Competition Rules
Final Event

Revision 1
May 25, 2021

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1. Introduction

This document describes the Competition Rules for the Final Event of the DARPA Subterranean (SubT) Challenge. This document supersedes the *SubT Challenge Competition Rules Final Event* document dated February 10, 2021. Significant revisions in this document are indicated by blue text. Teams are encouraged to closely review the entire document. The intent of this document is to provide participants guidance on competition design and scoring objectives to inform their development efforts in preparation for the Final Event. This document is subject to change and may be superseded by later versions. The latest official versions of all documents are posted on the SubT Challenge website (www.subtchallenge.com) and the SubT Community Forum (https://community.subtchallenge.com/).

With the exception of minor revisions, this document serves as the final *Competition Rules (Final Event)* that will be enforced in the Final Event.

The DARPA SubT Challenge Chief Judge has the final authority to make any decisions related to the rules or scoring. All decisions made by the Chief Judge are final.

The primary goal of the DARPA SubT Challenge is to discover innovative solutions that can rapidly and remotely map, navigate, and search complex environments, including human-made tunnel systems, urban and municipal underground infrastructure, and natural cave networks. The challenge elements and the competition structure itself are intended to address the secondary goal of increasing the diversity, versatility, cost-effectiveness, and robustness of relevant technologies and systems capable of addressing the myriad needs of a wide range of environments rather than single-purpose or specifically tailored solutions. The third goal of the competition is to establish a collaborative community by bringing together multi-disciplinary teams and cross-cutting approaches across disparate fields to address the autonomy, perception, networking, and mobility needs of the subterranean domain.

2. Overview

The DARPA SubT Challenge is organized into a Systems Competition and a Virtual Competition. Teams in the Systems Competition are developing physical systems to compete in live events on physical, representative subterranean courses. Teams in the Virtual Competition are developing software and algorithms using virtual models of systems, environments, and terrain to compete in simulation-based events. The Systems Competition focuses on discovering innovative breakthroughs in integrated physical systems that can successfully operate in real-world environments while the Virtual Competition focuses on developing software-driven innovations and a broader exploration of the capability trade space by leveraging the library of virtual models in the SubT Virtual Testbed. The two competitions are designed to cross-fertilize and accelerate development across both Systems and Virtual Competition participants. The objectives, rules, and events for the two competitions are closely related, but provide different avenues for development of innovative approaches and technologies.

The Systems and Virtual competitions will each hold coordinated challenge events to include three Circuit Events and a Final Event, each motivated by an illustrative vignette that will provide context and constraints for the mission scenario. The three Circuit Events (a.k.a. the Tunnel Circuit, Urban Circuit, and Cave Circuit) each focused on one of the three subdomains, and were intended to promote frequent "build-test-compete" iterations within and among all participating teams. The Final Event will combine elements of all three subdomains into an integrated competition course to demonstrate the versatility of solutions developed.

3. SubT Challenge Schedule Overview

The DARPA SubT Challenge is organized into three stages as illustrated in Figure 1. In the Development Stage, teams had approximately 12 months to complete their baseline design, development, integration, and testing of their proposed solutions. In the Circuits Stage, teams participated in the three Circuit Events that were approximately 6 months apart. In the Finals Stage, teams will finish their development, refinement, and testing to compete in their respective Systems and Virtual Final Events.

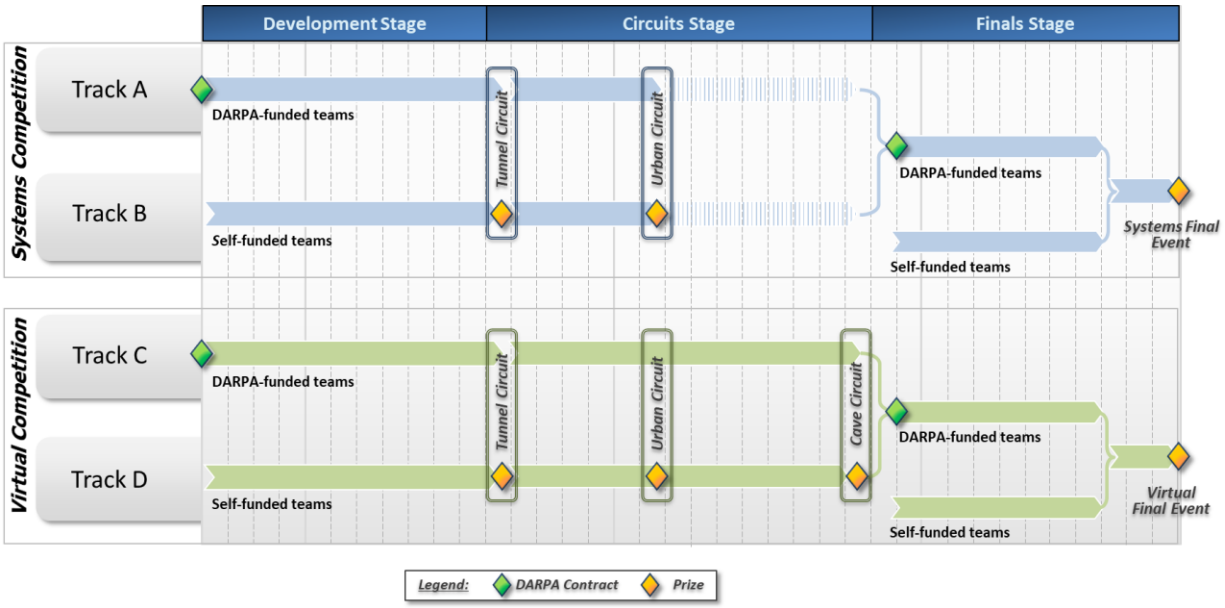

Figure 1: Program structure and schedule for the DARPA Subterranean Challenge

Event	Systems Competition Date	Virtual Competition Date
SubT Integration Exercise	April 5-11, 2019	June 10, 2019
Tunnel Circuit	August 15-22, 2019	October 30, 2019
Urban Circuit	February 18-27, 2020	February 27, 2020
Cave Circuit	–	November 17, 2020
Final Event	September 21-24, 2021	September 21-24, 2021

Table 1: Schedule of DARPA-organized SubT Challenge events

4. Prizes and Funding

Teams are charged with pursuing high-risk, high-reward approaches to meet and exceed the objectives of the challenge events, and are motivated by the potential for winning monetary prizes and/or pursuit of funding. Monetary prizes are awarded for both the Systems Competition and the Virtual Competition at each of the Circuit Events and Final Event as shown in Table 2. All teams are eligible for prizes in the Final Event.

<table>
<tr><th></th><th>Tunnel Circuit</th><th>Urban Circuit</th><th>Cave Circuit</th><th>Finals</th></tr>
<tr><td>Track A</td><td>(not eligible)</td><td>(not eligible)</td><td>(not eligible)</td><td rowspan="2">$2M (1st)
$1M (2nd)
$500K (3rd)</td></tr>
<tr><td>Track B</td><td>$200K</td><td>$500K (1st)
$250K (2nd)
$100K (3rd)</td><td>N/A
(due to COVID)</td></tr>
<tr><td>Track C</td><td>(not eligible)</td><td>(not eligible)</td><td>(not eligible)</td><td rowspan="2">$750K (1st)
$500K (2nd)
$250K (3rd)</td></tr>
<tr><td>Track D</td><td>$250K (1st)
$150K (2nd)
$100K (3rd)</td><td>$250K (1st)
$150K (2nd)
$100K (3rd)</td><td>$250K (1st)
$150K (2nd)
$100K (3rd)</td></tr>
</table>

Table 2: Prize Structure for the Circuit and Final Events per Competition Track

A team may register for both the Systems and Virtual Competitions. DARPA-funded Track A teams are eligible to compete as Track D teams in the Virtual Competition, and Track C teams are eligible to compete as Track B teams in the Systems Competition.

The Government's obligation for prizes under the DARPA SubT Challenge is subject to the availability of appropriated funds from which payment for prize purposes can be made. No legal liability on the part of the Government for any payment of prizes may arise unless appropriated funds are available to DARPA for such purposes.

To be eligible for prizes, teams must first be registered (see Section 5). The award process requires recipients to furnish information that may trace or identify recipients either individually or as an organization (e.g., Social Security Number or Tax Identification Number). The primary contact of each registered team is responsible for providing the award information necessary for prize disbursement. DARPA will reach out by email to the primary contact of each registered team to either confirm their vendor status or request the required forms. DARPA is not responsible for disbursement of prizes to any team members other than the primary contact/organization. Prizes will only be issued in U.S. dollars and require the bank of the prize recipient to accept U.S. dollars.

5. Team Registration

Teams may register their interest in participating and receiving informational updates by completing the *Team Registration* form at www.subtchallenge.com/register.aspx. Team registration is required prior to qualification and prior to event-specific enrollment. Registered teams will receive important competition-related updates and notices of information releases. Team registration is open on a rolling basis, but teams are encouraged to register early to avoid missing important updates.

6. Qualification

Prospective teams are required to demonstrate baseline performance and utility capabilities (e.g., safety measures for Systems, simulator usage for Virtual), to be eligible to participate in events. All teams (DARPA-funded and self-funded) in both competitions (Systems and Virtual) must qualify for each event including the SubT Integration Exercises, Circuit Events, and Final Event.

The latest revision of the *SubT Challenge Qualification Guide* will always be posted on the SubT Challenge Website and SubT Community Forum. Team Qualification submissions for the Systems Competition must be submitted by April 21, 2021 to be eligible to participate in the Final Event. Team Qualification submissions for the Virtual Competition must be submitted by June 29, 2021 to be eligible to participate in the event. The specific qualification deadlines for each event are provided in the *SubT Challenge Qualification Guide.*

DARPA may adjust the qualification rules for each event. DARPA does not anticipate issuing qualification waivers for the Final Event.

DARPA reserves the right to disqualify any team that is found to violate either the rules or applicable laws and regulations.

7. Competition Guidelines

7.1. Illustrative Scenario

The primary scenario of interest for the competition is providing rapid situational awareness to a small team of operators preparing to enter unknown and dynamic subterranean environments. Potential representative scenarios involve rescue efforts in collapsed mines, post-earthquake search and rescue in urban underground settings, and cave rescue operations for injured or lost spelunkers. Additional scenarios include a range of missions in which teams of systems could be sent in advance of service members to perform rapid search and mapping in support of follow-on operations. These scenarios present significant dangers that would preclude employing a human team, such as collapsed and unstable structures or debris, presence of hazardous materials, lack of ventilation, and potential for smoke and/or fire.

Each team is envisioned to deploy its systems to provide rapid situational awareness through mapping of the unknown environment and localization of artifacts (e.g., survivors, electrical

boxes). As the systems explore the environment, these situational awareness updates are provided via reach-back to a Base Station in as close to real-time as possible. Given the large-scale nature and complexity of subterranean environments, the courses could include small passages, sharp turns, stairs, rails, large drops/climbs, mud, water, and other mobility-stressing terrain features and obstacles (see Section 7.2). Challenge participants should expect, for example, both constrained areas with human-crawlable cross sections as well as larger underground open spaces that could include large ledges or vertical shafts. No breaching, burrowing, or use of explosives is permitted.

7.2. Technical Challenge Elements

The Circuits and the Finals competition courses are intended to assess performance across various challenge elements, including: austere navigation, degraded sensing, severe communication constraints, terrain obstacles, dynamic terrain, and endurance limits (illustrated in Figure 2). These challenge elements are also encoded into the SubT Virtual Testbed (described in Section 7.4) to the fullest extent possible.

1. **Austere Navigation:** The competition courses include features such as multiple levels, inclines, loops, dead-ends, slip-inducing terrain interfaces, and sharp turns. Such environments with limited visibility, difficult terrain, and/or sparse features can often lead to significant localization error and drift over the duration of an extended run.

2. **Degraded Sensing:** The courses include elements that range from constrained passages to large openings, lighted areas to complete darkness, and wet to dusty conditions. Perception and proprioceptive sensors need to reliably operate in these low-light, obscured, and/or scattering environments while having the dynamic range to accommodate such varying conditions. Dust, fog, mist, water, and smoke fall under this challenge element.

3. **Severe Communication:** Limited line-of-sight, radio frequency (RF) propagation challenges, and effects of varying geology in subterranean environments impose significant impediments to reliable networking and communications links. The physical competition courses as well as the SubT Virtual Testbed environments are designed to include these severe communications constraints.

4. **Terrain Obstacles:** Systems are required to demonstrate robustness in navigating a range of mobility-stressing terrain features and obstacles. Terrain elements and obstacles include constrained passages, sharp turns, large drops/climbs, inclines, steps, ladders, and mud, sand, and/or water. The environments may include organic or human-made materials; structured or unstructured clutter; and intact or collapsed structures and debris.

5. **Dynamic Terrain:** Terrain features and obstacles include dynamic elements, such as mobile obstacles, moving walls and barriers, falling debris, and/or other physical changes

to the environment that test the agility of the system autonomy to reason, react, and potentially recover from the possibility of a changing map.

6. **Endurance Limits:** The courses are designed such that successful systems need to be capable of a team-aggregated endurance of 60 minutes to be mission-relevant. This aggregate endurance requires novel deployment concepts, energy-aware planning, heterogeneous agents of varying endurance, energy harvesting or transfer technologies, and/or a combination of various approaches to overcome the various challenge elements.

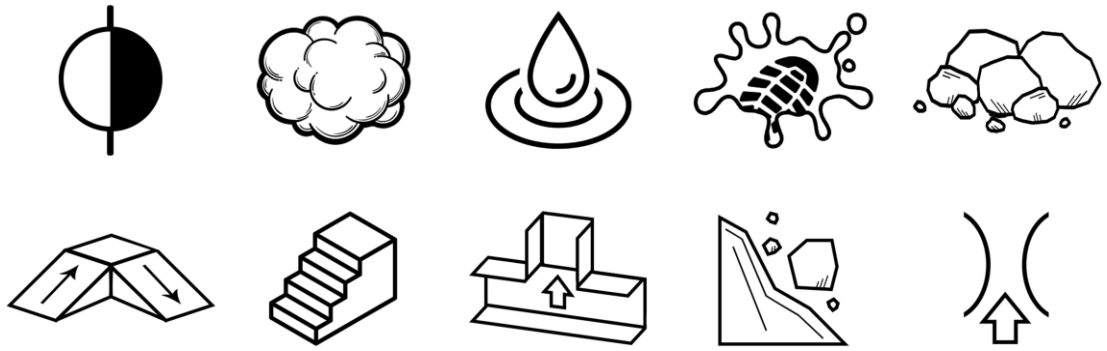

Figure 2: SubT Course Challenge Elements may include: (top row) light/darkness, particulates, water, mud, uneven terrain; (bottom row) inclines, steps/ledges, vertical shafts, dynamic obstacles, constrained passages

7.3. Artifacts

The main scoring objective is the need to search for, detect, and provide spatially referenced locations of artifacts relevant to each of the three subdomains. These artifacts vary in their size, quantity, and detection signatures (e.g., visual, thermal, chemical).

For the Systems Competition, it is expected that each run in the Preliminary Round will have 20 artifacts and the total number of allowed artifact reports for each run will be 25. It is expected that each run in the Prize Round will have 40 artifacts and the total number of allowed artifact reports for each run will be 45.

For the Virtual Competition, it is expected that all scenarios in the Final Event will have 20 artifacts and the total number of allowed scored reports for each run will be 25.

The perception problems of interest in the SubT Challenge are focused on the difficulties of sensing in low-/no-light, obscured, and/or scattering environments. The detection and/or recognition tasks may benefit from multimodal sensing approaches. Various sensor modalities and combinations are allowed, including but not limited to: visual, light detection and ranging (LIDAR), thermal, acoustic, radio frequency (RF), and multi-gas sensors. For example, the detection of a survivor could potentially be made using a combination of visual, thermal, and/or auditory cues.

Three artifacts are common to all three subdomains and appeared in all three Circuit Events (a.k.a. the Tunnel Circuit, Urban Circuit, and Cave Circuit). Two additional artifacts were specified for each Circuit Event that are event-specific and did not appear in the other Circuit Events. Thus, each Circuit Event had a total of five artifact types: the three common artifacts and two event-specific artifacts.

The Final Event will include a total of ten artifact types: the three common artifacts, all six event-specific artifacts, and the Finals-specific artifact. The Preliminary Round will use the following six (6) artifact types: Survivor, Cell Phone, Backpack, Fire Extinguisher, Vent, and Rope. The Prize Round will use the following ten (10) artifact types: Survivor, Cell Phone, Backpack, Fire Extinguisher, Drill, Vent, Gas, Rope, Helmet, Cube.

The *SubT Challenge Artifacts Specification* document provides specifications and descriptions for each of the artifacts. The latest revision of the *SubT Challenge Artifacts Specification* document will always be posted on the SubT Challenge Website and SubT Community Forum.

7.4. SubT Virtual Testbed

DARPA is investing in the development of a SubT Virtual Testbed, illustrated pictorially in Figure 3, comprising the (1) SubT Tech Repo, described below; (2) SubT Simulator, an extensible Gazebo-based simulation environment; (3) automated testing and assessment tools; and (4) associated software support infrastructure. This suite of simulation tools is intended to support teams in both the Systems and Virtual Competitions as they develop and evaluate their approaches.

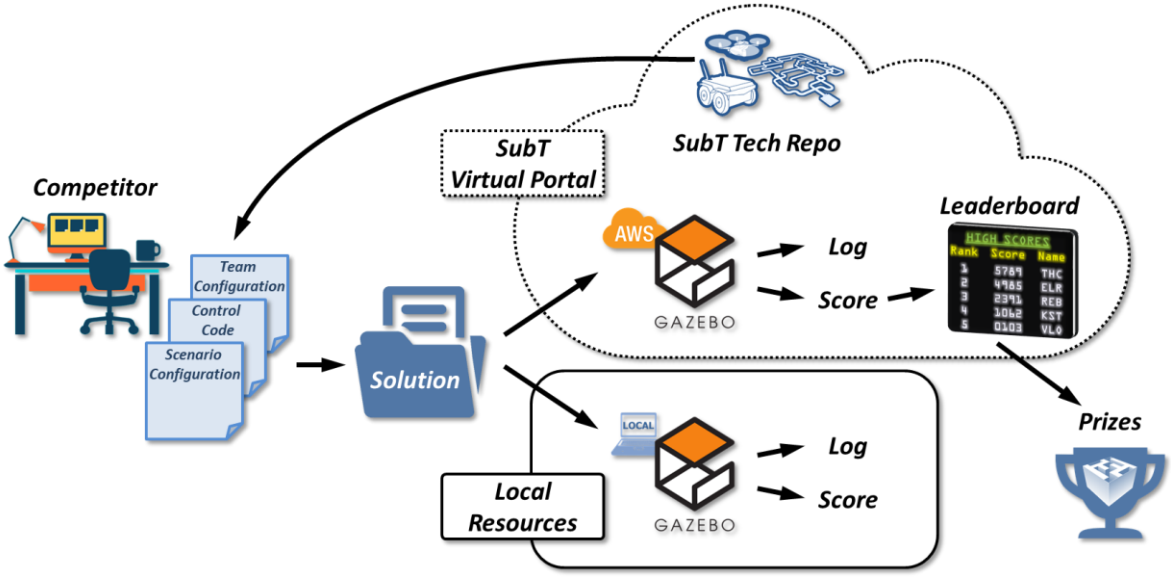

Figure 3: SubT Virtual Testbed Workflow

The SubT Tech Repo is an online catalog of virtual subterranean technologies including models of Government-developed, team-developed, and/or commercial off-the-shelf (COTS) systems. The SubT Tech Repo is continuously updated as new models are made available and validated.

The SubT Tech Repo also includes a catalog of scenarios made up of virtual environments and their associated configurable parameters. Some of the scenarios are distributed to teams in advance of the events to provide representative environments in which to develop and evaluate their solutions. Other scenarios will serve as the competition scenarios and will not be released until after the respective event has been completed.

Teams are able to compose a virtual Team Configuration comprising models selected from the SubT Tech Repo; load their own respective software-based innovations (e.g., algorithms for mapping, navigation, and search); and complete simulated runs in the virtual scenarios from the SubT Tech Repo. The simulations can be run either locally or in a cloud-based Ignition Gazebo environment. The simulations enable teams to evaluate how their systems and solutions perform in the selected scenario and generate a Run Score and Logfile which can be used to compare performance against other teams on the SubT Challenge Leaderboard.

7.5. Systems Competition Courses

Teams in the Systems Tracks are developing physical systems to compete in live competitions on physical, representative subterranean courses. Figure 4 shows a notional workflow and data sharing for the competition events. The competing team will set up and begin their run in the Staging Area, which will be outside of a known entrance. At the beginning of a run, teams will deploy their systems into the course where they will explore, map, and search for artifacts. Relevant observation data will be transmitted to the team's Base Station which will, in turn, provide regular map updates and artifact reports to the DARPA Command Post where the reports will be automatically evaluated and scored. The DARPA Command Post will provide score updates back to the team's Base Station.

An *Interface Control Document (ICD)* and reference implementation detail the mechanism for providing artifact reports and map updates to DARPA. The latest revision of the *SubT Challenge Interface Control Document* will always be posted on the SubT Challenge Website and SubT Community Forum.

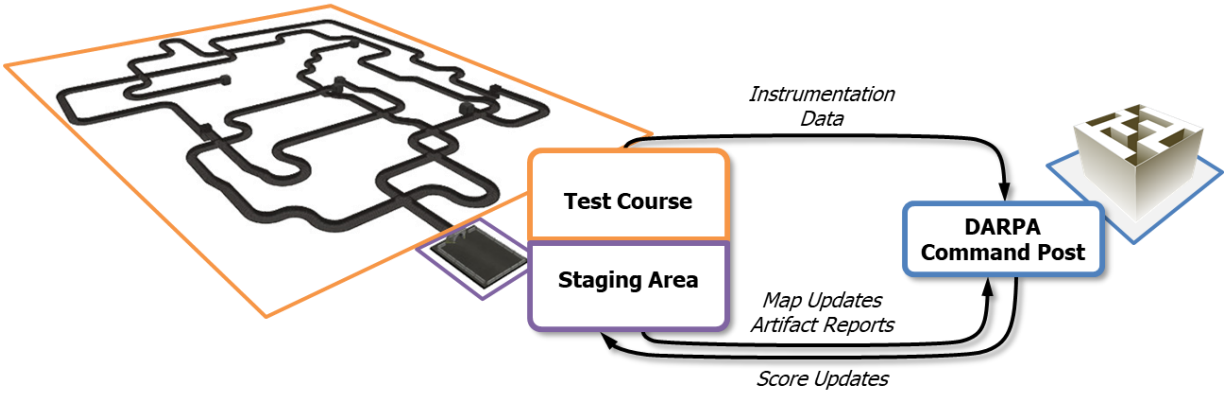

Figure 4: SubT Challenge Systems Competition Workflow

7.6. Mapping

Systems Teams must provide real-time 3D volumetric map updates to the DARPA Command Post at a minimum frequency of one update per 10 seconds. Virtual Teams will be asked to provide updates via a virtual Base Station, which is expected to provide both artifact reports and map updates to the DARPA scoring interface. These map data updates are expected to be in the same DARPA-defined reference frame that is used for artifact reports. The *Interface Control Document (ICD)* provides details on the supported map representations and data types, which were selected with the goal of keeping the computational and implementation burden on teams low.

Each team's provided map will be used to visualize and validate the team's progress and evaluate the team's perception and mapping capability. Both stakeholders and spectators will likely form opinions about the quality of a team's solution based on its map representation.

8. Systems Competition Rules

8.1. Event Operations

8.1.1. Competition Format

Prospective teams are required to demonstrate baseline performance and utility capabilities, as described in Section 6, to qualify for the Final Event. It is anticipated that up to 15 teams may successfully qualify for the Final Event. The Final Event includes two competition days as the Preliminary Round and a third competition day as the Prize Round.

Qualified teams will be eligible to participate in the Preliminary Round which will consist of two (2) scored runs, each 30 minutes in duration. The total score for the Preliminary Round will be determined based on the sum of a team's two run scores.

All qualified teams will advance to the Prize Round which will consist of one (1) scored run, 60 minutes in duration. The final ranking will be determined based solely on the Prize Round run score.

8.1.2. Competition Courses

The Final Event courses will combine elements from all three subdomains into integrated competition courses, designed to assess the versatility of the developed technologies. The courses will be divided into three distinct subdomain sectors with multiple connections and crossover points between subdomains.

8.1.3. Staging Area

All systems will be required to start in the Staging Area behind the Starting Gate at the course entrance. No systems will be permitted to operate above ground or outside of the competition course boundaries except within the Staging Area. Figure 5 and Figure 6 show the Final Event Staging Area which includes a netted area, Pit Crew area, and Human Supervisor area.

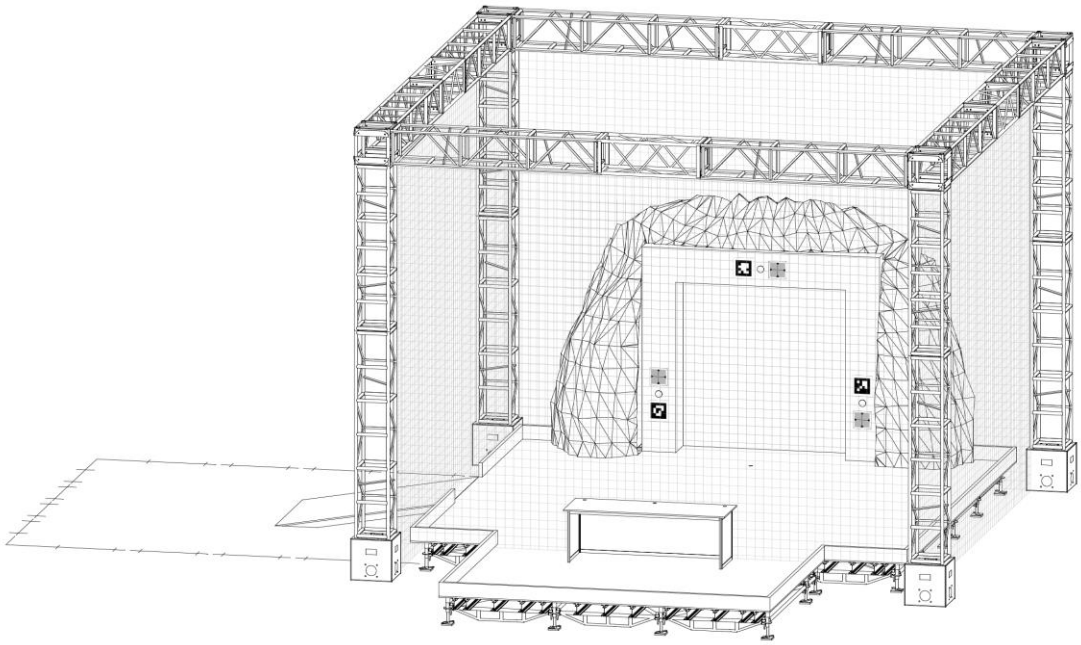

Figure 5: Final Event Staging Area

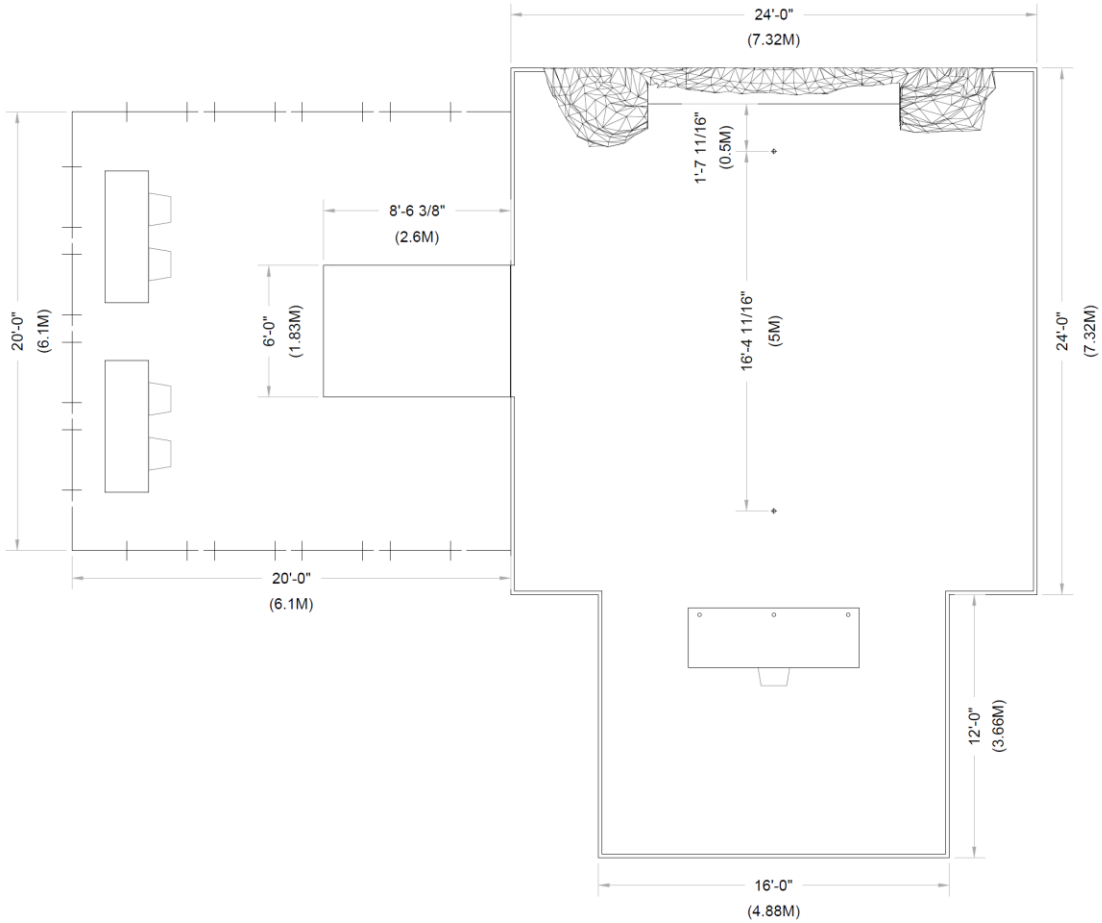

Figure 6: Floorplan for the Final Event Staging Area

The netted area is approximately 24 feet (7.3 m) wide x 24 feet (7.3 m) long and 18 feet (5.5 m) in height on an approximately level platform. The Human Supervisor area is approximately 16 feet (4.9 m) wide x 12 feet (3.7 m) long on an approximately level platform. The Human Supervisor area includes a Base Station workbench that is approximately 8 feet (2.4 m) wide x 3.5 feet (1.1 m) deep and 30 inches (0.76 m) in height. The Pit Crew area is approximately 20 feet (6.1 m) wide x 20 feet (6.1 m) long on venue terrain (i.e., dirt, rocks) that has been approximately leveled.

8.1.4. Course Access

Systems are allowed to enter, exit, or reenter the competition course at any time within the duration of the run. All human operators and personnel must stay within the Staging Area. No manual physical intervention or entry by any (human) team member on the course will be permitted. A system may only be handled or retrieved if it has crossed back into the Staging Area past the front face of the Starting Gate. Once a system has partially or completely crossed into the Staging Area, team personnel are permitted to handle the systems as long as the personnel stay within the Staging Area and do not pass the front face of the Starting Gate. Only authorized DARPA personnel are allowed to enter the course preceding, during, and following the run.

8.1.5. Run Termination

A scored run terminates upon any of the following conditions:

- Time Expiration: The scored run time expires before another termination criterion is met
- Run Completion: The deployed systems successfully report all artifacts, and successfully exit the course
- Run Cancellation: Competition Staff cancels the run due to an external factor such as weather, including lightning, rain, snow, or wind
- Emergency Stop: Competition Staff initiates an emergency stop because of an unsafe condition
- By Request: The Team Lead requests an end to the run

8.1.6. Terminated Runs

A team may be eligible for an additional attempt if a run is canceled or stopped due to an emergency or external factor outside of the team's control. The Chief Judge will review eligible cases and determine the course of action. The Chief Judge has the final authority to make any scoring-related decisions.

8.1.7. Prior Knowledge

The spirit and intent of the SubT Challenge is to develop technologies to rapidly and remotely explore unknown subterranean environments. While the use of prior knowledge from prior runs is not expressly prohibited, teams that align their solutions to these goals will be significantly more likely to succeed in the competition.

DARPA intends to take multiple approaches to limiting the viability of using prior knowledge:

- Course Access: Once the event site is announced, teams are not allowed to access the competition site for any reason other than completing their scored runs.

- Course Layout: DARPA intends to significantly alter the competition course to add sections, block passages, add obstacles, and/or move artifact locations. The layout and accessibility of the course segments is expected to significantly vary from run to run.
- Sequestration: Team personnel and systems may be sequestered from garage and observer areas to prevent gaining knowledge from another team's run.
- Staging Area Monitors: Competition Staff will be present in the Staging Area during each run to observe the Base Station, Human Supervisor, and other Pit Crew personnel.

For the Prize Round, the Human Supervisor and Pit Crew personnel will be sequestered to prevent teams that have not completed their runs from gaining knowledge about the courses. Sequestered personnel are not permitted to communicate with any other team personnel during the sequester period.

No cell phones, personal electronic devices, or wireless communications of any kind are permitted during the sequestration period. Teams are only permitted to use wired connections to interface with their systems. The wireless spectrum will be actively monitored, and teams found in violation may be disqualified from the competition.

Please see the "Systems Team Sequestration" section of the *Final Event Operations Guide* document for additional information.

DARPA reserves the right to disqualify any team that is found to violate either the rules or the intent of the rules. The Chief Judge has the final authority to make any rules-related decisions. All decisions made by the Chief Judge are final.

8.1.8. Score Disputes

Dispute Cards are intended to provide teams a mechanism to submit a formal dispute or request for review by the Chief Judge. The Dispute Card must be completed and delivered by the Team Lead to the relevant Course Official, Team Garage Coordinator, or Chief Judge. The Dispute Card must be submitted within 30 minutes of the completion of the run in question. All submissions will be reviewed by the Chief Judge in a timely manner. All decisions made by the Chief Judge are final.

8.2. Personnel Guidelines

Teams are permitted **up to five (5)** personnel in the Staging Area. Figure 7 provides a detailed workflow for how data may be shared between the systems, team Base Station, team personnel, and DARPA Command Post. For the sake of this discussion, two categories of data are delineated: ***status data*** and ***course data***. Status data is primarily derived from proprioceptive sensors for the purposes of calibration and internal health monitoring. Status data may also include exteroceptive sensor measurements that are collected within the Staging Area for the purposes of calibration. Course data is primarily derived from exteroceptive sensors that acquire information directly or indirectly from the competition course. Course data specifically includes any information related to mapping and/or artifacts.

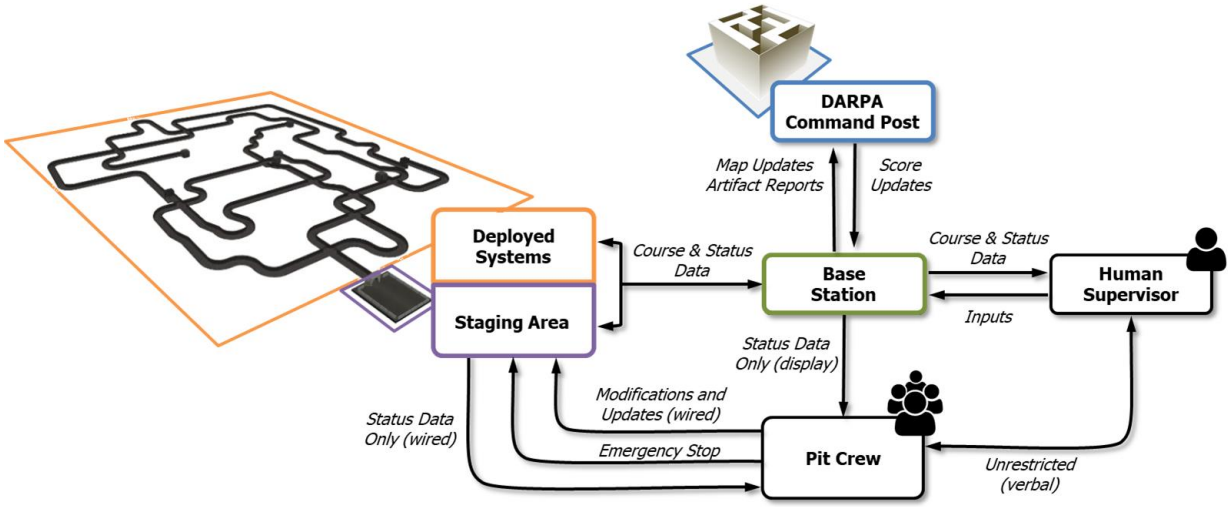

Figure 7: SubT Challenge Systems Competition Detailed Workflow

8.2.1. Human Supervisor

As the operational scenario suggests, DARPA is interested in approaches that are highly autonomous without the need for substantive human interventions; capable of remotely mapping and/or navigating complex and dynamic terrain; and able to operate with degraded and unreliable communication links.

The team is permitted to have a single Human Supervisor at a Base Station external to the course but within the Staging Area. The Base Station is defined as one or more computers or controllers that serve as the interface between the systems, the DARPA Command Post, and the Human Supervisor. The Base Station is responsible, either automatically or with supervisor monitoring, for communicating with the deployed systems and relaying artifact reports and map updates to the DARPA Command Post.

The Human Supervisor is permitted to monitor and manage the communications with their deployed systems as they choose. With the exception of the Safety Officers described in Section 8.2.3, **only the Human Supervisor is permitted to use wireless communications** with the systems during the competition run. The Human Supervisor is permitted to view, access, and/or analyze both course data and status data. The Human Supervisor is permitted to provide inputs to the deployed systems and/or to serve as a buffer between the deployed systems and the DARPA Command Post. Once a team's run has begun, the Human Supervisor may not be substituted with other personnel.

For the Final Event, teams are expected to use the provided Base Station workbench located in the Human Supervisor Area. Once the team's run has begun, only the Human Supervisor is permitted to be in the Human Supervisor Area.

In addition to cameras in the Staging Area, DARPA intends to observe and capture the Base Station display(s) via HDMI screen capture devices. The captured footage is anticipated to be used as part of the live-stream broadcast. Refer to the Interface Control Document for additional information regarding the Base Station display capture.

8.2.2. Pit Crew Personnel

In addition to the Human Supervisor, **up to four (4)** team personnel are permitted in the Staging Area to serve as a "Pit Crew" to assist with operations tasks such as physically deploying the systems, performing repairs, modifying software or firmware, and changing batteries. Once a team's run has begun, the Pit Crew personnel may not be substituted with other personnel. Once the team's run has begun, the Pit Crew personnel are not permitted in the Human Supervisor Area.

The Pit Crew personnel and Human Supervisor are permitted to verbally communicate without restrictions. The Base Station can also provide status data to the Pit Crew via a wired display to support operations tasks such as calibration and completing startup checklists. The Pit Crew is not permitted to directly interface with the Base Station in any way (e.g., toggling between windows via peripherals). Any wired displays providing status data to the Pit Crew must be located within the Pit Crew Area, outside of the netted area. The Pit Crew is only permitted to view limited system status data such as battery health, network status, and real-time telemetry as long as the data is derived only from proprioceptive sensors.

Pit Crew personnel are permitted to view and access status data but are not permitted to view or access course data collected from the competition course. Pit Crew personnel are only permitted to view or access exteroceptive data that are collected within the Staging Area (e.g., for the purposes of calibration). Pit Crew personnel are specifically prohibited from viewing or accessing information related to mapping and/or artifacts.

With the exception of the Safety Officer roles described in Section 8.2.3, Pit Crew personnel are only permitted to use wired connections to interface with the systems within the Staging Area, for example, to make software or firmware updates. Only wired peripherals (e.g., mouse, keyboard) can be used by the Pit Crew. The Pit Crew is permitted to use a wired controller for manual teleoperation as long as the system is completely inside the Staging Area. The Pit Crew is also permitted to plug in cables or extract physical storage devices to facilitate the transfer of data from the systems to the Human Supervisor at the Base Station. Once the system has crossed the front face of the Starting Gate, Pit Crew personnel may not send or receive data from the deployed systems, whether wired or wireless.

The restriction on wireless communications is not enforced during the setup time before the competition run begins. Pit Crew personnel are permitted to use both wired and wireless communications during the setup time (e.g., initialize, arm, or teleoperation).

8.2.3. Safety Officer

Teams may identify specific members of the Pit Crew to serve as Safety Officers. The role of the Safety Officer is to preserve the safety of personnel and property. Safety Officers are permitted to activate Tier 1 wireless emergency stop transmitters and/or operate remote controls for safety purposes only. Safety Officers may only use wireless communications for emergency stop transmitters and limited system initialization (e.g., arming, initial takeoff).

For aerial systems, the Safety Officer may aid in initial takeoff and hover as long as the system is within the Staging Area and does not intrude past the front face of the Starting Gate. However, any further maneuvering of the aerial system must be initiated or controlled by the Base Station (via autonomous or Human Supervisor commands). If the safety of Staging Area personnel is at risk, the Safety Officer is permitted to take control of the aerial system for the sole purpose of safely landing the system. The Safety Officer is not permitted to take control of a system that has crossed into the competition course beyond the front face of the Starting Gate except to trigger a Tier 1 emergency stop for the sole purpose of preserving the safety of personnel in the Staging Area.

All Pit Crew personnel, including Safety Officers, must be outside the safety netting and within the Pit Crew Area whenever aerial systems are active. The Human Supervisor must also be outside the safety netting but may be located either in the Human Supervisor Area or the Pit Crew Area.

The Safety Officer's primary role is to preserve the safety of personnel in the Staging Area rather than preserving the safety of the system. If the Safety Officer triggers a Tier 1 emergency stop for a system inside the competition course, the system that is triggered must stay inactive for the remainder of the competition run. A system may only have its Tier 1 emergency stop reset if it was triggered by the Human Supervisor.

8.2.4. Teleoperation

While not expressly prohibited, it is not expected that manual teleoperation of individual systems will be a viable strategy, and teams should expect to provide at most only high-level interactions due to the likelihood of a naturally degraded communications network. Any wireless teleoperation during the run, whether in the Staging Area or inside the competition course, must be under the exclusive control of the Human Supervisor. The Pit Crew is permitted to use a wired controller for manual teleoperation as long as the system is completely inside the Staging Area.

There are no restrictions on the use of tethers for power, communications, or physical retrieval. However, teams are encouraged to consider the significant limitations imposed by the large-scale, potentially dynamic, and complex environments of interest. No manual physical intervention or entry by any (human) team members on the course is permitted. Only authorized DARPA personnel are allowed to enter the course preceding, during, and following the run.

8.3. Final Event Course

8.3.1. Course Layout

The spirit and intent of the SubT Challenge is to develop technologies to rapidly and remotely explore complex and unknown environments. The exact course layout will not be known in advance and will be changed between runs. DARPA intends to alter the competition courses to add sections, block passages, add obstacles, and move artifact locations. The layout and accessibility of the course segments is expected to vary from run to run.

8.3.2. DARPA-Defined Reference Frame

Artifact reports and map updates shall be transmitted with respect to a DARPA-defined reference frame. The origin of the DARPA-defined reference frame is centered horizontally and aligned with the ground plane of the Starting Gate. The x-axis orientation vector is approximately aligned with the perpendicular centerline of the Starting Gate as shown in Figure 8.

Two survey markers are used to fully define the reference frame. The origin location of the reference frame (0, 0, 0) is defined by a physical origin survey marker (origin marker) permanently installed flush with the ground and horizontally centered between the inside edges of the Starting Gate. The z-axis is defined as facing upward from the origin marker and is aligned with gravity. The x-axis, y-axis, and z-axis are mutually perpendicular based on a right-handed coordinate frame definition as shown in Figure 8.

With the z-axis orientation aligned with gravity, the orientation of the reference frame can be fully constrained by defining the orientation of the x-axis in the xy-plane. The orientation of the x-axis can be defined by a line extending through the origin marker and any other point on the xy-plane. We choose to define the x-axis orientation using a second survey marker (orientation marker) permanently installed within the Staging Area. By definition, the y-coordinate of the orientation marker is exactly 0. The x-coordinate and z-coordinate of the orientation marker are arbitrary and depend on the installation accuracy and terrain of the Staging Area which may not be perfectly level.

The origin marker at the Final Event is installed approximately 0.5 meters away from the front face of the Starting Gate along the x-axis. The x-coordinates of the origin markers are, by definition, still exactly 0. The orientation marker at the Final Event is installed at approximately 5 meters along the x-axis from the origin marker.

The origin marker and orientation marker serve as the two control points from which all of the other fiducial locations are derived. The coordinates of the origin marker are, by definition, (0, 0, 0) in the DARPA-defined reference frame. The y-coordinate of the orientation marker is, by definition, exactly 0 meters. The x-coordinate of the orientation marker is approximately -5 meters but is dependent on installation accuracy. The z-coordinate of the orientation marker is approximately 0 meters but is dependent on the terrain of the Staging Area.

8.3.3. Starting Gate

The Starting Gate serves as the threshold between the Staging Area and the Competition Course. No team personnel are permitted to cross the front face of the Starting Gate or enter the competition course.

8.3.4. Reference Frame Fiducials

Several types of reference points are being provided to help teams align their systems to the DARPA-defined reference frame including survey markers, visual fiducials, and reflective fiducials. Three sets of visual and reflective fiducials are affixed along the perimeter of the Starting Gate and another set is installed some distance inside the competition course.

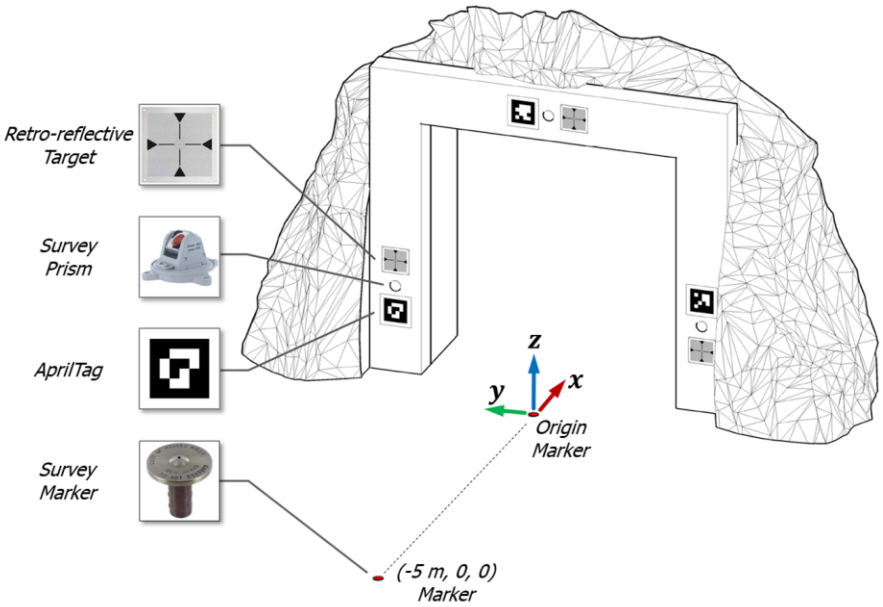

Figure 8: Reference frame fiducials on a representative Starting Gate

Survey Markers: The origin marker and orientation marker serve as the two control points from which all of the other fiducial locations are derived. The precise locations of both survey markers relative to the DARPA-defined reference frame are provided to teams at check-in.

Visual Fiducials: A series of three visual fiducials are arranged around the perimeter of the front face of the Starting Gate as shown in Figure 8. Each visual fiducial is a planar, black and white AprilTag[1] with a unique identification id. The AprilTag targets are in the 16h5 family and are mounted onto a rigid backing material. The outer white border dimensions are 12" x 12" and the black boarder dimensions are 9" x 9". The precise position, i.e., (x, y, z) coordinates relative to the DARPA-defined reference frame, of the center of each AprilTag are supplied to teams before any runs commence. The AprilTag targets are affixed to the Starting Gate, which is approximately aligned with the y-z plane. However, it is not expected that the AprilTag targets will be perfectly coplanar or parallel with the y-z plane.

[1] https://april.eecs.umich.edu/software/apriltag

Additional Fiducials: Three 0.22 m x 0.22 m retro-reflective targets and three survey prisms are also being provided as shown in Figure 8. The precise position, i.e., (x, y, z) coordinates, of the center of each fiducial in the DARPA-defined reference frame will be supplied to teams.

Distal Reference Points: Two additional fiducials, one AprilTag and one reflective target, are placed at 15-30 meters within the competition course. The precise position relative to the DARPA-defined reference frame, i.e., (x, y, z) coordinates, of the center of both fiducials will be supplied to teams. The AprilTag and reflective target are being mounted approximately perpendicular to the main axis of travel in the course. The distal reference points are not visible within line-of-sight of the Starting Gate. These distal reference points are intended to provide teams with a longer baseline to help align their systems to the DARPA-defined reference frame. No orientation information for the distal fiducials is provided.

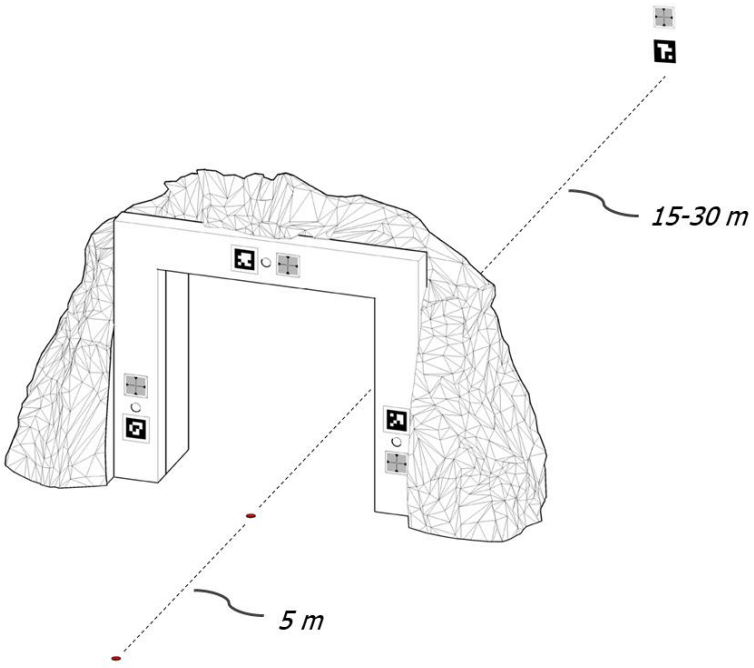

Figure 9: Distal reference points relative to a representative Starting Gate

Table 4 provides a notional table of coordinates for each of the reference points (cf. Figure 10). The x, y, and z coordinates of all reference points will be provided to teams, including the distal fiducials. By definition, the coordinates of the origin are (0, 0, 0) and the y-coordinate of the orientation marker is 0 since this survey marker is being used to define the x-axis orientation. **All other values in the table are approximate and given in meters.**

The "~" values in Table 4 are meant to convey that the coordinates of the distal fiducials are dependent on the topology and terrain of the site. Note that the x-coordinates of the Starting Gate fiducials are approximately 0.5 meters due to the origin marker being installed approximately 0.5 meters away from the front face of each entrance portal.

ID #	Reference Point	x	y	z
1	Origin Marker	0	0	0
3	Orientation Marker	-5	0	0
4	AprilTag (ID = 4)	0.5	1.5	0.6
5	AprilTag (ID = 5)	0.5	0.25	2.75
6	AprilTag (ID = 6)	0.5	-1.5	1.1
7	Distal AprilTag (ID = 7)	~	~	~
8	Reflective 1	0.5	1.5	1.1
9	Reflective 2	0.5	-0.25	2.75
10	Reflective 3	0.5	-1.5	0.6
11	Distal Reflective	~	~	~
12	Prism 1	0.5	1.5	0.85
13	Prism 2	0.5	0	2.75
14	Prism 3	0.5	-1.5	0.85

Table 4: Reference point identification numbers and notional coordinates

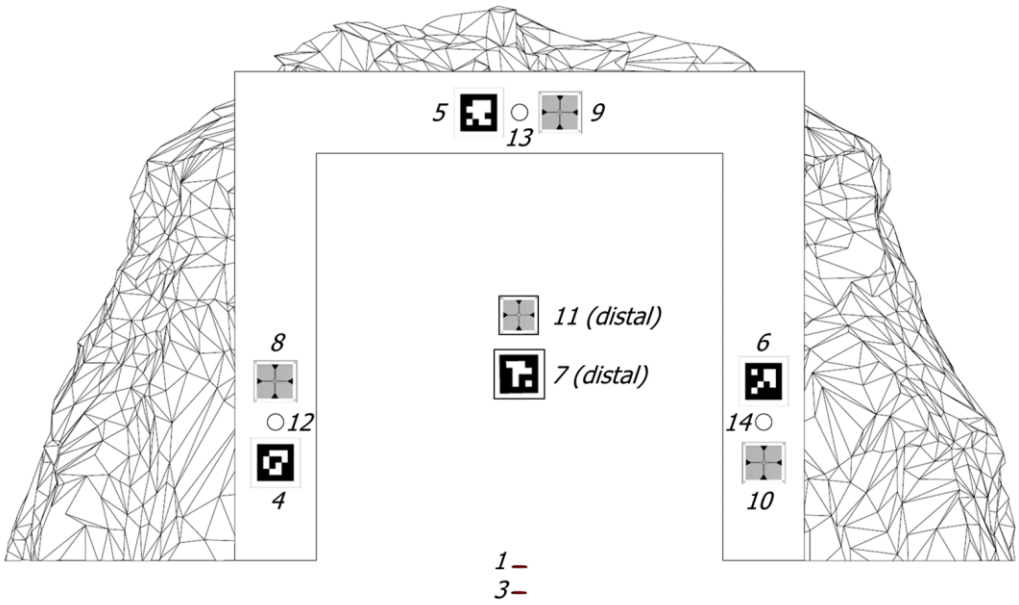

Figure 10: Mapping of reference point ID numbers for Starting Gate fiducials

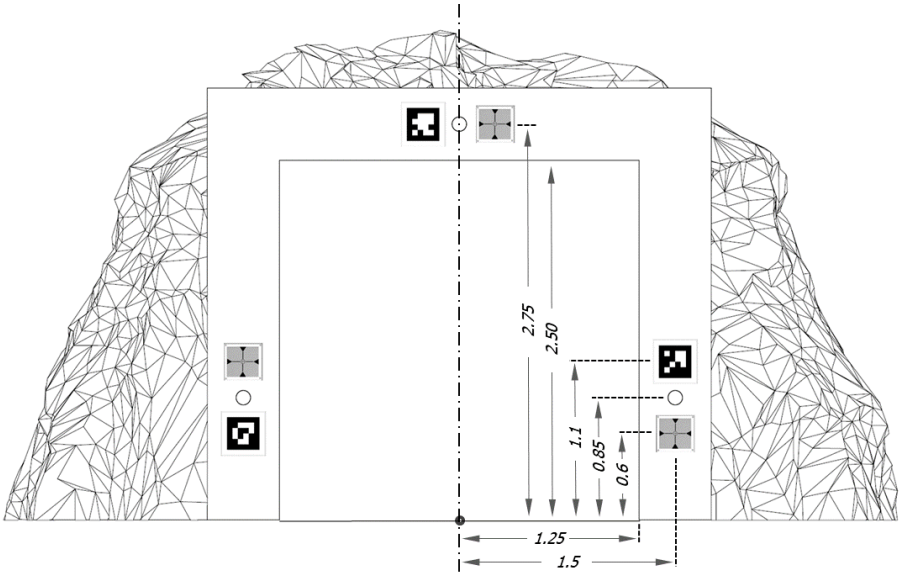

Figure 11: Starting Gate and reference frame fiducials dimensions in meters; dimensions are approximate pending final installation

8.3.5. Final Event Artifacts

The Final Event will include a total of ten artifact types: the three common artifacts, all six event-specific artifacts, and the Finals-specific artifact. The Preliminary Round will use the following six (6) artifact types: Survivor, Cell Phone, Backpack, Fire Extinguisher, Vent, and Rope. The Prize Round will use the following ten (10) artifact types: Survivor, Cell Phone, Backpack, Fire Extinguisher, Drill, Vent, Gas, Rope, Helmet, Cube.

Teams will know what artifacts to look for, but the locations and distribution of the artifacts within the course will not be known. The total number of artifacts will be known to the competitors but not the number of each type. It is expected that each run in the Preliminary Round will have 20 artifacts and the total number of allowed artifact reports for each run will be 25. It is expected that each run in the Prize Round will have 40 artifacts and the total number of allowed artifact reports for each run will be 45.

Additional details and specifications are provided in the *Artifacts Specification* document available on the SubT Challenge Website and SubT Community Forum.

8.3.6. Final Event Course Challenge Elements

The scale and complexity of competition courses is expected to vary from run to run due to configurations changes. The design of the Final Event courses is intended to assess the ability of teams to address the variety of challenging environments presented by each of the three subdomains.

All of the challenge elements listed in Section 7.2 are anticipated to be present. The Final Event courses are expected to include multiple levels, requiring teams to traverse stairs, ramps, and/or vertical shafts to access the entire competition course. Artifacts may be located on mezzanine

levels and in some cases may require elevated vantage points for line-of-sight detection. It is expected that some areas will include significant drop-offs and negative obstacles.

The width of passages at the Final Event is expected to vary greatly and include large open areas as well as narrow constrained passages (i.e., corridors, collapsed ceilings). It is expected that some portions of the course will only be accessible via passages that are approximately one meter in height and/or one meter in width. Doorways may use dimensions as narrow as standard doors (e.g., 36").

8.3.7. Final Event Run Duration

The Preliminary Round will consist of two (2) scored runs, each 30 minutes in duration. The Prize Round will consist of one (1) scored run, 60 minutes in duration.

8.4. System Guidelines

8.4.1. Human/Animal Use

Teams may choose to deploy a wide variety of systems to complete the course objectives including but not limited to robotic platforms, sensors, and communication components. No humans or animals will be permitted as any part of the deployed systems that enter the competition course. The representative scenarios of interest present significant dangers, such as collapsed and unstable structures or debris, presence of hazardous materials, lack of ventilation, and potential for smoke and/or fire that would preclude employing a human or animal team.

8.4.2. Size Limits

DARPA does not expect to place explicit limits on the size of deployed systems, but teams should consider how their systems will operate in the often space-constrained subterranean environments.

8.4.3. System Cost and Quantity Constraints

DARPA does not expect to place limits on the minimum or maximum number of deployed systems; however, teams should expect and plan for some level of failures and/or attrition. Such incapacitation could occur due to, e.g., inability to overcome obstacles, failed interactions with dynamic terrain (e.g., moving walls), loss in communications, or reaching of endurance limits. Due to these likely factors, DARPA is interested in solutions that are cost-effective and attrition-tolerant.

8.4.4. System Retrieval

All systems must begin the run in the Staging Area. It is encouraged but not required for the deployed systems to return to the Staging Area at the end of the run. Any systems that have not autonomously exited the course at the termination of a run will be retrieved by authorized DARPA Competition Staff. The Competition Staff will make their best effort to collect a team's systems after each run. However, if systems are not able to be recovered in a safe or timely manner by the Competition Staff, teams may have to operate without them on subsequent runs. Teams are

encouraged to provide audible and visual recovery aids such as flashing LEDs and audible cues to help Competition Staff locate deployed systems or components.

Due to the need for exclusive handling by Competition Staff, several safety measures will be required for robotic platforms. These include but are not limited to a DARPA-specified transponder and a DARPA-approved emergency stop.

8.4.5. Transponder

In addition to aiding extraction, the transponder is used to track and monitor progress of systems throughout the competition course. Teams are required to accommodate a third-party sensor package as described in the *Transponder and Emergency Stop Integration Guide*. To reduce the integration burden on teams, DARPA has integrated the transponder functionality with the Tier 2 E-Stop hardware described in Section 8.4.6.

8.4.6. Emergency Stop

The emergency stop (E-Stop) requirements are designed to ensure the safety of personnel, equipment, and the competition course environment. All systems participating in the SubT Challenge Systems Competition will utilize a complementary three-tiered emergency stop system.

Tier 1: Team Wireless E-Stop

Teams are required to implement a wireless emergency stop capability as a component of their system's communication architecture. The emergency stop must be able to be triggered from the team's Base Station and/or portable wireless transmitter. The Tier 1 E-Stop transmitter must instruct mobile platforms within effective communication range to come to a halt. The emergency stop procedures implemented on the mobile platforms must, upon receiving a Tier 1 E-Stop trigger, render a platform completely motionless within 30 seconds. The emergency stop must include clear visual feedback of the mobile platform's safe, halted state (e.g., red LED). The emergency stop capability may be targeted to a specific platform, but should also provide the functionality to rapidly render all platforms safe. A team must be able to render all platforms within communication range completely motionless within 60 seconds.

Tier 2: Recovery Wireless E-Stop

Teams must integrate a DARPA-defined emergency stop receiver on all mobile platforms weighing more than 0.5 kg. The module specifications and configuration guidelines for the Tier 2 E-Stop are detailed in the *Transponder and Emergency Stop Integration Guide*. The Tier 2 E-Stop receiver is designed with size, weight, power, and RF considerations in view to minimize the impact on teams.

The Tier 2 emergency stop capability is required to qualify and participate in all Circuit Events and the Final Event.

Teams must integrate and/or mount the receiver to their mobile platforms and monitor a single digital output pin that will indicate the trigger of a Tier 2 E-Stop. The remote trigger will come from

DARPA personnel carrying a DARPA transmitter while operating within an active course. The emergency stop procedures implemented on the mobile platforms must, upon receiving a Tier 2 E-Stop trigger, render the receiving platform(s) completely motionless within 30 seconds.

Tier 3: On-Platform E-Stop

Teams must integrate at least one emergency stop button on each platform that weighs more than 10 kg. The button must be a red mushroom-capped button at least 25 mm in diameter, with clear markings indicating that it is an emergency stop button. The buttons must latch when triggered and must require a twisting motion to release the latch. The buttons must be completely unobstructed and must be easily accessible by recovery personnel. The emergency stop procedures implemented on the mobile platforms must, upon receiving a Tier 3 E-Stop trigger, render all platforms completely motionless within 5 seconds.

E-Stop Qualification

In accordance with the *SubT Qualification Guide* document, all teams are required to demonstrate emergency stop compliance to be eligible for participation in the STIX Event, Circuit Events, and Final Event. Qualification requires teams to demonstrate fully functional emergency stopping in compliance with all three tiers outlined in this document. Demonstration requirements are outlined in the "Emergency Stop" section of the *SubT Qualification Guide*.

Emergency stop functionality and compliance will be verified by DARPA at each official SubT Challenge event. DARPA reserves the right to deny a team's participation in one or more runs if any of their mobile platforms are non-compliant with the emergency stop rules.

8.4.7. Dropped Components

Teams are permitted to make use of dropped components and leave-behind peripherals. However, all such components will need to be extracted by Competition Staff at the end of each run, so teams are required to provide the Competition Staff with reasonable methods to locate any deployed components to aid course reset. Such methods may include, for example, an inventory of deployed systems, log of estimated locations, and/or beacons (e.g., LED, sound).

8.4.8. Course Alteration

The course may not be willfully altered by any of the deployed systems, including but not limited to digging, burrowing, or intentional degradation or destruction of the environment's walls, floors, ceiling, immobile barriers or obstacles, or other course infrastructure or instrumentation.

8.4.9. Power Sources

All fuel and power sources must be safe for subterranean operations and will need to be approved by DARPA for use in the competition. Teams may be required to submit safety protocols and DARPA may require additional site-specific approvals which could require significant lead time. Most electric battery sources are expected to be approved. Teams are encouraged to address any potential concerns early.

8.4.10. Communications Frequency Spectrum and Power Limits

DARPA is interested in novel networking solutions and will work with teams to get their approaches approved if possible. However, each competition event location may have frequency spectrum limitations, including applicable FCC guidelines. Teams are encouraged to raise any potential concerns about their planned approaches early. Additional details and restrictions are expected to be released in the *Operations Guide* for each official event.

8.4.11. Internet and Cloud Resources

DARPA does not plan to provide or allow the use of internet or cloud connectivity during the runs in the Systems Competition. Access to such resources is often limited in the field and in real-world scenarios following natural disasters. Team personnel in the Staging Area are not permitted to access the internet or make phone calls on any devices (e.g., cell phone, tablet) during the competition runs.

9. Virtual Competition Rules

9.1. Scored Event Submissions

9.1.1. Versions and Releases

The SubT Virtual Testbed is based on Linux Ubuntu 18.04, Robot Operating System (ROS) Melodic Morenia, and Ignition Gazebo. The Circuit and Final Events will all take place in an Ignition Gazebo cloud environment using Amazon Web Services, so compatibility with these software tools is required of any Virtual Competition team.

9.1.2. Scored Competition Scenarios

Teams must submit their solutions to the SubT Virtual Portal where cloud-based simulations will be run against unreleased competition scenarios. The competition scenarios, run scores, and logs will not be released until the event results are announced.

Each qualified team must submit a single solution per round to be scored. The submitted solutions will be evaluated against ***m*** number of competition scenarios to test the versatility of the solutions. Each competition scenario will, in turn, be evaluated over ***n*** replications (reps) to account for random variability. See Figure 12 for a graphical depiction. The Event Score of the ***m***x***n*** runs is given by:

$$Event\ Score = \frac{1}{m}\sum_{i=1}^{m}\left(\frac{\sum_{j=1}^{n} run\ score_{ij}}{n}\right)$$

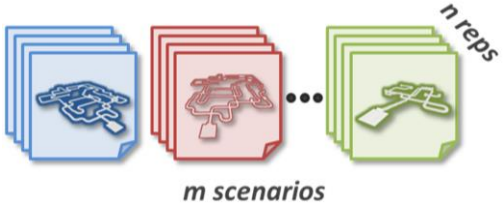

Figure 12: Virtual Competition approach to scoring competition scenarios

9.1.3. Solution Submissions

For scored event submissions, teams must submit their solution in the form of Docker Images to the SubT Virtual Portal, where it will be evaluated against the hidden competition scenarios. Submissions must be self-contained and evaluated through an automated process. Entries that require additional user input or external commands will not be scored.

The Final Event of the Virtual Competition will consist of a Preliminary Round and a Prize Round each with a separate solution submission window. The submissions to the Preliminary Round will be evaluated and the results are expected to be announced the week of August 9-13, 2021. The top 10 teams from the Preliminary Round will be invited to submit solutions to the Prize Round to compete for monetary prizes. The results and winners of the Prize Round will be announced at the Final Event being held September 21-24, 2021. Monetary prizes will be awarded to the top performing teams in the Prize Round as detailed in Table 2.

Round	Submission Window	Results Release
Preliminary Round	July 22-29, 2021	August 9-13, 2021
Prize Round	August 19-26, 2021	September 21-24, 2021

Table 3: Schedule of Virtual Competition Dates for the Final Event

9.1.4. Human Supervisor

The submitted solutions will be evaluated with no external operator interfaces such as command line inputs or user interventions. Virtual Teams are required to develop self-contained solutions that map, navigate, and search entirely autonomously without Human Supervisor interactions.

9.1.5. Staging Area

Each scored scenario begins with a Staging Area similar to the Systems Competition, inside which all platforms in the team may spawn. Platforms will not be spawned outside of the Staging Area. At spawn time, platforms are provided their ground truth location and orientation. Platforms may operate freely within the Staging Area, but are not allowed to leave its borders or ascend to a height greater than 15 meters above the Staging Area ground level. While in the Staging Area, all platforms will have access to a ROS service that provides their ground truth location relative to the artifact origin, which is located at the base of the entrance to the virtual environment.

Competitors will have up to 15 minutes of in-simulation time for their chosen robot team to prepare, spawn, start up, self-locate, or perform any other tasks in preparation for the scored simulation run. If the simulated vehicles have not entered the course or otherwise initiated a simulation run by the end of the allotted preparation time, the simulation run will automatically commence.

9.1.6. SubT Simulator Mechanics

The SubT Simulator utilizes a number of simulator mechanics to address the environmental accuracy of the competition and reduce the operational disparity between the Systems and Virtual Competitions. To that end, team submissions must fully utilize and not seek to circumvent use of

simulator mechanics including the RF propagation networking model, the built-in battery mechanic, and the vehicle damage plugin.

9.1.7. Disabled Platforms

During the course of a run, individual platforms may be disabled due to battery expiration, exceeding a vehicle damage threshold, or leaving the permitted operating regions. If a platform is disabled, it can continue to operate as a processing or communications node, but will no longer be able to move in the environment.

9.1.8. Run Termination

A scored run terminates upon any of the following conditions:

- Time Expiration: The given time expires before another termination criterion is met
- Disabled Platforms: All platforms are in a disabled state
- Maximum Score: All artifacts have been successfully reported and the maximum score has been achieved
- Artifact Reports Limit: The team reaches the maximum limit of allowed artifact reports

9.1.9. Score Disputes

Score Disputes are intended to provide teams a mechanism to submit a formal dispute or request for review by the Chief Judge. All score disputes should be sent by email to the SubT Challenge email address (SubTChallenge@darpa.mil) within 48 hours of receiving competition log files. All disputes or requests will be reviewed by the Chief Judge in a timely manner. All decisions made by the Chief Judge are final.

9.2. Final Event Scenarios

9.2.1. Final Event Competition Environments

The scale and complexity of the environments is expected to vary across competition scenarios and across events. DARPA intends to release practice scenarios in advance of the Final Event to provide representative environments in which to develop and evaluate solutions.

It is expected that some portions of the environments will only be accessible via passages that are approximately one meter in height and/or one meter in width. The most constrained portions of the competition environments are not expected to be immediately at the entrance, but may be located in sections that would preclude access to significant portions of the environment for systems that cannot traverse constrained passages.

9.2.2. Final Event Artifacts

DARPA will announce the expected artifacts in advance of each competition event. The artifacts used in the Virtual Competition will be similar to those used in the Systems Competition and will be made available in the SubT Tech Repo in advance of each event. Artifact placement throughout the competition scenarios will be consistent across all runs for any given scenario but will vary across scenarios.

Teams will know what artifacts to look for, but the placement of the artifacts within the course will not be known. It is expected that all scenarios in the Final Event will have 20 artifacts and the total number of allowed scored reports for each run will be 25.

The Final Event will include a total of ten artifact types: the three common artifacts, all six event-specific artifacts, and the Finals-specific artifact. The Preliminary Round will use the following six (6) artifact types: Survivor, Cell Phone, Backpack, Fire Extinguisher, Vent, and Rope. The Prize Round will use the following ten (10) artifact types: Survivor, Cell Phone, Backpack, Fire Extinguisher, Drill, Vent, Gas, Rope, Helmet, Cube. Additional details and specifications are provided in the *Artifacts Specification (Cave Circuit)* document available on the SubT Challenge Website and SubT Community Forum.

9.2.3. Final Event Run Duration

For the Final Event, scored runs will be 60 minutes in duration. For each scored run, the chosen team configuration will spawn inside the Staging Area. The run will be given 60 minutes of in-simulation time.

9.3. Team Configuration

9.3.1. SubT "Credits"

To ensure relevant mission constraints, the Team Configuration is limited by a maximum allowable budget of 1,000 "SubT Credits." Each of the configurations in the SubT Tech Repo has an assigned SubT Credit value, which is based on several factors of interest to DARPA (e.g., cost, packed volume, sensor payload). SubT Credit values are viewable on the SubT Virtual Testbed wiki. DARPA reserves the right to adjust the assigned values throughout the competition to encourage teams to better explore the design space. The Virtual competitors can compose their Team Configuration by "mixing and matching" one or more models selected from the SubT Tech Repo with an aggregate value up to the maximum allowable 1,000 SubT Credit budget. The Team Configuration is also limited to a maximum of five models of a given type (e.g., five X1 platforms of any payload configuration). Submissions composed of team configurations exceeding the allowable SubT Credit budget or more than five of a given robot type will not be scored.

9.3.2. Model Configurations

For the Final Event, competitors may use any combination of the configurations available through the SubT Tech Repo, also described on the SubT Virtual Testbed wiki.

9.3.3. Model Requests

Teams may request or contribute models for potential inclusion in the SubT Tech Repo in accordance with the Simulation Model Preparation Guide, but no guarantee is provided that such requests will be approved. In addition to platform models, teams may also submit sensors and scenarios as contributions for consideration. Any proposed models will undergo review and validation before being included in the SubT Tech Repo. Note that a model contributed by a team,

if found viable and deemed appropriate for the spirit of the competition, will be made publicly available to all teams through the SubT Tech Repo.

9.4. Communications and Score Reporting

9.4.1. SubT Simulator RF Propagation Plugin

The SubT Virtual Testbed will leverage a number of tools to create realistic radio-frequency behaviors in underground environments. As communications and networking is one of the cornerstones of the SubT Challenge, teams participating in this competition are required to utilize the SubT Simulator's RF communications interfaces for all inter-platform communication, including communications to report found artifacts to the Base Station computer. No other wired or wireless communications is permitted. Additional details are available in the SubT Simulator API documentation.

9.4.2. Reporting Artifacts

Similar to the Systems Track, teams should account for simulated environmental communications degradation and the need to present relevant information to a virtual Base Station to provide near-real-time situational awareness updates and reports that are scored in the same manner as the Systems Competition. To report an artifact for scoring, the artifact report must originate from a platform and be sent to the virtual Base Station using the RF Propagation Plugin. It is expected that all scenarios in the Final Event will have 20 artifacts and the total number of allowed scored reports for each run will be 25.

9.4.1. Log Files

At the termination of a run, relevant log files are generated. The log files include all artifact reports, their corresponding timestamps, score updates, and other details. Additionally, log files allow replaying and viewing of the run by Competition Staff to ensure fair and consistent team performance in the virtual scenario in keeping with the rules and spirit of the SubT Challenge.

10. Scoring Criteria

The goal of the DARPA SubT Challenge is to develop innovative solutions that provide rapid and actionable situational awareness in complex subterranean environments. As such, teams are evaluated based on the number of artifacts they accurately report within a single run. Upon receiving an artifact report, the DARPA Command Post evaluates the validity of the report and provides score updates back to the team's Base Station. Artifacts are distributed throughout the competition course in a manner which rewards teams that are able to rapidly explore and maneuver through more of the course elements. The placement of the artifacts is not known in advance of a run by competitors and may be varied from run to run.

Scoring Objective	***Find the most Artifacts before time runs out***

10.1. Accuracy

Upon identifying an artifact, the deployed system must report the type of artifact and its spatially referenced location to the DARPA Command Post via the team's Base Station. The location must be reported in the form of Cartesian coordinates (x,y,z) relative to the origin (*0*,*0*,*0*) of the DARPA-defined reference frame as established by the Reference Frame Fiducials (Section 8.3.2). The reported locations are compared against the DARPA ground truth dataset. To be designated a valid artifact report, the artifact type string (see the *SubT Challenge Artifacts Specification* document) must be correct **AND** its reported location must be less than or equal to five (5) meters (Euclidean distance) from the ground truth location.

A valid artifact report earns the team one (1) point. Any artifact reports outside of the allowed error range do not earn any points. Upon submitting an artifact report, teams receive a response that includes the report status and the score change. Score updates during a run are expected to happen immediately after a report receipt (within 1 second). Additional details are provided in the Interface Control Document (ICD) available on the SubT Challenge Website and SubT Community Forum.

If an initial report was deemed invalid due to insufficient accuracy or incorrect type, a team may submit another report, which would be scored using the same scoring metric. Such a scenario may arise, for example, when an initial report is not accurate but further exploration (e.g., loop closure, averaged readings) results in a more accurate estimate of type or location. Duplicate reports, whether valid or invalid, are subject to the limitations described in Section 10.3.

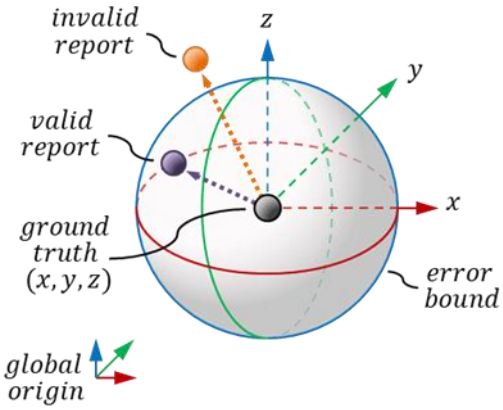

Figure 13: Accuracy-based scoring of artifact reports

10.2. Time

The time of artifact reports does not explicitly contribute to a team's score. Though time is not an explicit scoring factor, the course layout is designed such that finding a majority of the artifacts requires significant speed in covering the course. Furthermore, time serves as the tiebreaker as described in Section 10.4. Time is measured from the start of the run and is based on the time

that a valid report is received at the DARPA Command Post, regardless of when the original detection took place.

10.3. Artifact Reports

Artifact reports are expected to be transmitted to the DARPA Command Post over an Ethernet link from the Base Station. The detailed format, protocol, and example implementation are specified in the *Interface Control Document (ICD)* available on the SubT Challenge Website and SubT Community Forum.

To discourage false reports, the DARPA Command Post limits the total number of scored reports. Any further reports are rejected.

For the Systems Competition, it is expected that each run in the Preliminary Round will have 20 artifacts and the total number of allowed artifact reports for each run will be 25. It is expected that each run in the Prize Round will have 40 artifacts and the total number of allowed artifact reports for each run will be 45. For the Systems Competition, once an artifact has been successfully reported, any duplicate reports will be considered invalid and will count against the total number of reports.

For the Virtual Competition, it is expected that all scenarios in the Final Event will have 20 artifacts and the total number of allowed scored reports for each run will be 25. For the Virtual Competition, exactly duplicate reports will not be counted against the total number of reports; details are provided in the SubT Virtual Testbed API.

DARPA intends to perform additional validation tests to discourage false reports and invalid guesses. For example, artifact reports in areas of the competition course that have not been explored by a team's systems may be deemed invalid.

10.4. Final Ranking

For the Systems Teams, the final ranking in the Preliminary Round will be determined based on the sum of the team's two scored runs. The final ranking in the Prize Round will be determined based solely on the Prize Round scored run. In the event that multiple teams have an identical score in either round, tiebreakers will be applied in the following order until the tie is broken:

- earliest time that the last artifact was successfully reported, averaged across the team's runs in that round
- earliest time that the first artifact was successfully reported, averaged across the team's runs in that round
- earliest time that a team's system ingressed into the course, averaged across the team's runs in that round

For the Virtual Teams, the final ranking in the Preliminary Round will be determined based on each team's event score as described in Section 9.1.2. The final ranking in the Prize Round will

be determined based solely on the event score for scored runs completed in the Prize Round. In the event that multiple teams have an identical event score, tiebreakers will be applied in the following order until the tie is broken:

- earliest time that the last artifact was successfully reported, averaged across all of the team's runs in that round
- earliest time that the first artifact was successfully reported, averaged across all of the team's runs in that round
- furthest Euclidean distance from the Staging Area traveled by any deployed system

Appendix 1 SubT Challenge Glossary

Base Station – One or more computers or controllers that serve as the interface between the systems, the DARPA Command Post, and the Human Supervisor

Chief Judge – DARPA-designated individual with the sole and final authority to make any decisions related to the rules or scoring

Competition Course – Physical or virtual environment in which deployed systems are expected to explore, map, and search for artifacts

Course Official – DARPA-designated individual that is based in each Staging Area to apply and enforce the rules and make safety-related decisions, with decision-making authority only superseded by the Judge and Chief Judge

DARPA Command Post – Computer interface which receives artifact reports and map updates from teams and returns score updates. Also refers to the main headquarters where the DARPA staff execute the Challenge.

Human Supervisor – Team-designated individual permitted to interface with the Base Station, provide high-level interactions with the deployed systems, use wireless communications, and access both course data and status data

Judge – DARPA-designated individual with authority to make decisions related to rules, scoring, and safety, with decision-making authority only superseded by the Chief Judge

Pit Crew – Team personnel permitted in the Staging Area to assist with operations tasks such as physically deploying the systems, performing repairs, modifying software or firmware, and changing batteries

Safety Officer – Team-designated members of the Pit Crew responsible for preserving the safety of personnel and property, activating emergency stop transmitters, and/or operate remote controls for safety purposes

Staging Area – Specified area immediately outside of the Competition Course entrance from which teams deploy their systems

Starting Gate – Installed structure or existing entrance which serves as the threshold between the Staging Area and the Competition Course

Starting Gate Fiducial – An easily identifiable object attached to or near the Starting Gate to assist teams to align with the official coordinate frame in which artifacts are reported. These may include 2D barcodes (AprilTags), reflective targets, or survey prisms

SubT Simulator – Simulation environment being used for the SubT Challenge that is implemented in Ignition Gazebo and can be either cloud- or desktop-based

SubT Tech Repo – Online catalog of virtual subterranean technologies including models of systems, sensors, environments, and artifacts models (subtchallenge.world/models)

SubT Virtual Portal – Web-based point-of-entry (subtchallenge.world) for accessing simulation resources, submitting solutions, and leaderboards

SubT Virtual Testbed – Suite of simulation tools comprising the SubT Virtual Portal, SubT Tech Repo, SubT Simulator, automated testing and assessment tools, and associated software support infrastructure

Team Lead – Team-designated individual responsible for making official team decisions (e.g., termination of a run) and communicating with the DARPA Competition Staff