DRC Finals Rule Book

April 9, 2015. DISTAR Case 24388

Deleted: March 25

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Part 1. Rules of the DRC Finals

Part 2. Communications between Operator and Robot for the DRC Finals

Part 3. Scoring Guide for the DRC Finals

Rules of the DRC Finals

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Revision History

This section captures major changes to this document.

Date	Section	Description
6/24/2014	Document	Release 1
11/2/2014	Document	Release 2
11/13/2014	Document	Release 3
4/9/2015	Document	Release 4
	Sequestered Operator	In exceptional conditions, the Team Field Lead can communicate with the Operator.
	Tasks	8 tasks instead of 10. After completion of wall task, encourage turning off the drill for safety.
	Resets	Teams may reset robot during run.
	Vehicle	Provides details on allowable vehicle modifications.

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1 Introduction, Scope, and Precedence

This document defines the rules for the DARPA Robotics Challenge (DRC) Finals. The rules apply to all participants in the DRC Finals. The intent of this document is to inform teams as they prepare for the DRC Finals. Further documents are planned for publication in April 2015 with details for participation in the DRC Finals.

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Nothing in these rules, to include this document and all subsequent rules documents, may be interpreted as modifying the statement of work or authorizing work outside the terms and conditions of any existing agreements or contracts with DARPA.

DARPA may release additional documents with rules updates, procedures, and other information for teams as needed. These additional documents carry the full authority of the rules in this document.

An individual or entity must show they are capable of performing the tasks by passing initial qualification testing. The *DRC Finals Qualification* document describes qualification requirements and the qualification process for the DRC Finals.

DARPA will post all official documents on the DRC website (www.TheRoboticsChallenge.org).

2 Rule Modifications

This version of the rules is subject to change and may be superseded by later versions. The Chief Official has the authority to modify and interpret the rules at any time. DARPA will communicate any modifications to the rules with a statement on the DARPA Robotics Challenge website.

Requests for rules clarifications, questions about proprietary or sensitive matters, and questions about logistics of the event should be sent to TheRoboticsChallenge@darpa.mil. DARPA will post responses on the DRC website (www.TheRoboticsChallenge.com) and send notifications of updates to the DRC website forum. DARPA will ensure that answers do not give any team an unfair advantage.

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Decisions by the Chief Official are final.

3 Eligibility

Individual participants and teams of participants, of all nationalities and of all ages, except as noted below, are eligible to participate in the DRC Finals.

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An individual or entity is not eligible to register or otherwise participate in the DRC Finals if the individual or entity is on the Specially Designated Nationals list promulgated and amended by the Office of Foreign Assets Control of the United States Department of the Treasury (http://www.treasury.gov/resource-center/sanctions/SDN-List/Pages/default.aspx).

In order to receive the DARPA cash prize (after successfully competing in the DRC Finals), the winner must provide a U.S. taxpayer identification number (TIN), for example, a social security number. Information on how to obtain a TIN is available on the U.S. Internal Revenue Service website at www.IRS.gov.

Participants who are U.S. citizens or lawful permanent residents under 18 years of age may be required to obtain the written consent of a guardian and/or meet other applicable legal requirements as a prerequisite to accepting the prize under this Challenge.

Challenge participants are solely responsible for complying with all applicable laws and regulations. DARPA expressly disclaims any liability or responsibility thereto. In case of doubt about applicable laws and regulations, interested parties may choose to consult their legal counsel.

Subject to Federal law, regulation and applicable agency policy, Federal entities and Federal employees acting within the scope of their employment are eligible to participate in the Challenge, but shall not be eligible to receive the DARPA cash prize. Federal employees acting outside the scope of their employment should consult their ethics official and appropriate management before participating in the Challenge.

To avoid the appearance of unfairness, DARPA employees and DARPA support contractors and their spouses, dependents, and household members are not eligible to participate in the Challenge.

DARPA reserves the right to disqualify a participant whose actions are deemed to violate the spirit of the competition for any reason, including but not limited to, the violation of laws or regulations in the course of participation in the DRC Finals.

4 Registration and Qualification

4.1 Registration of Intent to Compete

Teams wishing to participate in the DRC Finals must first register their intent to compete. Teams that were named Finalist (having received at least eight (8) points) at the DRC Trials in 2013 do not need to register their intent.

Teams may register their intent to compete in the DRC Finals by providing their team and robot information at www.theroboticschallenge.org/participate. Please note the registration dates in Section 5, below.

4.2 Qualification

For teams that have registered their intent to compete, the next required step is to qualify. The DRC Finals Qualification document explains the qualification procedure. Qualified teams who wish to significantly change their robot must re-qualify the final robot to be used at DRC Finals. Please note the qualification dates in Section 5, below.

4.3 Registration of Team Participation

For teams that have qualified, the next required step is to register their complete team roster for the DRC Finals at a registration site that will be provided with the notice of Qualification Status. Please note the registration dates in Section 5, below.

5 Key Dates

Table 1 shows some of the key dates leading up to the DRC Finals.

Event	Date
Announcement of Finals	6/26/2014
Registration of Intent to Compete, Open	6/26/2014
Registration of Intent to Compete, Closed	2/2/2015
Qualification Video Submissions, Open	6/27/2014

Qualification Video Submissions Due	2/2/2015
Qualification Video Notifications	2/28/2015
Registration of Team Participation, Open	3/2/2015
Registration of Team Participation, Closed	4/15/2015
Deadline for obtaining visas (if necessary)	5/1/2015
Deadline for final robot re-qualification (if necessary)	6/1/2015
First day of DRC Finals competition (*)	6/5/2015
Second day of DRC Finals competition	6/6/2015
Workshop (**)	6/7/2015

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Table 1. Key dates

(*) DARPA will publish a detailed schedule following notification of qualification status. Teams should reserve from at least 6/1/2015 through 6/8/2015 to be at the competition site.
(**) Teams must be prepared to present a talk on their technical approach, with part of the talk suitable for non-experts, and with part of the talk suitable for expert robotics practitioners.

6 Tasks

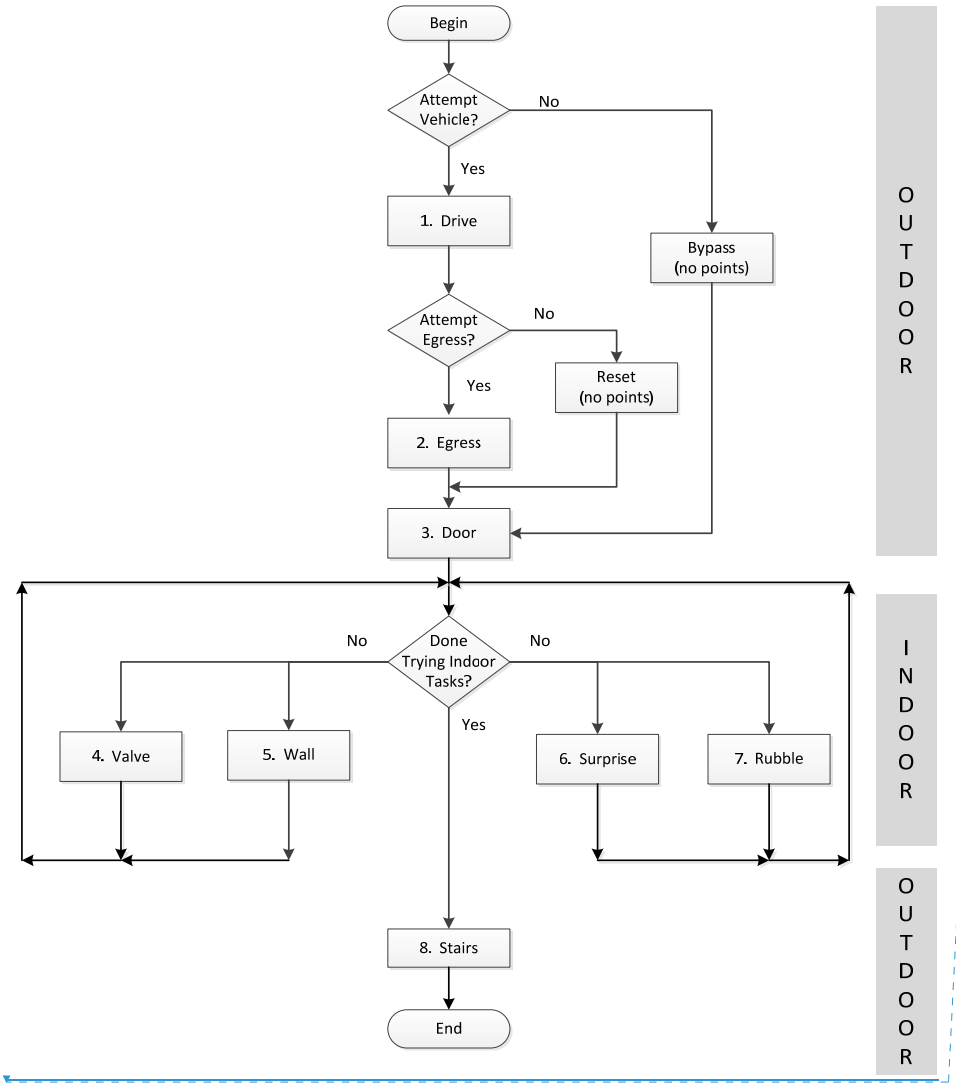
The actual tasks used in the Finals have been determined, but remain subject to change. DARPA is currently planning the following N=8 tasks:

1. Drive the vehicle (same vehicle type as in Trials[1])
2. Egress from the vehicle (get out of the vehicle)
3. Open door and travel through opening
4. Open valve (similar to one of the three valves in Trials)
5. Use a cutting tool to cut a hole in a wall (similar to one of the two tools and the wall in Trials)
6. Surprise manipulation task (not disclosed until Finals)
7. Traverse rubble - Either cross debris field (by moving the debris or traversing it, similar to Trials) or negotiate irregular terrain (similar to Trials)
8. Climb stairs (fewer steps and less steep than in Trials)

Each task is worth one (1) point.

Figure 1 shows a flowchart describing the order in which teams may attempt the tasks. The total number of tasks is subject to change.

[1] See the DRC Trials Task Description document at http://archive.darpa.mil/roboticschallengetrialsarchive/media/index.html



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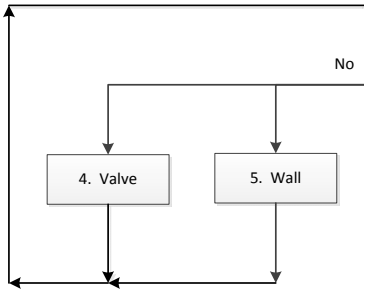

Figure 1. Flowchart describing constraints on task order

The labels Indoor and Outdoor on the right-hand side of the figure indicate that some of the tasks take place outdoors, where communications are not degraded, and some of the tasks take place in a simulated indoors environment, where communications are degraded. (See the *DRC Finals Communications* document for details of the degradation.) In reality, all of the tasks will take place outdoors. The simulated discrepancy reflects a commonly encountered situation wherein a cell phone call has good communications quality outdoors, but poor quality indoors.

The figure shows that Task 1 (Drive) and Task 2 (Egress) have a single bypass path that allows a robot to circumvent the two tasks by traveling (for example, walking) along the bypass path. The bypass path is at least as long as the path the vehicle must traverse. If a team elects to bypass Drive and Egress, the robot must travel along the bypass path to the Door. No points will be awarded for Task 1 or Task 2 if the robot takes the bypass path.

The figure shows that the only way to perform Task 2 (Egress) is by first performing Task 1 (Drive).

The figure shows that once the robot has completed attempting the Indoor tasks and begins the Stairs task, it may not attempt more Indoor tasks.

For Task 1 (Drive), the robot may only drive the vehicle forward, and may not drive rearward.

For Task 2 (Egress), after getting out of the car, the robot must locomote to a Task Completion Area (2 meter x 2 meter) that will be marked on the pavement in front of the door (Task 3). A platform 4 feet wide by 8 feet long and approximately 5 inches high will be placed on the “driver” side within the finish area of the Drive course. Teams may choose to drive the vehicle to a point adjacent to the platform so that their robot will have a shorter height to descend when exiting the vehicle. Whether or not the robot uses the platform, it must locomote to the Task Completion Area to earn the point for Task 2.

To earn the point for Task 2 (Egress), the center of mass of the robot (with no accessories) must do Task 1 (Drive) and start Task 2 (Egress) inside the unmodified vehicle. If the robot’s COM falls outside the vehicle as it was before modifications were made, it cannot achieve the point for Egress. A practical test for this is whether the robot passively stays in the unmodified vehicle when all hands and any other grips and attachments are released.

Teams may also omit Task 2 (Egress) by requesting a Reset (see Section 11) at the end of Task 1 (Drive). Once a Reset has been granted, the Field Team may manually remove the robot from the vehicle and place it in the Reset Zone. At least ten (10) minutes must elapse before resuming the run, and no Egress point will be awarded.

Teams that complete both Task 1 (Drive) and Task 2 (Egress) with the center of mass of the robot outside of the vehicle do not need to request a Reset. They will receive one (1) point for Task 1 (Drive), no points for Task 2 (Egress), and will not need to wait for 10 minutes to elapse.

For Task 3 (Door), the door will open inward (away from the robot). The door will not include a threshold. Once fully opened, the door is designed to remain open.

For Task 4 (Valve), DARPA will use a circular handle with a diameter between 4 inches (10 cm) and 16 inches (40 cm). The valve opens by counter-clockwise rotation.

For Task 5 (Wall), a circle will be drawn on the wall, approximately 8 inches (20 cm) in diameter. The cutting operation must entirely remove all wall material from the designated circle.

Teams may choose between two drills:

- Dewalt DCD980M2 cordless drill or similar, and an additional side handle. This drill has a Morris 13042 bit or similar. The DCD980M2 has a trigger; to operate, the robot must grasp the drill and squeeze the trigger. This drill has a side handle, which the teams may set in any orientation or remove. The drill only runs for approximately five (5) minutes before it must be re-triggered.
- Dewalt DCS551 cordless rotary cut out tool or similar. The DCS551 has an on/off switch, not a trigger. This rotary tool has a DW6609 0.25 inch bit or similar. To operate this drill, the robot must grasp the drill and press the on/off switch. (Note that the on/off switch is guarded by a piece of yellow plastic that prevents accidental switching. Some robot "fingers" might have trouble making contact with the switch. Teams might consider adding a "bump" on the finger that improves access to the switch.)

One shelf, approximately 44 inches above the ground, will hold one of each type of drill. A second shelf, approximately 32 inches above the ground, will also hold one of each type of drill. All drills will be fully charged, set to the highest speed, in the OFF position, with pre-installed bits. The drills will be standing upright on their batteries (as opposed to lying on their sides on the shelf). If one of the drills ceases to function (for example because the robot dropped it, or the bit broke), the robot may use another drill.

After completing the task, the robot should turn off the drill and return it to the shelf or place it on the ground. These actions (turning it off and placing it) are not required for earning the point for completing the task; however, DARPA strongly encourages taking these actions for safety.

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For Task 6 (Surprise), the task will require manipulation and no mobility (except to get to and from the task site).

For Task 7 (Rubble), the robot will earn one point for successfully traversing either the debris field or the terrain field. The robot may traverse both fields; however, it will earn at most one point.

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For Task 8 (Stairs), the robot may only ascend, and may not descend. The stairway has a rail on the left side and no rail on the right side.

For Tasks 1-6, teams should not assume that the floor surface is smooth and level. However, DARPA has not introduced purposeful irregularities into these surfaces.

For Tasks 2-8, the tasks include transit (by robot locomotion).

Teams will be allowed two runs, meaning two attempts to perform the tasks. Each run will include all of the tasks (unlike the DRC Trials, in which each task was attempted separately). Teams may attempt different tasks on different runs; that is, the runs are independent of each other.

For all DRC Finals tasks, unlike for the DRC Trials, the robot may **not** use a safety belay, may **not** use a power tether, and may not use wired communications with the Operator.

In planning which tasks to attempt and in what order to do them, teams should consider the risk of the robot becoming broken, "stuck" or otherwise disabled.

7 Ranking

This section defines the ranking approach for the DRC Finals.

7.1 Task Completion

The task completion rating C shall be the number of tasks completed during a run.

The worst possible value for C is zero. This indicates that the robot accomplished none of the tasks.

The best possible value for C is N (the total number of tasks, see Section 6). This indicates that the robot accomplished all of the tasks.

7.2 Task Completion Time

The maximum time allotted for a run is 60 minutes.

The task completion time rating T shall be the (cumulative) run time up until the last point is awarded for a run. Time taken after the most recent point is scored that does not lead to an additional point does not count in the rating. Thus, from the perspective of ranking, it always makes sense for a team to try to continue a run (unless it is certain the robot can make no further progress).

Example: The robot system completes all tasks in forty (40) minutes. Then T = 40.

Example: The robot system completes the first few tasks in fifteen (15) minutes, and tries unsuccessfully for the remaining forty-five (45) minutes to complete additional tasks. Then T = 15.

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7.3 Final Ranking

Teams will perform two runs. The runs will be scored individually, and only the better of the two runs will be used for ranking purposes. The lower-scored run will be disregarded.

Teams will be first ranked by task completion C, with larger values of C ranked higher. The DRC Finals is expected to be a highly competitive event, so teams may expect that the winner will complete most, and likely all, tasks.

Teams with equal C values will be ranked by T, with smaller values of T ranked higher.

Cases in which teams have equal rankings for both task completion and task completion time will be referred to the Chief Official for resolution, possibly by conducting additional runs.

8 Communications

Previous versions of this document described communications between the operator and the robot in Sections 8.1, 8.2, and 8.3. A separate document now covers those topics.

8.4 Communications for Emergency Stops

DARPA will supply a wireless emergency-stop system to teams that have qualified for the DRC Finals.

Teams must integrate this system on their robot and demonstrate its functionality before they may compete in the DRC Finals.

Teams must have a light on the robot that indicates when the robot is safe to approach.

8.5 Sequestered Operators

Operators will be sequestered.

At no time may any of the operators receive information from anyone or anything viewing the robot during a run. There are five exceptions to this rule: the Team Field Lead may notify the Operator: (a) when the run has begun, (b) when a Reset has been requested, (c) when an e-stop has been activated, (d) when the run has been completed or interrupted, or (e) when instructed by a Finals Official.

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9 Run Termination Criteria

A run terminates upon any of the following conditions:

- Run Completion - The robot completes all tasks within the given time
- Run Cancellation - A Finals Official cancels the run due to an external factor such as weather, including lightning, rain, wind, earthquake, and tremor. DARPA will publish the exact criteria in the future.
- Time Expiration - The given time expires before the robot completes the run

- Emergency-Stop - A Finals Official activates the emergency-stop because of an unsafe condition
- By Request - The Team Lead requests that the run end
- Touch - A Team Member touches the robot outside of an officially requested and approved Reset

A team may be eligible for a re-run if a run was cancelled or emergency-stopped. The Chief Official will review eligible cases and determine the course of action.

If a robot falls during a run, it may continue if it can resume the task without physical intervention, or if the team requests a Reset (Section 11). Robots that have durability and the capability of getting up from a fall are encouraged.

10 Hardware Reconfiguration

A robot may reconfigure its hardware during a run, but may not receive human help to do so.

Robots may use passive tools and leave them behind at any point during a run. For example, a robot may use Ski Poles.

Teams may reconfigure a robot's hardware between runs.

Teams may NOT use a UAV or a throwable or launchable device. For safety, airborne devices are not permitted.

11 Resets

If a robot is unable to progress, a team may request a Reset. Once a Reset is declared, at least ten (10) minutes must elapse before resuming the run.

If a Reset request is made while the robot was performing Task 1 (Drive), a team may decide to attempt Task 1 again, or choose to walk instead. If the team decides to attempt Task 1 again, the robot and vehicle will be repositioned at the start line for Task 1. If the team decides to walk and not attempt Task 1, the robot will be positioned at the start line for walking and no points will be awarded for Task 1.

If a reset is requested while the robot is performing Task 2 (Egress), the robot will be positioned in the Reset Zone, which is adjacent to the Task 2 Task Completion Area and is on the same side of Task 3 (Door) as Task 1 (Drive). In this case, no point will be awarded for Task 2.

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If a reset is requested during Tasks 3-8, the robot will be positioned in the Reset Zone, with the door set in the open position if the robot has already earned a point for Task 3 (Door) or with the door set in the closed position if the robot has not yet earned the point for Task 3.

12 Vehicle

The vehicle (Polaris Ranger) will be available in two configurations:

1. Roll-bar on with padded seat
2. Roll-bar off with flat board for seat.

Seat belts and side safety handles will be removed in both versions. Teams may use either version of the vehicle, but need to declare which one by June 3rd.

For the Drive task, once the robot is ready to start the run, the vehicle will be started and put into gear by the DRC Operations staff. After Task 1 (Drive) is achieved and the team has completed driving, the DRC Operations staff will press the Vehicle E-stop so that the robot may attempt Task 2 (Egress) with the vehicle off.

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Teams may make temporary modifications to the vehicle provided that they require no more than five (5) minutes to install, require no tools, are passive (neither require nor provide power), and do not damage the vehicle. Approved examples include temporary handles taped on to the steering wheel, and a replacement seat that fits into the same connectors as the original seats. Disallowed examples include a second robot for driving, a generator or battery to provide additional power, and an actuator on the wheel or gas pedal.

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Teams should consult with DARPA when designing any modification that may not clearly be allowed.

Appendix A. Definitions

Chief Official
The Chief Official is the DARPA Program Manager or an official designated by the DARPA Program Manager. The Chief Official is the final authority on all matters referred to in the rules and on all matters pertaining to the DRC that are not explicitly referred to in the rules.

DARPA Robotics Challenge Website
Application forms and the most authoritative and up-to-date information about the DARPA Robotics Challenge program in general, and the DRC Finals in particular, can be obtained at www.TheRoboticsChallenge.org.

Entrant
An entrant is a team that has not been disqualified.

Media Representative
A media representative is anyone who is accredited by DARPA as such.

Official
An official is a person designated by DARPA for the purpose of administering or monitoring any aspect of the DRC.

Qualification
The qualification process performs an initial check in advance of DRC Finals to guarantee that teams can demonstrate basic functionality and safety in order to be allocated a place at the Finals.

Rules
The rules posted on the DARPA Robotics Challenge website are the official governing set of regulations and guidelines of the DARPA DRC Finals and apply to all participants. The rules include this document as well as subsequent procedure documents and rules updates that are released on the website. The Chief Official is the final authority on all rules and all aspects of the DARPA DRC Finals.

Run
A trial of a sequence of tasks, as defined above in the Tasks section.

Team Leader
A team leader is the individual identified to DARPA during the application process and is responsible for acting as the primary point of contact for team communication with DARPA.

Team Member
A team member is a team leader or individual who has been designated by the team leader as a team member.

Communications between Operator and Robot for the DRC Finals

April 9, 2015. DISTAR Case 24388

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ITEMS IN RED FONT ARE NEW OR UPDATED IN THIS VERSION.

1 Introduction

The communications (comms) infrastructure now being created for the DARPA Robotic Challenge (DRC) Finals has been designed with two primary goals: reliability and the encouragement of robot autonomy.

Reliability is being addressed by pre-assembling the Finals infrastructure at ~~a~~ the SPAWAR Systems Center Atlantic (SSC LANT) facility in South Carolina and allowing teams to test end-to-end comms at this facility using their own robot or their own surrogate system. In addition, DARPA will supply all teams qualified to compete in the Finals with preconfigured radio equipment that is known to be compatible with DRC Finals comms infrastructure. Teams will be required to use these radios and only these radios. Radios, antennas, and robot e-stops will be provided by March 1, 2015 to all qualified teams.

DARPA considers that autonomy can be gauged by how much and how quickly data needs to be exchanged between a human operator and a robot in order to execute a given task. When performing a particular task in a specified time, the fewer bits exchanged, the greater the demonstrated autonomy. To promote autonomy DARPA will create controlled network service interruptions with substantial duration in which only low data-rate communication between humans and robots will be possible. The blackouts will be structured so that teams with more autonomous systems will be able to progress through a run more quickly. However, there will also be sufficient data exchange during some periods so that teams with less autonomy will be able to perform some tasks successfully, albeit more slowly. Note that teams that score the same number of points for successfully completing tasks will be ranked on how quickly they completed these tasks. (See Section 7, Rules of the DRC Finals.)

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In a significant change from the DRC Trials of December 2013, all robots will be un-tethered at the DRC Finals in June 2015. This means there will be no belays, no power cables, and all comms to the robot will travel over wireless links provided by the DARPA supplied radios.

2 Overview of the DRC Finals Comms System

Figure 1 shows a simplified logical diagram of key communications links. The diagram shows the Robot at the top, a wireless link below that, the Field Computer in the middle, the Degraded Communications Emulator below that, and the Operator Control Station (OCS) at the bottom. Items shown in green will be supplied at the Finals by DARPA.

2.1 Field Computers

The Field Computer is an **optional** computer (or multiple computers) that teams use to process data, for example, streams of images for visual odometry. The Field Computer serves as a surrogate for the vastly improved computers that are expected to be available in the future and that could be built into future disaster response robots. Teams will not be rewarded or punished for using Field Computer(s).

2.1.1 Power for Computers

Teams will have a total out-of-the-wall power budget for computing of 8KW, which will be provided by four (4) twenty (20) Ampere 110V circuits. This budget is shared by any Field Computers and Operator Control Stations. (In addition, DARPA will provide a separate circuit for operating and charging robots.)

DARPA networking systems will not support Power over Ethernet (PoE).

2.1.2 Field Computer Connectors

The Field Computer(s) shall connect via CAT5e Copper Twisted Pair Gigabit Ethernet using RJ45 connectors.

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2.1.3 Field Computer Location and Access

Field Computers will be operated in a dedicated room supplied by DARPA that is remote from the team garages. Teams will have access to this room to service their Field Computers prior to the competition. Field Computers must be installed and tested no later than 5:00pm Thursday 04 June. Teams will normally not be allowed physical access to their Field Computers on Friday 05 June and Saturday 06 June. In the case emergency maintenance on the Field Computer requires physical access, this may only be granted with permission of DARPA and with a DARPA escort. Electronic communications through the network to the Field Computer will be maintained at all times.

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2.2 Cloud Services

The cloud services, connected to the Operator Control Station by a Virtual Private Network (VPN), provided by DARPA, are **optional** and may be used for increased computing power and storage. The data rate to the cloud services will be 50 Mbit/sec in each direction.

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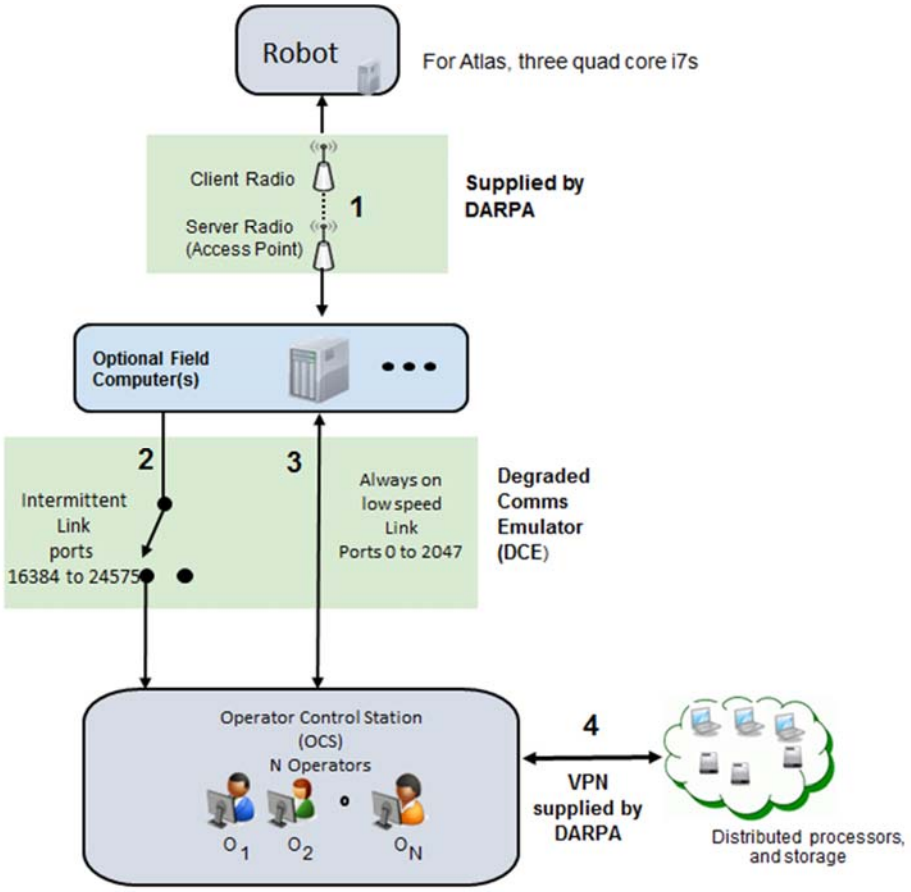

Figure 1. Simplified Logical Communications Diagram. The communications links (as numbered in this figure) are described in the following sections.

3 Wireless Link to Robot

Robots will communicate with their operators bi-directionally over wireless Link 1 in Figure 1, which will be supplied by DARPA. DARPA will have supplied teams that have qualified for the DRC Finals with radios, each with a wired Ethernet interface by March 1, 2015.

DARPA expects the wireless communication link to provide 300 Mbit/sec (Megabits per second) of bandwidth. To maximize throughput, teams should avoid sending small packets and multicast

or broadcast packets, and teams should self-regulate packet rates in both directions. ~~DARPA's radios will discard excess packets.~~

The wireless link will have greater packet loss than a wired connection. Teams should plan for approximately 2-10% packet loss. DARPA will not intentionally degrade the wireless link.

3.1 Wireless Radio Selection

The Netgear R7000 (3x3 MIMO) platform, utilizing DD-WRT software with DARPA specific configurations, will be the radio used for DRC finals. The radios bought and supplied by DARPA are the official radios. Other radios, even those by the same manufacturer and the same model number, are not supported and may not work as intended.

3.2 Antenna Selection

DARPA will provide 3 wireless data radio flexible "rubber duck" antennas on the robot.

These antennas provide an omnidirectional signal, stock RP-SMA connectors for radio antenna leads, acceptable size and weight, and optimal working range.

3.3 Antenna Mounting

Teams are free to mount the radio and antennas on the robot as they see fit, including the possibility of separating the antennas from the radio for better antenna placement.

If a team desires to remove the antennas from the radio DARPA, will provide three (3) three-foot RF cables to accommodate separating the robot radio from the antennas. Routing of the cable will require a minimum bend diameter of at least six (6) inches for all antenna cable changes of direction. Longer cables can likely be accommodated, but DARPA testing will focus on antennas directly connected to the radio and with the antennas connected utilizing the DARPA supplied three-foot RF cables.

When mounting the antennas, teams should consider the following:

- Occlusion
    - During testing, metal obstructions (i.e. a robot's head) between the radio pair will vastly reduce the achievable throughput
    - Participants should consider achieving a clear line of sight to the antennas between an Access Point and client antennas

- Participants can assume a ≥20° upward angle from the robot to the DARPA-supplied Access Point
- The range of motion of their robot

- Antennas dislodged during a run may be repaired but only if the team requests a Reset and incurs the associated penalties.
- Possible impact zones in the event of a fall

3.4 Operating Frequencies

Configuration Type	Setting
Frequency Band	5 GHz
Channel Width	80 MHz
Channel Number (Frequency)	36 (5.180 GHz), 132 (5.660 GHz), 52 (5.260 GHz), 149 (5.745 GHz)

3.5 Radio Configuration

The connection used to establish network connectivity between the client and AP wireless radios is known as a wireless client bridge. The AP radio (fixed site, i.e. located on/near the test course) will be configured in Access Point mode and the client radio (Robot mounted) will be configured for Client Bridge mode. (See Figure 1.)

DARPA will provide one pair of preconfigured radios to each participant (team) for testing at their home location prior to the DRC Finals.

The Access Point used during DRC Finals on the test courses will be installed and configured by DARPA. The Access Point used in the teams "private" garage area for practice will be the one provided by DARPA for the teams' use at their home site prior to arriving at DRC Finals. Teams must use the provided robot mounted client radio for DRC Finals both in the garage and when on the test course.

When a team is active on the DRC Finals course they are required to utilize the DARPA installed Access Point on / near the test course location. As a result, all participants are required to utilize the preconfigured software and configurations. NO participant shall make changes to the DARPA provided configurations. **DARPA is not responsible for incompatible radio pairing due to any unauthorized software or configuration changes made by a participant.**

DARPA reserves the right to reload software and configurations on any radio at any time for any reason.

Prior to ~~a participant moving from the garage area onto~~ competing on the DRC Finals course, DARPA will require a series of network checkouts to confirm connectivity between the operator

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and robot via the DARPA network. ~~More information regarding the network checkout will be provided at a later date.~~ The Operations Book lists the network checkout procedure.

~~DARPA will provide a configuration file with each radio pair along with instructions on how to load the configuration file in the event the radio requires a factory default reset.~~

3.6 Wired-Wireless Connection

DARPA will supply three (3) twenty-foot long RF cables and proper attenuators. These components will allow the wireless radio mounted on the robot and the DARPA-provided wireless Access Point radio (provided to allow testing while at the team's home location) to be "hardwired" together. This hardwiring is done to allow a full system test (minus only the radio antennas) without having to deal with uncontrollable wireless interference.

Teams will be required to use a hardwired approach ~~for full system testing~~ at all times during Finals, except while on the course. ~~in the garage.~~

3.7 Restrictions and Limitations

3.7.1 Throughput Restrictions

DARPA will install throughput limits of 300 Mbit/sec in each direction on data flowing to and from the robot over the wireless link, however teams should self-regulate their aggregate bandwidth to not exceed 300 Mbit/sec. ~~(i.e., data the Robot is transmitting over the wireless link + data the Robot is receiving over the wireless link) ≤ 300 Mbit/sec.)~~ DARPA has no position on what size packets a team chooses to utilize so long as MTU = 1500.

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IP Fragmentation is not supported. If packets, including header data, are larger than 1500 bytes and are fragmented, only the first fragment will successfully traverse the network; all subsequent fragments will be dropped by the Degraded Communications Emulator (DCE).

Teams should assemble their network traffic such that no packets exceed the established Maximum Transmission Unit (MTU) of 1500 bytes in order to prevent IP fragmentation.

3.7.2 Packet Loss

There will be packets dropped due to the inclusion of the wireless link into the network. (No wireless network is as reliable as a wired network.) DARPA suggests that teams be prepared to address packet loss in the 2-10% range, to and from the robot. Antenna placement, high mobility, and other team / robot issues affect both throughput and loss characteristics of wireless networks and are the sole responsibility of the teams. This packet loss is **not** part of the intentional communication outages that DARPA will be imposing during runs.

3.7.3 UDP/TCP

DARPA has no position on UDP versus TCP and the teams are free to utilize either or a combination of both where appropriate. However, all throughput results and all testing was conducted utilizing UDP and DARPA's specifications for throughput only apply to UDP.

3.7.4 Disallowed Technology

Since DRC Finals is leveraging wireless technology as the networking backbone between the operators and the robots via the 5GHz band, we are requiring that no teams activate 5GHz Access Points or any other transmitter/receiver of any kind while at the competition. DARPA will be actively scanning for 5GHz transmitters at the courses and in the garages.

On Thursday 04 June, Friday 05 June, and Saturday 06 June, all wireless communication (including Wi-Fi, cell phones, and Bluetooth), except that provided by DARPA, is prohibited in the team garages. On these days, all Wi-Fi communication is prohibited in the stands and on the courses. The intent is to ensure sequestration of the operators and prevent interference with robot Wi-Fi.

On Thursday 04 June, Friday 05 June, and Saturday 06 June, DARPA will provide ~~wired communications for~~ Internet connectivity in the garages for teams to use in their development. During each team's run time, general Internet access will be disabled, and all ports, except OCS ports, will be disabled on the garage switch for that team. ~~For the teams that are conducting runs, this wired communications will be turned off during the run.~~

While conducting runs at Finals, communications to either the Operator, the Robot, or the Field Computers, must use only the DARPA-provided network infrastructure. Any attempt to circumvent or augment communications using any other methods or technologies is prohibited.

4 Communications between Robot and Operator

4.1 Link Properties

Link 1 in Figure 1 is the wireless link to and from the robot.

The Operator Control Station (OCS) communicates with the Robot (possibly through a Field Computer) through Link 2 and Link 3 in Figure 1 by way of a Degraded Communications Emulator (DCE). The DCE will emulate signal loss that might occur due to poor RF signal penetration through walls.

Link 2 is unidirectional and carries data from the robot to the OCS. Data on this link will use ports 16384 to 24575. Because it is unidirectional, Link 2 cannot be used for TCP.

Link 2 will operate in two modes: while the robot is attempting Tasks 1, 2, 3, ~~9,~~ and 8, Link 2 will support about 300 Mbit/sec of data. Link 2 will have minimal latency to the OCS. At all other times, Link 2 will provide one second bursts of data at approximately 300 Mbit/sec, interspersed with blackouts of varying lengths. The length of the blackouts will be between 1 and 30 seconds. Due to the small buffer size used on the DCE, large, unregulated bursts of packets may also experience loss, even if the average rate of the data offered falls within the 300Mbit/sec maximum.

Figure 1 shows the signal-loss emulator as a Single Pole, Single Throw (SPST) switch. When the switch is open, no data flows and there is a blackout. When the switch is closed a one second burst of data is transmitted at 300 Mbit/sec.

At the start of a run no blackouts will last more than 30 seconds. The average length of blackouts will decrease during the course of a run. At about 45 minutes into a run, blackouts will no longer occur.

Packets held by the DCE at the start of a blackout will be discarded; packets received by the DCE during blackout will be discarded.

The blackout schedule for a given day will be made available to teams the previous day. The same schedule will be used on all courses and for all runs through a given day. The schedule may change from day to day.

Link 3 is an always-on bidirectional link between the OCS and the robot. Link 3 will have a constant data rate of 9600 bit/sec and will support TCP and UDP. Link 3 will also carry bidirectional traffic for Internet Control Message Protocol (ICMP) which will have a throughput of 1024 ~~4800~~ bit~~s~~/sec. Data on this link will use ports 0 to 2047. ~~Link 3 will be the default route.~~

Link 4 is a DARPA provided Virtual Private Network (VPN) connection to optional cloud computing resources available to teams. The link supports 50 Mbit/sec data rates in each direction.

Figure 2 is a plot of an example of a comms blackout schedule. The vertical axis is the length of a blackout in seconds. The horizontal axis is the elapsed time in a run.

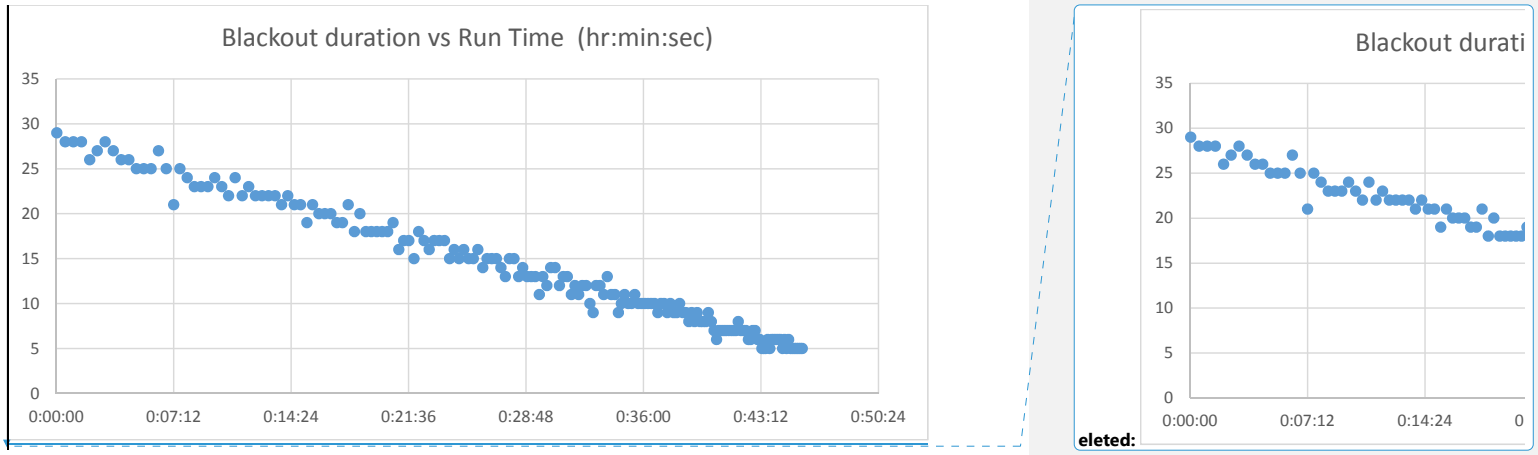

Figure 2. Example of blackout duration during the course of a run.

Figure 2 shows an example of a sequence of data bursts during a run. In this example, after about 45 minutes into a run, there are no more blackouts.

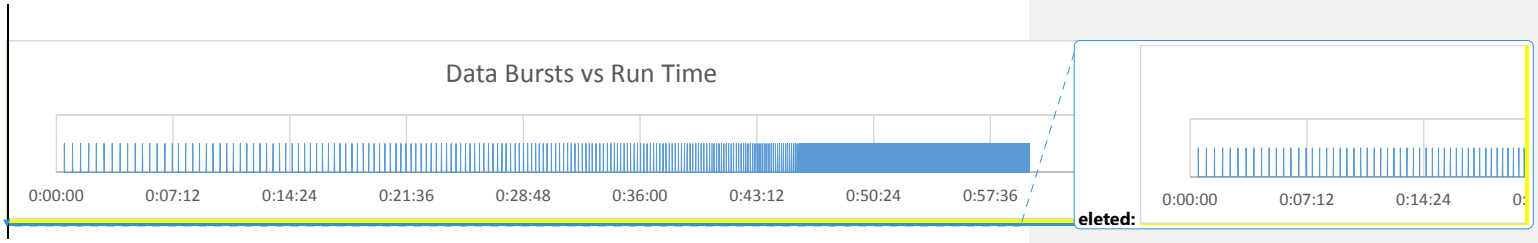

Figure 3. Example of 1 second data bursts. The horizontal axis is elapsed time.

4.2 IP Version, IP addresses, Subnets, Ports, and Packet Size

Teams will use IPv4 for all communications using the DARPA infrastructure. IPv6 will not be supported.

Teams will use the following convention for IP addresses: Each team will be assigned an identification number, N, between 1 and 30. Team N is assigned 10.N.y.x as its subnets for the entire competition.

10.N.1.x is the subnet that team N will use for its Internet Access Only Computers. These are any systems not related to the operation of the Robot, Field computer(s), or Operator Control Station(s). DHCP will be available for Internet Access Only Computers.

10.N.2.x is the subnet that team N will use for its Operator Control Station computer(s). All IPs must be statically assigned, within the following range: 10.N.2.10 – 10.N.2.199.

10.N.3.x is the subnet that team N will use for its Robot computer(s) and Field computer(s). All IPs must be statically assigned, within the following range: 10.N.3.10 – 10.N.3.199.

Ports 1-2047 will specify that Link 3 (Bidirectional ~~2000~~ 9600 bit/sec) will be used for a particular message.

Ports 16384 - 24575 will specify that Link 2 (Unidirectional 300 Mbit/sec) will be used for a particular message.

The IP address settings need to show the IP Prefix lengths which will be /24.

At the DRC Finals, teams will use the subnet mask 255.255.255.0 and 10.N.x.1 default gateway. For testing radios in the absence of the event routing infrastructure, teams may change the subnet mask for their systems to 255.0.0.0 to allow for direct, non-routed, communications.

~~Do not use the address .1 in any of these subnets as that will be the IP of the subnet router.~~

4.3 Physical Connections

~~Physical connections between any field computers, the OCS, and the DARPA network will be made by male RJ45 cables supplied by DARPA~~

Teams will be required to provide all Ethernet wires necessary to make any wired connections between computers and the DARPA provided network switch in the garage, as well as to their Field Computer(s). Additionally, the use of additional non-DARPA provided network switches is prohibited. DARPA will inspect each team's network wiring before the competition.

When the robot is in the garage it also can be connected to the DARPA network with a male RJ45 cable.

Teams are encouraged to make use of the DARPA network as soon as possible upon arrival to assure that any networking problems are resolved quickly.

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5 Wired Connectors

In the unlikely event of a wireless communications failure in the DARPA infrastructure, DARPA requires that teams be prepared to use wired comms connections between robots and Field Computers (if present) or Operator Control Stations (if there is no Field Computer). DARPA will supply the cable~~s~~, but teams must supply a single female RJ45 connector~~s~~ mounted on their robots. Since there may be significant tension on such cables, teams should provide strain relief mechanisms to reduce the chance of damage to their RJ45 connectors.

6 Communications for Emergency Stops

By March 1, 2015, DARPA will supply a wireless emergency-stop system to teams that have qualified for the DRC Finals. The e-Stop is supplied by HRI; see appendices A and B. Teams must use this e-stop during Finals.

Teams must integrate this system on their robots and demonstrate its functionality before they may compete in the DRC Finals.

7 Simple Example

As a hypothetical example, assume that Team 5 wants to send a command to their robot to move its arm. Team 5 wants to receive a simple command of “success on complete” back to the OCS from the Field Computer. It also wants to receive a video from one of the cameras while the arm is in motion.

Team 5 is assigned 10.5.x.x as its team's subnets for the entire competition.

10.5.1.x is the subnet that Team 5 will use for its Internet Access Only computer / computers.
10.5.2.x is the subnet that Team 5 will use for its OCS computer / computers.
10.5.3.x is the subnet that Team 5 will use for its Robot computer / computers and Field computer / computers.

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Let’s say in order to get the robots arm to move, some processing must be done on the field computer.

Let’s also say in order to get the robot’s arm to move, the OCS needs to send a command to the Field Computer to start the processing.

Step 1: Team 5 sends a command on port 23 from the OCS (10.5.2.12) to the Field Computer (10.5.3.32)
- Since this port is in the low bandwidth range (0-2047), it will use Link 3 in order to get to the Field Computer.

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Step 2: After processing the commands, the Field Computer would then send the commands needed to the Robot (10.5.3.54)

Step 3: Robot completes the arm motion. During this time, the robot is capturing video that it is trying to send back to the OCS.
- In order to receive quality video, it would want to use Link 2 to retrieve the video.
-To accomplish this, the robot would need to use a higher port number somewhere in the range of (16384-24575) so that traffic is sent correctly back to the OCS if Link 2 is turned on.
- If the robot is 'inside' (see Rules of DRC Finals, section 6 for definition of inside vs outside) the video may not arrive due to Link 2 being turned off.

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Step 4: Robot sends completion notice back to OCS.
- This could be accomplished by sending over a smaller port such as telnet (port 23)
- This will guarantee arrival due the traffic flowing back over Link 3 to the OCS at the slower data rate.

Scoring Guide for the DRC Finals

April 9, 2015. DISTAR Case 24388

Deleted: March 25

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Revision History

This section captures major changes to this document.

Date	Section	Description
4/9/2015	Document	Created

Deleted: 3/25

Introduction

This document describes the approach to scoring the tasks performed at the DRC Finals.

Task 1. Drive

Completion Criteria

- All four (4) wheels of the vehicle cross the finish line

Notes

- If the robot walks instead of drives, crossing the finish line does not constitute completion

Task 2. Egress

Completion Criteria

- All points of robot contact are on the ground, and no point of robot contact is on the vehicle

Notes

- If the robot walks instead of drives, touching the ground does not constitute completion

Task 3. Door

Completion Criteria

- All points of ground contact lay on the “indoor” side of the door threshold

Notes

- The location of robot parts that are not touching the ground do not affect the completion criteria. For example, if the robot arm and hand are “outside” the door but all points of ground contact are “inside” the door, then the task is considered complete.
- No points are awarded if the robot goes the wrong way, that is, if the robot starts “inside” and goes through the door to the “outside” (may not be possible depending on exact layout)
- Upon completion of this task, communications switch from “outside” mode to “inside” mode

Task 4. Valve

Completion Criteria

- The valve has been rotated to the “open” position

Notes

- Opening the valve will trigger an audio-visual indicator

Task 5. Wall

Completion Criteria

- An opening has been cut in the wall that entirely removes the circle drawn on the wall

Notes

- The robot must not cut any part of the wall marked as “No Touch” (if any)

Task 6. Rubble

Completion Criteria

- All points of ground contact lay on the “stair” side of the rubble finish line

Notes

- The robot may choose to move the debris out of its path or cross over the debris
- No part of the robot may contact the ground off the rubble course

Task 7. Surprise

Completion Criteria

- To be announced

Notes

- To be announced

Task 8. Stairs

Completion Criteria

- All points of ground contact lay on the landing

Notes

- Parts of the robot may be in contact with railings -- these are not ground contacts