c. For integer values equal to or less than 94%, the integer value will be adjusted upward by 5 percentage points.

   d. The adjusted percent value from (c) will be multiplied by 60 and the product rounded up to the next integer value.

   e. The integer value from (d) will be the final coverage score.

C. Examples:

   a. A team achieves a coverage of 94.2% using the Geosoft “UCEFOOTPRINTCOV” GX and a 0.5m footprint input value for the calculation. Ninety-four point two is rounded up to 95%, which is greater than 94%. The final coverage score is therefore 60 points.

   b. A team achieves a coverage of 78.2% using the Geosoft “UCEFOOTPRINTCOV” GX and a 0.5m footprint input value for the calculation. Seventy-eight point two is rounded up to 79%. The final coverage score is calculated as: (79% + 5%) x 60 = 84% x 60 = 50.4, which is rounded up to 51. The final coverage score is therefore 51.

H.7. ATTACHMENT B

Copy of Revised Geophysical Mapping Area

August 6, 2011

Robotic Range Clearance Competition

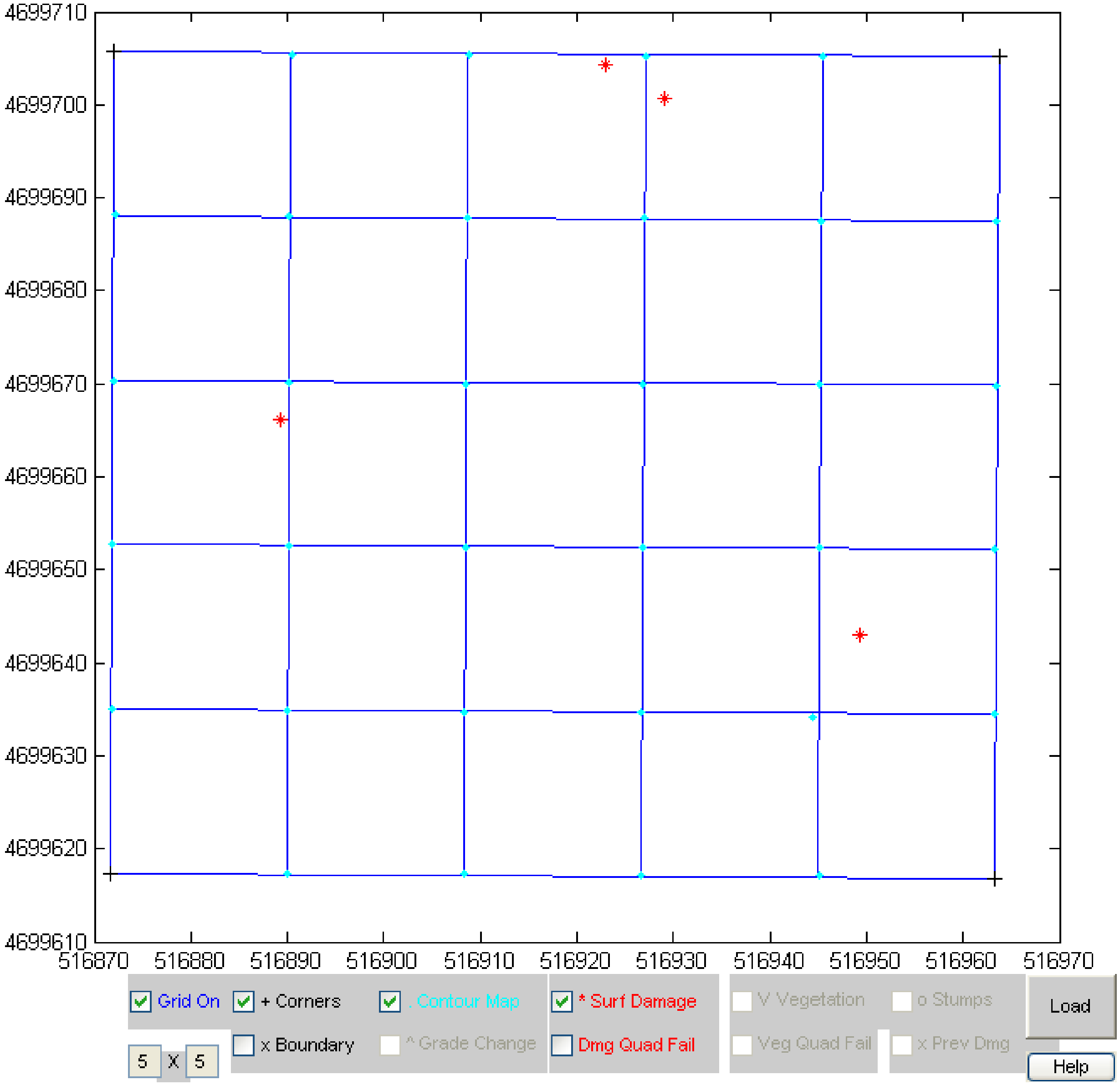
Geophysical Mapping Challenge

To better meet the R2C2's objectives of having all competitors complete a designated area within the allotted time, the northern boundary of the geophysical mapping area has been revised to reduce the total area over which competitors will be scored. The new northeast and northwest mapping area coordinates are:

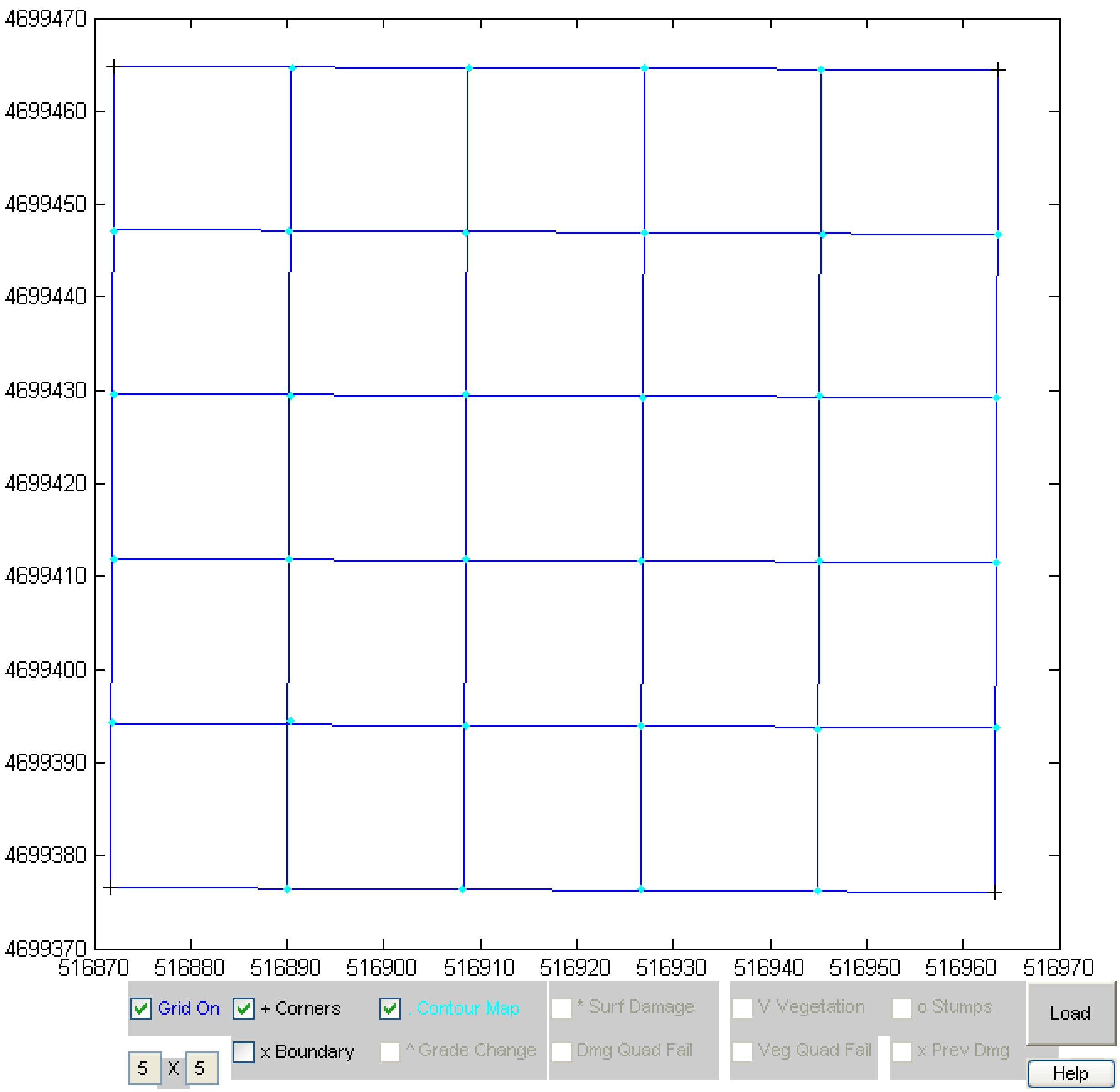
Revised Northeast Corner:	516,379.0 East	4,699,292.0 North
Revised Northwest Corner:	516,287.2 East	4,699,290.0 North

All coordinates are UTM Zone 13 North, units are in meters.

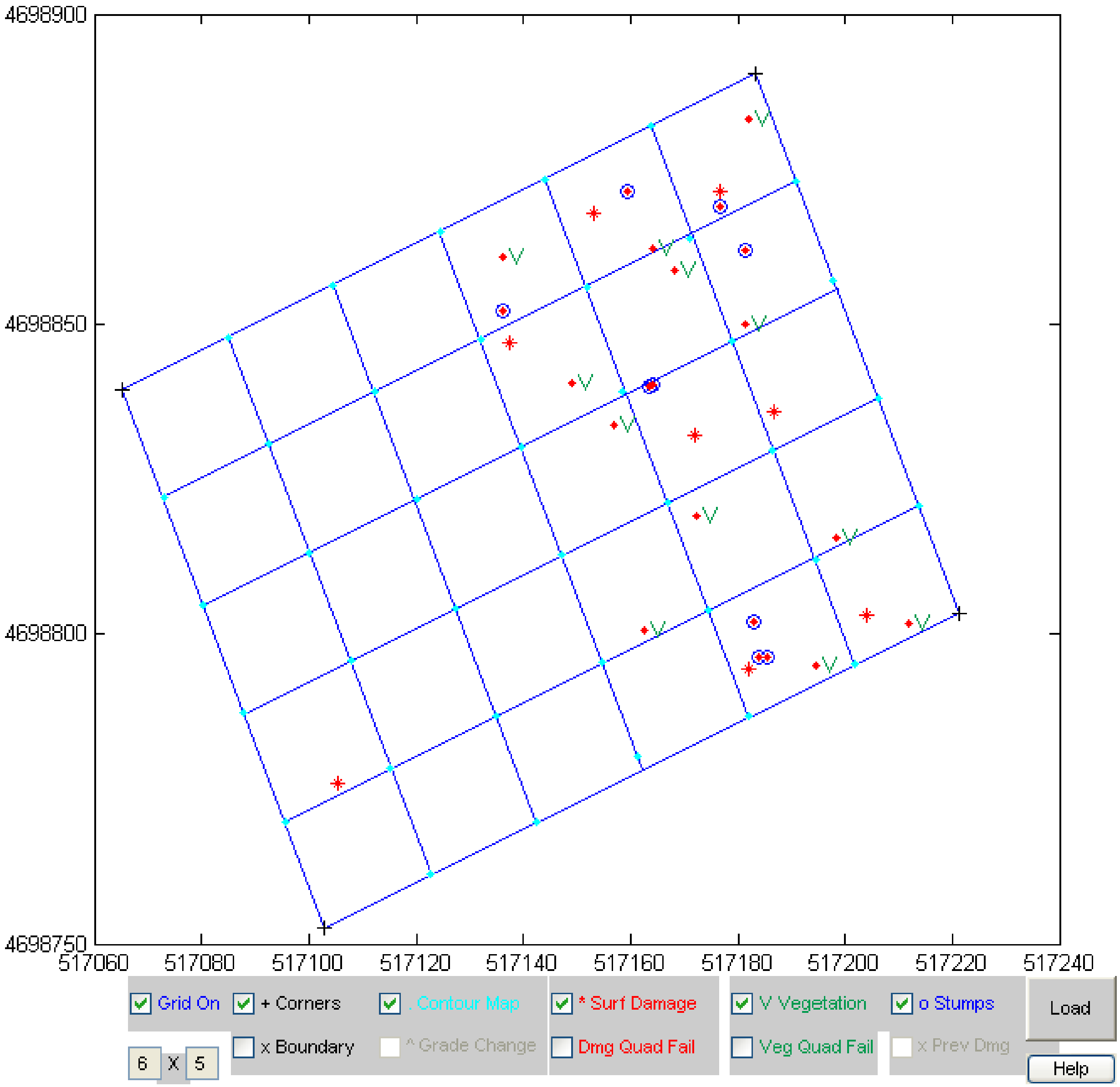
Competitors are not required to map the northern portion that has been deleted. Any mapping performed in the deleted area will not be used in any manner for scoring or other purposes. The original Area of Operation boundary and the original Buffer boundary remain unchanged.



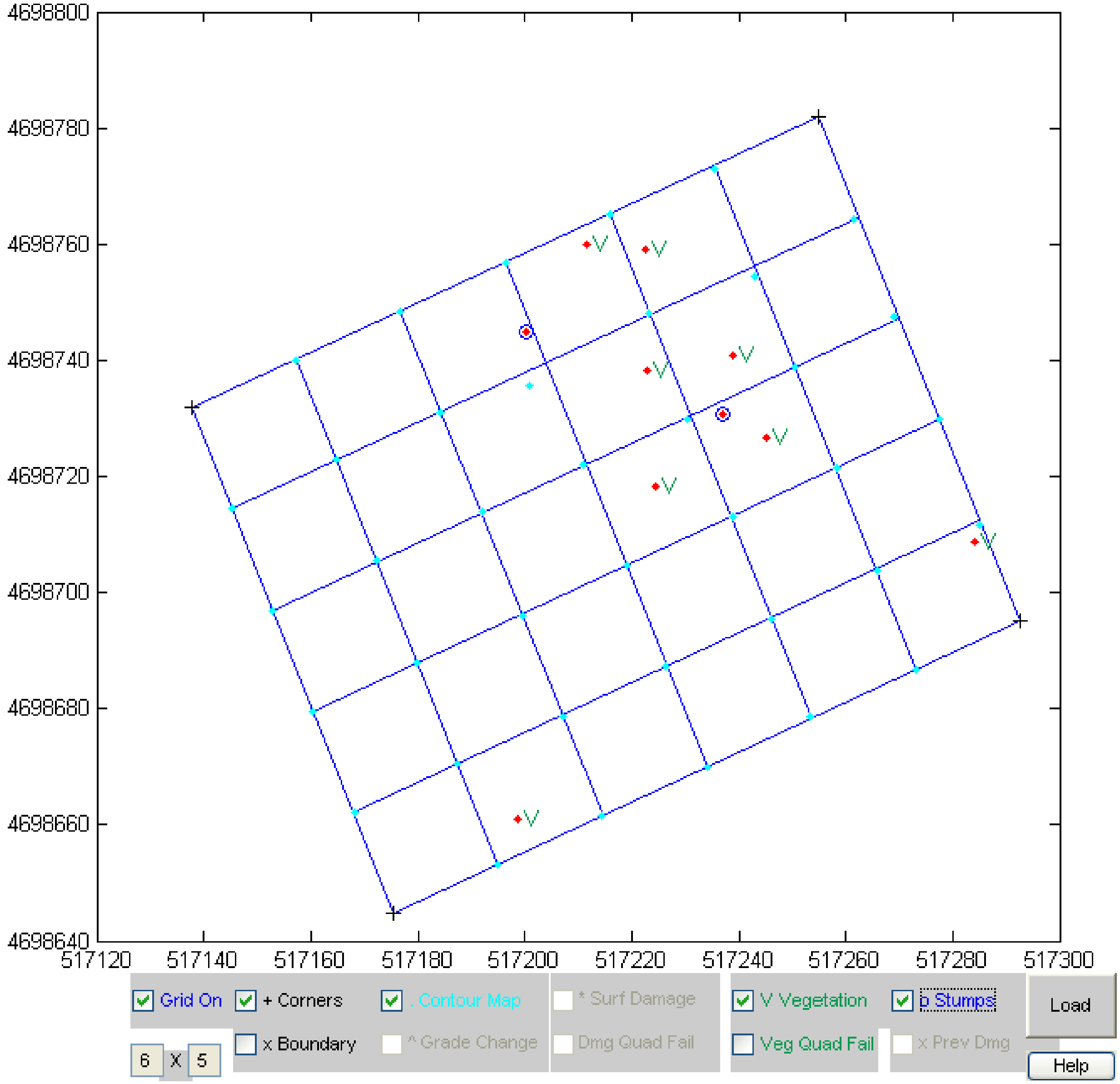
R1SUB
Subsurface Clearance Range 1
Team UXOD
Surface Damage



R2SUB
Subsurface Clearance Range 2
Team D4C
Surface Damage



R1VEG
Vegetation Clearance Range 1
Team UXOD
Surface Damage/Vegetation Failures/Stump Failures



R2VEG
Vegetation Clearance Range 1
Team D4C
Surface Damage/Vegetation Failures/Stump Failures

Appendix J: Q&A

Joint Ground Robotics Enterprise Robotic Range Clearance Competition (R2C2)

Competition Questions and Answers

v. 6 AUGUST 2011

Document Change Summary

Section	Description	Date
2.3.3	Answered all previously unanswered questions and moved to 2.2.2.	11 March 2010
2.2.3.43	Added question and answer re: AUVSI schedule.	18 March 2011
2.2.1.10	Added question and answer re: potential government shutdown.	18 March 2011
2.2.2.28	Added question and answer re: density of seeded items.	18 March 2011
2.2.2.29	Added question and answer re: magnetic sifters.	18 March 2011
2.2.2.30-39	Added questions regarding competition rules.	19 MAY 2011
2.2.2.40-44	Added questions related to safety testing rules.	27 July 2011
2.2.3.44-50	Added questions related to competition procedures.	27 July 2011
2.2.2.45	Added a question related to Army geophysical mapping QC requirements	6 AUG 2011

CONTENTS

1. EXECUTIVE SUMMARY

1.1. Scope

This document lists questions posed by kickoff meeting attendees, Industry Day meeting attendees, and other potential competitors in the Robotic Range Clearance Competition (R2C2) about the competition rules, logistics, scoring, etc., and their answers.

1.2. Purpose

The purpose of this document is to establish a reference for questions that competitor teams have asked and the answers provided by the R2C2. The intent is to periodically update this document as questions are added or as answers change.

It is important to note that these answers are intended to be informational and supplement other sources of information about the R2C2 competition. The R2C2 Competition Rules and Metrics document acts as the authoritative source for competition rules and metrics. In the event of a conflict between the text of this document and the current R2C2 Competition Rules and Metrics document, the text of the current version of the R2C2 Competition Rules and Metrics document takes precedence.

2. COMPETITION QUESTIONS AND ANSWERS

2.1. Questions related to the IDIQ

2.1.1.1 Will the IDIQ be a service contract or equipment supply?

ANS: Acquisition decisions will be made after market research. Current expectations are an IDIQ service contract.

2.1.1.2 What are the IDIQ evaluation criteria?

ANS: TBD. Typical criteria include cost, quality, schedule, experience, capability, past performance. The Performance Work Statement (PWS) = End state, not how to.

2.1.1.3 What is the size of the IDIQ?

ANS: TBD. Maybe $40M.

2.1.1.4 How does the competition criterion differ from the IDIQ contract criteria, particularly as it relates to the level of autonomy?

ANS: The prize competition is designed to push autonomous solutions that are safe, cost effective and deliver the necessary level of quality. The IDIQ contract is seeking similar outcomes therefore the criteria will be similar.

2.1.1.5 What contract vehicles are expected to provide the bulk of the work in the next 5 years? Is WERS expected to be a big player? Or will the IDIQ support the UXO clearance market?

ANS: The Government will use all available vehicles as to its best interest.

2.1.1.6 Can you layout the difference in Service market size? Has the Army already spoken to present vendors on this robotics need?

ANS: No to the first question, and yes to the second.

2.1.1.7 Will the USAEC explain the relationship of the Competition and the selection criteria for the IDIQ?

ANS: IDIQ will evaluate experience, capability and cost. We likely won’t separately evaluate autonomy. The IDIQ contract will require unmanned operation. Teleop is required; autonomy will add productivity.

2.1.1.8 Will you provide cost data for range clearance services that are competitive today? This is requested so we will know if our automation is cost effective for the IDIQ.

ANS: Yes. We can provide money and time to perform the various range clearance tasks.

2.1.1.9 Is there any possibility that the IDIQ RFP would be restricted to small business?

ANS: Yes. See FAR available on the internet for small business requirements.

2.1.1.10 Will the IDIQ contract be a MATOC or SATOC?

ANS: Market research will dictate.

2.1.1.11 Do you have to be involved in the prize competition to bid on the IDIQ?

ANS: No. The prize competition will provide an avenue for demonstrating past performance.

2.1.1.12 Are you going to be looking for night operations on a UXO site?

ANS: Yes. Range schedule, economy. Range schedules often limit day light access yet provide free access at night.

2.2. Questions Related to the Competition

2.2.1. Competition Goals

2.2.1.1 Any thought on funding upfront costs and lowering the prize?

ANS: Funding cannot be provided up front to lower the costs to competitors. Unlike the DARPA challenges, which did provide funding to selected competitors, a contract may be awarded to one of the competitors in this prize competition. Though the IDIQ award is a separate action from the competition, the Government is not allowed to fund an effort that may ultimately be submitted in response to a procurement action. To help alleviate the cost burden to competitors the Qualification Trials to be held at Camp Guernsey have been cancelled and replaced by an In-Process Review at the competitor team site.

2.2.1.2 Can you publish the reports documenting the work, production, lessons learned, what worked and what doesn't, strategies used, etc. ?

ANS: There is be a public release approved document available online at www.roboticrangeclearance.com that captures prior work AFRL has done in this domain.

2.2.1.3 If existing tele-op systems are already more cost-effective than manual system, why require autonomy in the competition? Shouldn't tele-op be allowed to compete?

ANS: Tele-operated systems are invited to participate in the competition. However, the competition is to advance technology and find a balance between the tele-op systems that are now available and more autonomous approaches that increase cost effectiveness, productivity, and safety. We believe the R2C2 Rules and Metrics document reflects this.

2.2.1.4 It appears to me that an autonomous robot would still require the same amount of ―handlers‖ as a tele-op capability, i.e., more expensive but no savings in manpower. So, why the push for autonomous?

ANS: The Government believes there are significant savings in automated robotics operations.

2.2.1.5 The competition should be designed either for a FUDS type clearance, a range clearance, or a range construction mission.

ANS: The competition will be designed to simulate a range clearance operation.

2.2.1.6 Is there a preference to a single vehicle vs. multiple vehicles to complete the tasks?

ANS: No.

2.2.1.7 AFRL has supported projects in MMR, Honey Lake, Ft. Bliss, etc. If the USACE can simply request AFRL to perform a clearance somewhere, why or how could the private sector compete with that? Eventually autonomy in operations will be attained by AFRL.

ANS: AFRL performs R&D and conducts experiments in Autonomous Range Clearance. AFRL does not compete with industry for range clearance.

2.2.1.8 Will the teams and their competitors be publicly announced?

ANS: We expect to announce the competitors.

2.2.1.9 Taking into consideration the current political and economic environment-What impact or risk will the announcement of the administration's decision to send an additional 30 thousand troops into Afghanistan have on this effort, i.e., schedule slip; loss of identified funding, etc., keeping in mind that this troop increase is not in the current budget. So the military and Congress will have to find money to support and typically look to sourcing through cuts to programs either ongoing or new programs/efforts.

ANS: OSD and DA G-3 have committed as long as we have competitors.

2.2.1.10 Will the potential Government shutdown and / or continuing resolution situation affect the Robotics Range Clearance efforts? Are there contingency plans if this occurs?

ANS: Yes a potential Government shutdown could affect the R2C2. All the necessary funds have been obligated for the preparation, management and operation of the event, but a lengthy or untimely shutdown could impact the government personnel's ability to run the competition. A contingency plan has not been developed for this unlikely scenario, but the competition would be conducted at a later date. This may include an alternate location and possibly reduced scope based on the situation.

2.2.2. Competition Rules

2.2.2.1 Are we considering GPS denied areas as a consideration in the scoring?

ANS: Robust solutions are desired but performance will be measured, not GPS denied specifically.

2.2.2.2 Interactions per acre or per time?

ANS: Interactions will be measured during the entire operation. No association between interactions and acreage has been established. See R2C2 Rules and Metrics document.

2.2.2.3 In the business there is enhanced teleops—automated. Will teleop be prohibited?

ANS: Tele-op is not prohibited.

2.2.2.4 Will we pick a site that matches what a team intends to do?

ANS: There will be a common geophysical mapping range for all competitors in that category. Other sites will be assigned based on the categories the competitor team intends to perform in.

2.2.2.5 On vegetation - how are you to rate vegetation removal by size of equipment and level of autonomy? An expensive high production compared to several inexpensive low capability units?

ANS: It will be evaluated on productivity, capability, and effectiveness.

2.2.2.6 How will competitors be judged? Example, under vegetation clearance is clearance rate more or less important than amount of material removed. For example, if I can leave large trees in place, I may be able to do it quicker.

ANS: Competitors performance will be judged on the end state achieved in relation to the performance requirement.

2.2.2.7 You have stated that each competitor will have a different area to clear at Camp Guernsey. Will these areas be mapped ahead of time so that you know what is there? Otherwise, how will you evaluate vehicle performance at that location?

ANS: Yes. Sites will be surveyed ahead of time.

2.2.2.8 Will foreign clearance companies be allowed to participate as a sub-contractor to a US prime contractor?

ANS: Yes, pending legal review and approval.

2.2.2.9 Is the sensor suite for mapping and marking specified? Can you describe it, or what are the characteristics of ordnance, i.e., metallic, etc.?

ANS: No, not specified. Ordnance items of interest will include 20mm to 155mm and are metallic.

2.2.2.10 Why is marking with flags separate from excavation for an autonomous robotic system?

ANS: Marking is no longer a part of the competition. See current R2C2 Rules and Metrics.

2.2.2.11 How large an area for vegetation clearance? What is comms range? LOS? Frequencies? Will there be comms deconfliction? What will be the slope?

ANS: The exact size of the area is TBD. The communication range will depend on the communication strategy created by the competitor team. No personnel will be allowed within the exclusion zone of 870M. Line of site is not ensured. Frequencies will be requested by the competitor and de-conflicted by competition oversight primarily through geographic separation and scheduling. Based on Camp Guernsey's spectrum, bands and power limits will be suggested. Slope see R2C2 Rules and Metrics doc.

2.2.2.12 Can we change the 3000 feet exclusion to say 3000 feet from the operational equipment as opposed to 3000 feet from the perimeter?

ANS: Yes. See current Rules and Metrics doc. This rule now states 870 M from the robot.

2.2.2.13 How many shifts per day?

ANS: The competitor team will establish how many shifts per day. R2C2 is not specifying. Teams will address this in their operational safety plan. Any shift duration deemed to be unsafe will be addressed.

2.2.2.14 Will we be given a chance to give them a return home function if comms are lost?

ANS: See R2C2 Rules and Metrics doc. The ―Loss of Communications Stop‖ rule requires that the system halt and cease operations. Communications can be regained and operations resumed. If a team proposes a retro-traverse, please tell us and we will consider it.

2.2.2.15 Define range perimeter?

ANS: For the purposes of the competition the range perimeter is the work space boundary for the performance task. See R2C2 Rules and Metrics doc.

2.2.2.16 JGRE JAUS compatibility?
ANS: It is not required.

2.2.2.17 How does the ESCIP focus on UXO classification apply to the geophysical mapping component of the prize competition?

ANS: Competition and rules focus on deployment of the sensor, not evaluation/classification of the data.

2.2.2.18 Driver is cheaper, safer (?). If someone is to bring a teleop system will they be able to compete.

ANS: Yes. Tele-op can compete.

2.2.2.19 Does monitoring equate to human interaction?

ANS: No

2.2.2.20 Will duration of interaction be measured?

ANS: Yes

2.2.2.21 Define payload? Driving or buck ops is payload? (?)

ANS: There is no specific reference to payload in the R2C2 Rules and Metrics doc. This question is unclear but seems to ask if there is a difference in interaction weighting between driving and bucket operations. It is the intent of the competition to capture all human interactions and level of interaction with the systems.

2.2.2.22 Would a pre-range walk count:

ANS: as a human interaction – No
ANS: as a function of time – Yes
ANS: what if you gathered data on the walk around and uploaded the data? Uploading is an interaction

2.2.2.23 Will competitors be allowed to perform a range walk prior to employing their system for any/all categories?

ANS: Yes

2.2.2.24 How many acres will be clear cut for vegetation removal?

ANS: The scope of the competition, to include the size of the ranges, will be determined after all Letters of Intent have been received and the R2C2 makes a determination on the number of viable competitor teams relative to the available resources.

2.2.2.25 For competition, what will be the mass required to be lifted?

ANS: The maximum mass required to be lifted will be the mass of the largest piece of simulated munitions of concern representing a 155 mm artillery round.

2.2.2.26 How fast do tasks need to be completed? What is the time limit on the competition?

ANS: The scope of the competition, to include the duration of each event, will be determined after all Letters of Intent have been received and the R2C2 makes a determination on the number of viable competitor teams relative to the available resources. The intent of the R2C2 is that events will last from a few days to no more than a week.

2.2.2.27 If they fly a manned vehicle, how does this affect the scoring?

ANS: Given that the competitor team receives permission from Camp Guernsey and follows all applicable regulations and procedures, time and man-hours to fly any mission will count against the team's event score.

2.2.2.28 For all of the areas, can the organizers provide additional detail regarding the density of seeding for the areas? Are there metrics or guidelines available that will give guidance as to the number of objects per acre or some other quantitative measure?

ANS: Each area will be from 2-5 acres in approximate size. The areas will simulate artillery and mortar targets with up to 182 kgs per acre of UXO debris with an approximate 70/30 surface to sub-surface ratio. The types and sizes of the UXO items are described in the ISO description document on the R2C2 SharePoint site. The vegetation clearance area will be composed of a mix of tall grass, large bushes, and trees with up to 25 trees per acre (up to 36 cm trunk dia.)

2.2.2.29 If the seeding of the areas is expected to be dense, will the organizers be providing magnetic sifters similar to the ones used at Camp Edwards for the competition, or are teams expected to purchase sifters as part of the surface clearance event?

ANS: No, teams must provide all of their own equipment.

2.2.2.30 Will there be any canopy issues that may deny GPS reception?

ANS: There are no anticipated or planned areas in the competition where canopy should interfere with GPS reception. For the geophysical mapping, surface clearance, and sub- surface clearance events there should be no canopy issues. For the vegetation clearance event, no canopy issues are anticipated due to the density of the tree cover. But the competition organizers cannot rule this out. Teams should plan accordingly.

2.2.2.31 Will the competition areas for geophysical mapping and both clearance tasks be cleared from obstacles such as boulders, trees, etc.? Will there be large enough obstacles that we would need OD/OA (boulders, etc.) for a vehicle such as an ATV to traverse?

ANS: Each of the ranges will have obstacles constructed of railroad ties that competitor vehicles and equipment are expected to avoid. There is no explicit competition requirement for traversing these obstacles.

2.2.2.32 What data will be provided on the sites and when (i.e., terrain, site location, maps, photos, collection area location for debris and seeded items, command area location, ingress/egress path from pit area to task areas, etc)?

ANS: Data, such as the types mentioned above, will be provided to all competitors two weeks prior to the start of the competition.

2.2.2.33 What will be the distance between command location and the task area?

ANS: Competitors should be prepared to operate vehicles more than 870 meters from the command location.

2.2.2.34 For the subsurface clearance task, will the dig coordinates for 50 buried ISOs contain the buried depth of the seeded item?

ANS: Competitors will be provided dig coordinates and measures of signal strength for each of the seeded metallic items. The current version of the rules does not specify the actual number of ISOs.

2.2.2.35 Can you provide any information on the dispersed density of the seeded items? For example, will the seeded items be equally dispersed throughout the task area or will there be just a few higher density areas?

ANS: For the sub-surface clearance event, competitors will be provided a dig list of seeded metallic items (ISOs) to remove. For the other events, no more information is provided about seeded metallic item density or location.

2.2.2.36 Will any of the tasks be done over the same ground? Or will each task that a team will perform be done over new ground?

ANS: The only shared range for all competitors is the geophysical mapping range. Competitors will be provided a range area that only they will operate on for each of the other events.

2.2.2.37 Can you provide information on the containment area? Will there be a bin that the seeded items have to be placed in or just an area on the ground?

ANS: All containment areas will be areas marked on the ground.

2.2.2.38 Can you provide more information on the penalties for surface grade and surface damage?

ANS: The rules document specifies the penalties for changes in surface grade and surface damage.

2.2.2.39 Can you explain and give more detail on the survey speed requirement? What is the point of maintaining constant speed for geophysical mapping?

ANS: The competition assumes that electromagnetic induction sensors are typically most effective in geophysical mapping when accelerations of the sensor are minimized.

2.2.2.40 The system shall have an Emergency Stop (E-Stop). The system must halt within 15 meters and cease all equipment operations when the E-Stop is initiated. The E stop must be remotely activated. Question: to us all "cease all equipment operation" means - vehicle stops and is not moving, - nothing on the vehicle is moving. However, it could be interpreted to mean "engine is stopped". Could you clarify? Specifically, do we need to turn of the engine when the E_stop is engaged? Note that this would mean that we have to manually restart the engine.

ANS: For the e-stop the best case is for the engine to be stopped. You are allowed to go down range to restart it. It just cost the time to do it. It can be left on, but you must show how your design would prevent unintended movements.

2.2.2.41 Is it acceptable if the flashing light is on continuously when the system is powered up, or can it only be on when the system is moving (and 10 seconds prior to this?)

ANS: per the rules document page 11. "Each vehicle shall be equipped with a warning light that is activated according to the state of the E-Stop system.
Each vehicle shall display one or more flashing amber warning lights, the combination of which results in visibility 360 degrees azimuthally around the vehicle. The warning light(s) shall operate when the vehicle is in E-stop RUN mode. The vehicle may not commence movement until the warning light(s) has been in operation for 5 seconds. The warning light(s) shall comply with SAE Class 1 standards for warning lights and shall not produce light(s) than can be confused with those of public safety vehicles such as law enforcement, fire, or ambulance." Strictly following the rules your light should only operate when the vehicle is in the e-stop "RUN" mode. The best way to accomplish this is to wire

the light power into the e-stop circuit. The required delay before movement is 5 seconds not 10.

2.2.2.42 Warning Devices - We interpret that you want the warning light to be flashing - at least 5 seconds prior to the vehicle is supposed to start moving (it sounds like 20 seconds would be fine as well) -while the vehicle is moving. When the vehicle is not moving, and is not supposed to be moving, the light should be off. When the motor is running, but the vehicle is not supposed to be moving, the light should be off. Can you confirm that this is correct?

ANS: For the warning light, the rule is self explanatory. If you have it on when the system is off that is your choice, but it is not very useful to warn of impending motion.

2.2.2.43 Loss of communications stop - The system shall automatically halt and cease operations if communications with the system are lost or interrupted for a maximum of 2 seconds and may travel no farther than 30 meters. The question here is similar to the one for the E-stop. We assume that loss of communication should result in the vehicle stopping. However, we would leave the engine running (so that if comms was lost and then resumed the vehicle could continue the mission). Could you confirm that this assumption is correct (ie loss of communication stop allows for vehicle engine running as long as vehicle is stopped?)

ANS: You're correct in your interpretation of the loss of communication rule. Once again the rule is self explanatory.

2.2.2.44 No freewheel - The systems shall not be capable of motion when stopped or un-powered. The way we interpret this is that when the vehicle is stopped or the engine is off it cannot freewheel. Our stop solution (which applies the brake) is powered from a battery. We assume that this is allowed? So, un-powered purely applies to the engine, and not to the control system?

ANS: For the no freewheel rule, unpowered means unpowered. So the use of battery power to hold the brake does not conform to this rule. There are many methods available to apply brakes or stop motion when no power is available.

2.2.2.45 Are the Army Corps digital geophysical mapping QC requirements required for this competition?

ANS: No. Each competitor is solely responsible for the quality of their geophysical data.

2.2.3. Competition Procedures

2.2.3.1 Can you publish the reports documenting the work, production, lessons learned, what worked and what doesn't, strategies used, etc.?

ANS: There is a public release approved document available online at www.roboticrangeclearance.com that captures prior work AFRL has done in this domain.

2.2.3.2 Will competitors have access to area prior to run?

ANS: Yes.

2.2.3.3 What will be the slope?

ANS: Terrain will vary from relatively flat to sloping up to 45% with interspersed ravines, ditches, rocks.

2.2.3.4 Communications de-confliction?

ANS: Will be included in the packet. Will cover test, entire band, wattage will be constant, will need advance notice of requirements. De-confliction shall be accomplished through geographic separation and through scheduling.

2.2.3.5 Will communications be line of sight or indirect?

ANS: Line of site is not ensured.

2.2.3.6 Foreign national visitor approval?

ANS: Foreign national visitors must comply with Camp Guernsey site physical security requirements which will include escort provided by competitor team.

2.2.3.7 Will competitors have to prepare and submit work plans and safety plans?

ANS: Yes.

2.2.3.8 EM 385-1-97 and other DoD publications state that when mechanical means are utilized for UXO removal, the maximum fragmentation distance will be observed as an exclusion zone, i.e., 155mm HE projectile + 2,577 feet. Will an exclusion zone be established for personnel standoff distance?

ANS: Yes. For the purposes of the competition the exclusion zone is 870M from the system.

2.2.3.9 What is the expected range of (LOS/NLOS) operation?

ANS: LOS is not ensured. The competition does not specify your comms solution.

2.2.3.10 Limit on the number of competitors?

ANS: No.

2.2.3.11 How many competitors to move forward? 2-3?

ANS: OSD will decide.

2.2.3.12 Will Competition documents be available in the public domain? For example, Competition rules, Qualification results, Evaluation criteria.

ANS: Yes.

2.2.3.13 Can we get an example GIS.DQM.SMP (sp?) file package from Guernsey to review and consider in planning and design?

ANS: Yes. This has been requested based on the anticipated competition site.

2.2.3.14 Spectator area?

ANS: Maybe. The R2C2 plans to establish a spectator area if the resources are available to safely establish one.

2.2.3.15 Sponsors: are you going to make this a media event so sponsors will care?
ANS: Yes.

2.2.3.16 Will frequencies in 5-6 GHz be available?
ANS: Camp Guernsey cannot make any frequencies ―available‖ as the Wyoming National Guard is not a communications regulatory authority. There are no users on Camp Guernsey in that band. A brief license search with the FCC turned up no local licenses in that band except at 5.9452 GHz. Assuming your operating compliance with FCC regulations there is nothing that would restrict your use of frequencies in the 5-6 GHz range.

2.2.3.17 Can you provide a section in the FAQ that records questions asked but yet to be answered so we know the question has been received?
ANS: Yes. If R2C2 feels that the question is a duplicate of one already received and answered no attempt will be made to capture the new question. In short, we expect that a competitor has reviewed the latest version of the Q&A to determine if their question has already been answered before asking a new question.

2.2.3.18 How will we know the teams have lost comms?

ANS: We will simulate loss of comms to test and confirm the system is compliant with rules.

2.2.3.19 Applies to loss of either E-stop comm and (?)?

ANS: ― Loss of communication‖ is the loss of all communication with system.

2.2.3.20 Fire extinguishers in each vehicle?

ANS: We are not requiring fire suppression systems on the competitor systems. Fire extinguishers will be available at Camp Guernsey for team and pit areas. Teams are encouraged to bring their own extinguishers. The potential of a fire will be addressed by teams in their safety plan.

2.2.3.21 Halon required on the vehicle?

ANS: No. See above.

2.2.3.22 What are the qualifications of the safety officer? Will they be required to be UXO (?) …

ANS: The team will be responsible for determining qualifications. UXO teams are not required.

2.2.3.23 If remotely 3000 feet away, how will you know the boundary?

ANS: We will provide GIS.

2.2.3.24 Will accurate mapping and contour be provided?

ANS: Teams will be given a GIS data package for their competition site. R2C2 intends to determine the accuracy of the mapping data via ground truth survey and make that data available to competitors.

2.2.3.25 Can they fly UAVs first?

ANS: The anticipated competition sites are within the restricted airspace R-7001 at Camp Guernsey. There is no restriction in the rules regarding UAS operations but competitors will be required to comply with UAS regulations. Please provide the R2C2 oversight with more information as soon as possible to discuss the use of UASs by teams. It should be noted that there are no prepared airfield capabilities within R-7001.

2.2.3.26 Civilian manned aircraft … (?) .

ANS: The anticipated competition sites are within the restricted airspace R-7001 at Camp Guernsey. There is no restriction in the rules regarding civilian manned aircraft operations but competitors will be required to comply with Camp Guernsey flight regulations. Please provide the R2C2 oversight with more information as soon as possible to discuss the use of manned aircraft by teams.

2.2.3.27 If all systems to be used in the competition are fully functional and in operational mode at active installations, do we have to participate in the qualification trials?

ANS: The Qualification Trials have been cancelled and replaced by an In-Process Review. See R2C2 Rules and Metrics doc.

2.2.3.28 How do you expect robot operations to begin at 3000 feet?

ANS: See R2C2 Rules and Metrics document.

2.2.3.29 What about hard cord connection?

ANS: There is nothing in the R2C2 Rules and Metrics Document that precludes cable control operations.

2.2.3.30 Could you provide more explanation on what the competitive field generally may look like?

ANS: Yes. When the sample GIS data package has been prepared we will include photographs and general site description.

2.2.3.31 How accurate is GIS, slope, etc.?

ANS: Undetermined. Camp Guernsey has GIS data that has not been ―ground truthed‖ in the competition site yet.

2.2.3.32 Range footprint for DGM site?
ANS: Will be survey on total station and that data will be available.

2.2.3.33 What altitude does the installation own?
ANS: Camp Guernsey's restricted airspace R-7001 dimensions are in the public domain. The altitude that the installation ―owns‖ depends on what tier of R-7001 is activated.

2.2.3.34 Will packet of lessons learned be made available for review? When? Will the package be posted to the web site?

ANS: Yes. They are available at www.roboticrangeclearance.com

2.2.3.35 The statement was made that the decision to allow an inspection of the performance has not been made. My suggestion would be to allow a site-walk consistent with an inspection of the range area prior to a procurement. The benefits include visual recognition of hazard areas or avoidance features. Would a site-walk of this nature be allowed?

ANS: Yes.

2.2.3.36 Who is liable for a fire?

ANS: The competitors will be responsible to meet the guidelines they have established in their safety plan. If those have been met the installation will be liable.

2.2.3.37 Not to change profile. Does this include the sub-surface task?

ANS: Yes. The tolerances are provided in the R2C2 Rules and Metrics doc.

2.2.3.38 Will the geophysical mapping area be located in open terrain where GPS signal is attainable?

ANS: Yes.

2.2.3.39 How does the 300 foot exclusion compare to the 3000 feet exclusion?

ANS: Removed. See latest R2C2 Rules and Metrics doc

2.2.3.40 Will you expect the system to look for and avoid UXOs during brush cutting operations?

ANS: Not at this time.

2.2.3.41 How will we be judged? Time, production, quality?

ANS: See Rules and Metrics Doc. The three major judging categories are Task Performance, Level of Human Interaction, and Man-hours.

2.2.3.42 Are unit operating costs going to be evaluated as part of the prize competition?

ANS: No.

2.2.3.43 Are the organizers aware of the AUVSI Unmanned Systems North America Conference that will be held Aug. 16-19 in Washington, DC? This is the largest unmanned systems conference in the nation, and a majority of the teams will want to participate in this conference. Will the organizers consider moving the dates of the R2C2 to accommodate this conference?

ANS: Yes we are aware of AUVSI's schedule. The selection and use of Camp Guernsey for the competition allows a small window to accommodate the competition (R2C2). The R2C2 must be conducted after the majority of the summer military exercises at Camp Guernsey (June and July) and before inclement weather sets in (possible in September).
With the current field of four (4) competitors, the R2C2 should run from Monday 8 August to Sunday 14 August (if there are no weather days) allowing team personnel time to travel to AUVSI if they desire. It is possible to begin R2C2 on Thursday 4 August (end on Thursday 11 August), by reducing the onsite practice time to 3 days. All teams would have to agree to this. (Teams are not permitted to conduct practice runs during other teams' scheduled competition events).

2.2.3.44 For the testing effort and for the actual competition we will have groundpower available in our pit area?

ANS: Yes

2.2.3.45 For the week of august 1st, we will have access to a test area. This test area will not have seeded items, but will be similar in terrain to the competition area?

ANS: Yes

2.2.3.46 One thing I am not sure about is whether in the test area there will/will not be obstacles similar to those in the competition area. Could you let me know?

ANS: Yes

2.2.3.47 We know that we will get the coordinates of the obstacles (I guess 8 corner points). Would we also get the corner points of the obstacles on the test range?

ANS: Yes

2.2.3.48 Would you be able to tell us in which coordinate system and with reference to which datum these points will be provided? Note that there is always some difference between NAD83 and WAG84, and it is thus important for us to know what coordinates these would be in so we can work with similar coordinates in our off site validation efforts.

ANS: Answer part 1: Coordinate System is in UTM/WGS 84/UTM zone 13N. UTM zone 13N is the datum reference. Answer part 2: Because of the inherent nature of GPS the JTEC base station is about +/-0.5 to +/-0.25 meters accurate in reference to the UTM GLOBAL coordinate system so we will provide additional information in the form of localization points such that the LOCAL coordinate system is has centimeter level accuracy. Three Localization points (in the competitor information packet) will be provided for each field (many fields share localization points). These localization points will be provided both physically (physical monument locations) and digitally (in the provided SHP file). The shape files for the site will be supplied two weeks prior to the competition as discussed. We will provide this information no later than close of business on Friday 22 July, 2011.

2.2.3.49 I was wondering if you can provide some additional details wrt industry day on the 11th. Specifically, will it take place on the competition site, or at a nearby practice site? What facilities (if any) will there be for us to use (e.g. tables/tents, power)? In case of inclement weather, will we be inside somewhere?

ANS: Please refer to the email sent on June 30 regarding the details for the visitor day. This will take place at the competition site. The excerpts that describe the activities are: "As a reminder for the media and visitor day on 11 August, this will be a publicly attended event with news media reporting. The sample itinerary for the media day is attached. Note - the details and times may change slightly but this is the general flow. Please understand, the presentation time allotted to your team is at your discretion for what you want to present and demonstrate, including what information you wish to divulge. My recommendation is that you provide an introduction and overview of your team and organizations capabilities, the technology you have chosen to use (your choice on detail), demonstrate your system(s) in the practice area (as much or little as you want), and then tour the systems or have a Q&A session or just network - entirely up to you. We are providing the forum for you to present your team and capabilities to the media and visitors. We will provide tent space and practice ranges for the briefs and demos, but once again it's your time to present what you choose. Please let us know any resources or special needs that you may have to enable your presentations." Once again please let us know what if any resources you require and we will try to accommodate them and arrange it prior to your departing for Wyoming.

2.2.3.50 We know that we will have to hand you the raw data within 30 minutes of completion. This will not be an issue. We also know that we will have to provide merged data (ie data with position information) within 48 hours. This will not be an issue. We are not clear about whether we are expected to do anything else. Specifically, there are four following additional tasks:- noise level determination, - sensor coverage assessment, - anomaly location accuracy, - survey speed assessment. We have some questions both about WHO does this, and HOW this is done (see below). Noise level determination - this will be determined by the R2C2 Competition Team. -> is that us, or is that you? (from what I can see, this is the only time the term " R2C2 Competition Team" is used). Sensor coverage assessment - score will be determined by the percent of the range covered.
Q1: I assume this is the percent of the range minus the obstacles?
Q2: how will you determine coverage? The requirement is 0.5 m line spacing. However, at some moment there was the comment "we want you to go right up to the obstacle". Could you clarify this?
Q3: who determines this? Do you determine this? Do we determine it as well? Anomaly Location Accuracy – is this us, or is this you? If this is us, do we provide you with the standard Oasis output? When is this due? Survey speed - is this us, or is this you? Does survey speed only get calculated for when we are collecting data or also for turns
outside the survey data? When is this due?

ANS: According to the rules, competitors are only required to deliver raw data within 30 minutes and merged data within 48 hours. The other assessments are made from the competitor-provided data by the R2C2 judges.

2.2.4. Competition Procedures (GFE)

2.2.4.1 More on GFE – Geophysical sensors as GFE?

ANS: No.

2.2.4.2 ARTS GFE with attachments?

ANS: ARTS only.

2.2.4.3 ARTS equipment and robotic support GFE?

ANS: ICD and maintenance support.

2.2.4.4 Excavator, dozer, etc. GFE?
ANS: No.

2.2.4.5 Do you have an idea of how many ARTS vehicles would be available as GFE?

ANS: We said 9 at Industry Day. It is highly unlikely that anyone will get one for the whole time much less two. It will depend on the level of interest.

2.2.4.6 Superday?

ANS: There will be a media event scheduled for the competition.

2.2.4.7 Flail or range master will a 10-15% growth rate (?)

ANS: If the growth rate is outside of the surface grade change limit of 15cm there will be penalties assessed.

2.2.4.8 The OSD is mandating at least two mobilizations of the equipment to the test site. First for the qualification and the second for the competition. Given the cost of equipment mobilization and since the primary purpose of the qualification is to verify the equipment meets the competition published safety requirements will OSD consider the following: 1. Have the evaluation team travel to the competitors site to view equipment and perform the qualification or: 2. Allow competitors to skip the qualification phase and work at their risk up till the competition. At which time the competition committee will inspect equipment in two phases. Phase one is on the trailer. If the equipment does not meet requirements it is not unloaded until meets standard or rejected completely. Phase 2 is operational test. Again if the equipment does not meet requirements and cannot be promptly modified it is disqualified without further testing/evaluation. It will be the compet it or ’s responsibility to promptly remove the equipment from the test site?

ANS: R2C2 has considered this and has cancelled the Qualification Trials and replaced them with an In-Process Review at the competitor's site. See R2C2 Rules and Metrics.

2.2.4.9 If a company is and has known capabilities are they required to physically attend the qualification round or can they submit a video of systems?

ANS: The Qualification Trials have been cancelled and replaced by and In-Process Review.

2.2.4.10 Will the seeded range that you perform DGM work?

ANS: The seeded geophysical mapping range will utilize buried industry standard objects. See R2C2 rules and Metrics doc for more information.

2.2.4.11 Would that be the same that we'll perform removal action on?

ANS: The geophysical mapping range that is to be used for the geophysical mapping task score is not the same as the surface or subsurface removal sites.

2.3. Unanswered Questions

2.3.1. Questions related to the IDIQ

2.3.1.1 Is there a guarantee of funding for IDIQ?

ANS:

Appendix K: 2009—Robotics Prize Competition Kick-off Meeting Briefing

Joint Ground Robotics Enterprise

Robotics Prize Competition Kick-Off Meeting

Mr. Brian Skibba
AFRL/RXQF Robotics Group
Competition Technical Director

1

Agenda

- **0800-0820 hours – Opening/Welcome (Mr. Tony Melita, Mr. Scott Miller)**
- **0820-0930 – Competition Overview (Mr. Brian Skibba)**
  IDIQ Overview (Mr. Plyler McManus)
- **0930-0950 – Break**
- **0950-1050 – Range Clearance Process Overview (Mr. Andy Schwartz)**
- **1050–1135 -- AFRL Robotics Clearance Overview (Mr. Brian Skibba)**
- **1135-1300– Lunch**
- **1300 – 1330--Camp Guernsey Brief (Mr. Brian Beyer)**
- **1330- 1430--Q and A**
- **1430-1600 – Networking**

2

Robotic Prize Competition Goal

- Advance the state of the art in robotics range clearance technologies to more safely and efficiently clear munitions ranges of debris and unexploded ordnance
- The ultimate aim is to be able to clear the millions of acres currently encumbered with spent training rounds and munitions' debris to place the land back into productive use.

3

Robotic Prize Competition Technical Goal

- To advance the state of the art from remote controlled tele-operation to semi/full autonomous robotic operation
- But, this is not about sensor or platform development … it is an integration and robotic algorithm/behavior challenge

There already existing a wide variety of machines and implements to perform all the required tasks for UXO range clearance. What is needed are autonomous controls to perform the task more safely and efficiently.

Prize Competition Authority

"I have pleaded with DoD labs to conduct prize competitions. There are many DoD programs with difficult technological challenges that could be addressed through the use of a prize competition model. Additionally, the fringe benefits of such a competition are incredible for DoD, small businesses, industry, young people and the Nation. I again challenge DoD labs and program offices to identify challenges and conduct new prize competitions."

John J. Young
USD(AT&L)

Congress has given us the authority, let's use it!

Public Law 110-36 Section 2374a. Prizes for Advanced Technology Achievements

5

Competition Concept

- In order to effect a smooth transition from technology development to system procurement, the competition will be predicated on key decision points.

1. Determine the level of industry interest in participating in a competition as well as the ability to develop, then produce quantities of robotic range clearance systems.
   Complete as evidenced by the participation – 18 RFI responses, 50+ organizations at kick-off
2. The competition event will be preceded by a qualification requirement. Competitors must first demonstrate that they can enter a viable robotic system capable of safely executing tasks inherent in clearing ranges.
3. If a sufficient quantity of competitors qualify to participate in the competition, the DoD will proceed with the competition and award $2M in cash prizes and also pursue a procurement contract to purchase robotic range clearance systems.

6

Competition Concept

- The competition is will be an assessment of the competitors' system performance against a specified set of metrics that satisfy the operational requirements for range clearance.
  - These metrics are being finalized by the competition committees.
- The systems will not to be compared against each other. The winner(s) will be determined by achieving the best performance to the metrics for the designated tasks.
- The system performance may be characterized based on multiple executions of each task with the score being the average of each trial value.
  - The specific rules and metrics are being finalized by the competition committees.

7

Notional Prize Competition Parameters

- **Prizes awarded based on measurable performance, e.g.:**
- **Vegetation Clearance**
  - **For a given area, automated system to clear all vegetation from area (up to 14" trees and other parameters)**
- **Sensor employment for Detection, Mapping & Marking :**
  - **Given a sensor suite, provide an automated system that can map surface/subsurface clutter.**
- **Surface Clearance:**
  - **For given previously mapped grid – speed at which surface is cleared, % surface clutter cleared (with allowances for variable density)**
- **Subsurface Clearance:**
  - **For given previously mapped grid – speed at which subsurface is cleared, % subsurface clutter cleared (with allowances for variable density)**

8

Proposed Cash Prize Distribution

- A Cash Prize of $1M will be awarded to the Overall Competition Winner.
- A Cash Prize of $250K will be awarded to the best performance in each of the Performance Areas.
- Competitors can choose to compete in one or more Performance Areas.
- The Overall Winner will be that competitor who scores the best across multiple Performance Areas.
- It will be possible for the Overall Winner of the $1M cash prize to also win the Performance Area cash Prizes.

9

Notional Prize Scope

- autonomous vegetation clearance ($250K)
- autonomous sensor employment for detection, mapping & marking ($250K)
- autonomous surface debris clearance ($250K)
- autonomous sub-surface UXO clearance ($250K)

- End Goal: Area Autonomously Cleared of UXO ($1M)

Focus is on increasing safety and operational effectiveness via robotics automation as well as reduce time and cost

10

Prize Competition Parameters

- **16 months for competitors to develop and qualify systems**
- **Range location and preparation conducted simultaneously with vehicle development**
- **Qualification and competition events under control of range owners and DoD UXO personnel … not competitors**
- **Competitors wishing to compete agree to conditions of competition being not entirely identical … performance assessed based on "normalized" metrics … this is a competition not a test**
- **Prize awarded based on best performance not on perfect clearance of live range acreage**

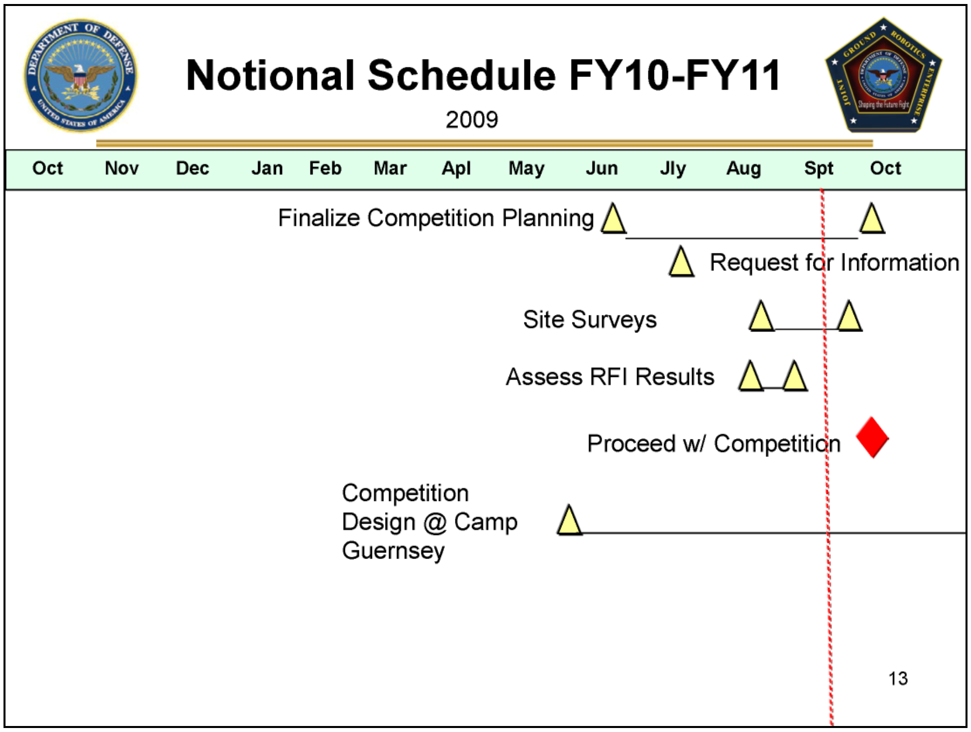
SAFETY SAFETY SAFETY!!!

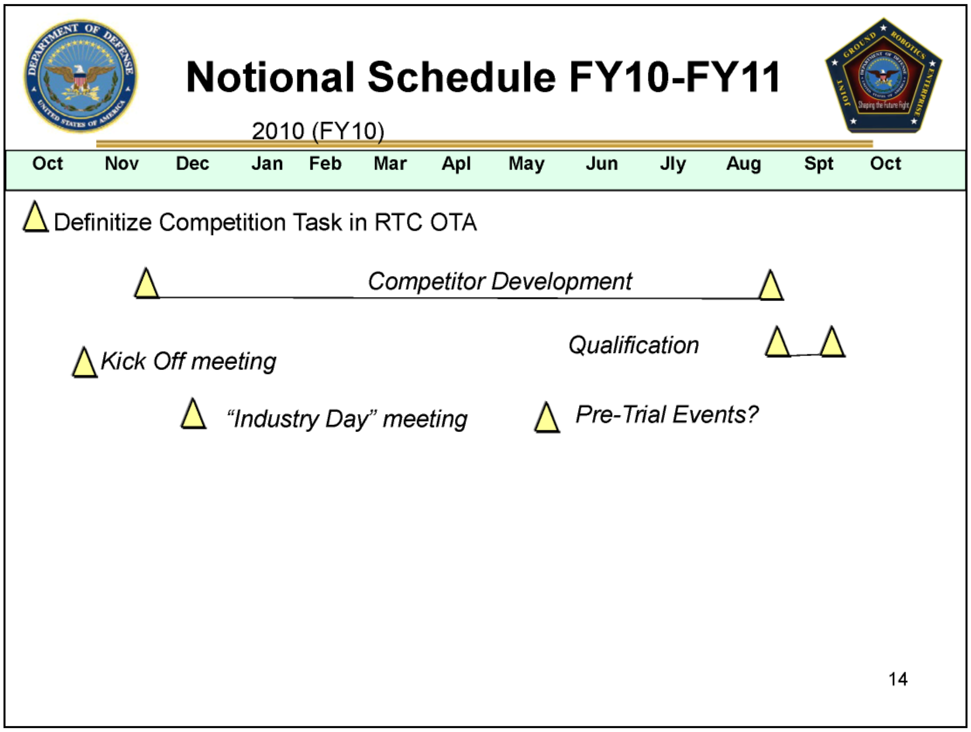
11

Roles and Responsibilities

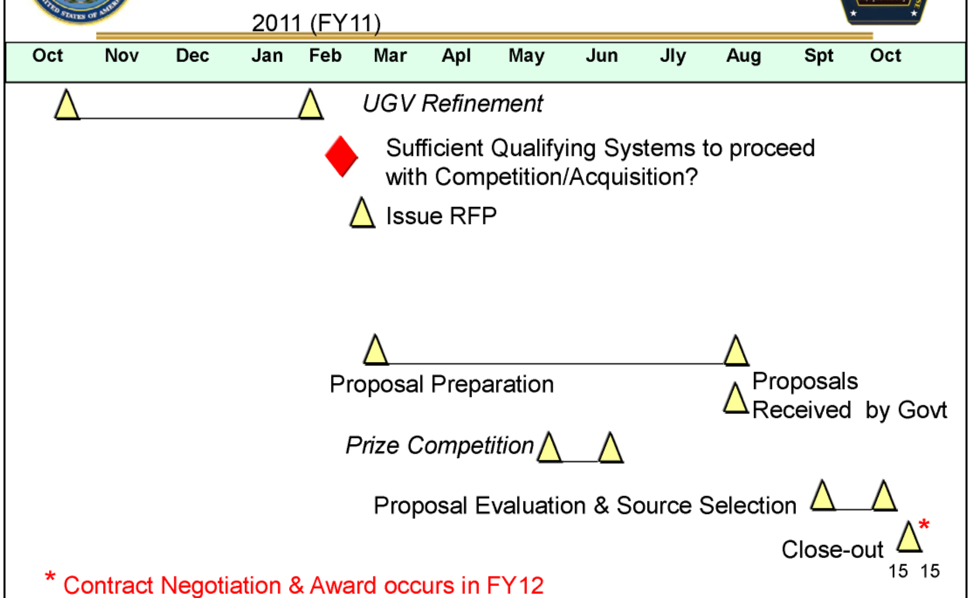
- OSD/JGRE
  - Provides competition design, management, and cash prize funding
  - Provides oversight to competition planning, design, coordination with industry, allocation and execution of funds
- US Air Force Research Laboratory
  - Serves as the Technical Manager to ensure appropriate autonomy technical considerations in design, management, and execution the qualification trails and competition
- US Army Corps of Engineers:
  - Serves as the Operational Manager to ensure appropriate operational considerations in design, management, and execution of the qualification trails and competition itself
- US Army G3/5/7
  - Serves as the voice of the customer with respect to range clearance concerns
  - Provides IDIQ contract funding
- US Army Environmental Center
  - Provides operational support to design, manage, and execute qualification trails and competition trials

12


Notional Schedule FY10-FY11
2009
Oct
Nov
Dec
Jan
Feb
Mar
Apl
May
Jun
Jly
Aug
Spt
Oct
Finalize Competition Planning
Request for Information
Site Surveys
Assess RFI Results
Proceed w/ Competition
Competition Design @ Camp Guernsey
13


Notional Schedule FY10-FY11
2010 (FY10)
Oct
Nov
Dec
Jan
Feb
Mar
Apl
May
Jun
Jly
Aug
Spt
Oct
Definitize Competition Task in RTC OTA
Competitor Development
Kick Off meeting
Qualification
"Industry Day" meeting
Pre-Trial Events?
14

Notional Schedule FY10-FY11



15 15

Competition Contract Concept

- **The concept for the competition is to gather data and advance technologies to enable a competitive acquisition award by the Army Corp of Engineers for Robotic Range Clearance Equipment and services**
- **Possible scenarios:**
  - No competitor(s) comes close to objectives - thus no award and no follow-on contract. OSD works to program future funding to continue technology development to provide autonomous capability for next rotation
  - Competitor(s) proves ability to automate clearance tasks but not at sufficient maturity level to immediately field - possible follow-on acquisition contract would require appropriate level of development leading to a procurement contract
  - Competitor(s) demonstrates successful "fieldable" solution – follow on competitive acquisition contract could be initiated immediately.

16

Competition Concept

- To determine as early as possible the likelihood of the 3 possible outcomes qualifying trials will be scheduled to ensure a meaningful final competition.
- Two types of awards will be offered, a cash prize and a follow-on contract award:
  - *A cash prize of $2M will be awarded against the main range clearance tasks.*
  - In addition to the cash prizes, competitors will also be evaluated *for award of a follow-on contract to either develop a fieldable system (outcome 2)* or the desired IDIQ contract for deployment of the new capability to conduct actual clearance of live ranges (outcome 3).
- In order to achieve the desired outcome of the IDIQ contract, competitors will be asked to submit formal Proposals in response to a formal Request for Proposal (RFP).
  - Proposals will be evaluated in accordance with a basis of selection outlined in the RFP which will include proposal evaluation factors along with the competitors' resulting performance in the final physical cash prize competition.

Possible that a competitor may win a cash prize but not be selected for the follow-on contract award and also possible that a competitor may win both a cash prize and follow-on contract award.

17

Key Considerations and Resources

- **Government can provide up to 16 All-Purpose Remote Transport Systems (ARTS) and the Robot Intelligence Kernel (RIK)**
- **Competitors can choose to use Government Furnished Equipment (GFE) or not**
- **Cooperative Research And Development Agreements (CRADA) or Other Transaction Agreements (OTA) provide legally binding agreements for liability/ accountability**
- **Need a process for adjudication if more competitors intent to use ARTS than the number of platforms available (first come/first served; lottery; etc.)**

18

All-Purpose Remote Transport Systems (ARTS)

Background: The ARTS is a fielded, low-cost, survivable robotics platform (8100 lbs.) capable of remote operations in various mission profiles. The system can remotely employ an array of tools and attachments to detect, assess, and render safe large improvised explosive devices (IEDs) and large-vehicle bombs as well as clear unexploded ordnance (UXO) from prepared areas. In addition, the system employs a variety of advanced navigation, control, and sensing systems.

Performance:
Endurance: 6-8 hours
Control: Radio-1.5 mile radius
(minimum; line of sight)

19

Robot Intelligence Kernel

The RIK provides the following core behaviors:

- Mapping and localization, obstacle avoidance, and path planning for autonomous navigation
- Recognize changes in map and video
- Levels of autonomy
- Adaptive communication

Operational parameters or remote robotics operations:

- Enables operations in communication- and GPS-denied environments
- Novices using the Intelligence Kernel out-perform experts using teleop
- Remote operations extend for hundreds of miles instead of meters

20

CRADA

Definition - The Cooperative Research and Development Agreement (CRADA) is a contractual mechanism used for technology transfer. It is an Agreement between a prospective industry partner and the government in which research and development knowledge, facilities, resources, and/or capabilities are used in cooperation to the mutual benefit of both private and government sectors.

- With regard to resources, Federal law prohibits the payment of government funds to any non-federal partner
- While a CRADA is a contract, it is not a part of the government's acquisition and procurement process. Federal acquisition regulations do not apply.

21

Key Dates and Information

- Industry Day:
  - 10 December 2009, Tyndall AFB, Panama City, FL
  - Formal announcement with rules, metrics, and team commitment
  - Demonstrations of robotic range clearance technologies, Q&A and hands on time with robots
- Competition website:
  http://roboticrangeclearance.com/
- Official announcements through DoD RFI process

Competition website will be main focal point for all announcements and distribution of data.

Summary

- DoD is looking for the Robotics Prize Competition to:
  - advance the state of the art in robotics range clearance technologies
  - foster opportunity for COTS procurement for Robotic Range Clearance
  - Provide the best balance of efficiency and innovation in robotic technology development
- Hope we see you at the Competition!

23

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

AFB	Air Force Base
AFRL	Air Force Research Lab
AHITM	Assitant Human Interaction Team Member
ARA	Applied Research Associates
ARTS	All-Purpose Remote Transport System
AUVSI	Association for Unmanned Vehicles Systems International
CIMAR	Center for Intelligenct Machines and Robotics
DoD	Department of Defense
dvr	digital video recorder
EOD	explosives ordnance disposal
E-stop	emergency stop
GPS	Global Positioning System
HI	human interaction
IDIQ	indefinite delivery indefinite quantitiy
IOI	items of interest
IPR	in process reviews
IPT	Integrated Product Team
ISOs	Industry Standard Objects
JGRE	Joint Ground Robotics Enterprise
JTEC	Joint Training and Experimentation Center
LOI	Letter of Intent
OCU	operator control unit
OUSD/AT&L	Office of the Undersecretary of Defense, Acquistion, Technology, and Logistics
PA	public announcement
PHITM	Primary Human Interaction Team Member
Q&A	questions and answers
QC	quality control
R&D	research and development
R2C2	Robotics Range Clearance Competition
RF	radio frequency
RFI	Request for Information
RXQE	Materials and Manufacturing Directorate, Airbase Technologies Division's Airbase Engineering Development Branch
SAE	Society of Automotive Engineers
SPAWAR	Spacea and Naval Warfare Systems Command
TARDEC	Tank Automotive Research Development and Engineering Center
UF	University of Florida
USA	United States Army
USACOE	United States Army’s Corps of Engineers
USAF	United States Air Force
USN	United States Navy
UTM	Universal Transverse Mercator
UXO	unexploded ordnance
VAC	volts alternating current