

University Rover Challenge 2018 – Requirements and Guidelines

Any issues not covered by these published rule sets will be addressed on a case-by-case basis by the University Rover Challenge (URC) Director. Please consult the Questions and Answers (Q&A) portion of the URC web site (<http://urc.marssociety.org>) for updates. All matters addressed in the Q&A are applicable to the requirements and guidelines.

1. Competition Overview

- 1.a. The 2018 University Rover Challenge will be held May 31 – June 2, 2018 at the Mars Society's Mars Desert Research Station (MDRS) near Hanksville, Utah. The competition is open to both graduate and undergraduate students, although teams are permitted to include secondary (high school) students. Students must be enrolled at least half-time in a degree or high school diploma granting course. Students from multiple universities may compete on the same team. A single university may field multiple rovers and multiple teams, however there may be no overlap between team members and leaders, budget, donated equipment, or purchased equipment.
- 1.b. Teams are encouraged to work with advisors. However, advisors are expected to limit their involvement to academic level advising only. It is incumbent upon the student team leaders to ensure that their respective teams uphold the integrity of this competition. Nontechnical team management duties, including tracking finances, registration, submission of deliverables, and communication with URC staff, fall within the duties of the students.
- 1.c. The rover shall be a stand-alone, off-the-grid, mobile platform. Tethered power and communications are not allowed, except as noted in Section 2.c of the rules.
 - 1.c.i. A single connected platform must leave the designated start gate and return to this location (except when otherwise indicated). In the open field, the primary platform may deploy any number of smaller sub-platforms, so long as the combined master/slave sub-platforms meet all additional requirements published.
 - 1.c.ii. Due to increased FAA (United States Federal Aviation Authority) restrictions, no airborne vehicles will be allowed at URC2018.
- 1.d. Teams will operate their rovers from designated command and control stations. These stations will be metal trailer units (such as the back of a small moving truck provided by URC) or structures at the Mars Desert Research Station. Visibility of the course to the operators in the control station will be blocked. Basic power (120V, 60Hz), tables, and chairs will be provided. All of the competition events will be held in full daylight.
- 1.e. There is no restriction on the number of team members or operators allowed. All operators must remain in the designated operators' area. Nobody may follow alongside the rover for the purpose of providing feedback to the operators. Members of the judging team, media, and non-operator team members may follow a rover at the judges' discretion. Team members following the rover may participate as runners in accordance with Section 2.f, or activate an emergency kill switch (in the event of an emergency), but may not otherwise participate in that task.
- 1.f. The MDRS field site is located in the desert of southern Utah. As such, the site will have a full spectrum of sloped terrain from flat to vertical. Teams should be prepared for any ground conditions that would appear at MDRS. The GPS standard shall be the WGS 84 datum. Coordinates will be provided in latitude/longitude format (decimal degrees). The rover shall also be capable of withstanding such an environment in the early summer, including airborne dust and temperatures that can easily reach 100°F. Rovers shall be able to withstand light rain but will not be expected to compete in heavy rain or thunderstorms.

- 1.g. There should be radio communication line-of-sight from the command station to the rover for the Science Cache and Equipment Servicing Tasks. For the other tasks, line of sight communication is not guaranteed for more than 50% of the courses. Rovers are not expected to travel more than 1 km at most from the command station.
- 1.h. Testing at or near MDRS before, during, and after URC is subject to the following restrictions: URC does not have the appropriate permits for off-road activities on Bureau of Land Management (BLM) controlled lands, and only has permission to use the two State Trust Land areas outlined (in the blue boxes) on the MDRS BLM map: <http://urc.marssociety.org/files/CowDungRdMap.pdf>. All land managed by the Bureau of Land Management (BLM) may NOT be used at any point. Please ask URC staff if you are uncertain where these boundaries are. Additional details regarding testing on MDRS-leased land (highlighted on the above map) will be published closer to the competition. Unless specifically authorized by the URC Director or the MDRS Director, teams shall not scout or test on MDRS-leased land. During URC no scouting or testing on the courses is allowed. If asked to leave an area by URC staff or other officials, please do so.
- 1.i. Registration, Milestone Reviews and Down-Selections
Prospective teams will undergo a review and down-selection process, meaning that only teams who pass each milestone will be invited to compete in the field. Specific details for each deadline (including deliverable format, submission requirements, and judges' expectations) will be posted to the URC web site (<http://urc.marssociety.org>). Judges may respond to teams with follow-up questions or requests for clarification at any of these milestones.
 - 1.i.i. Declaration of Intent to Compete
Teams are required to register and declare their intent to compete no later than Friday, November 3, 2017. No significant deliverables are required for this deadline, aside from team details requested via the URC web site.
 - 1.i.ii. Preliminary Design Review
Teams are required to submit a Preliminary Design Review (PDR) document no later than Friday, December 1, 2017. The PDR document is expected to focus on the team structure, resources, and project management plan, including a Gantt chart, initial budget, fund-raising plans, recruiting and educational outreach. Technical details regarding the rover are highly encouraged but are not the main focus. Judges will be assessing each team's overall level of readiness to compete in the URC competition. Teams will be assessed on their own merits, not against other teams. PDRs may be submitted as early as November 6, 2017, and will be reviewed by judges on a rolling basis.
 - 1.i.iii. System Acceptance Review
Teams are required to submit a System Acceptance Review (SAR) Package no later than Friday, March 2, 2018. The SAR Package will focus on the overall system design, science plan, and progress to-date of the final system. The SAR Package will consist of both written and video components. The SAR is a competitive milestone and packages will be judged against other teams' submissions by the judges. Only teams who pass the SAR milestone will be invited to compete in the field.
- 1.j. Teams shall be required to track all finances as related to this project, and submit a final expense record no later than May 21, 2018 (if necessary, teams may submit an updated record – hard or soft copy – on the first day of the URC event – May 31, 2018). Teams shall be penalized 10% of total points per day if they are late in submitting the expense report, and will be disqualified for not submitting their expense report by the end of the URC event (June 2, 2018).

- 1.j.i. The maximum allowable cash budget to be spent on the project is **\$17,500 US**, which shall include money components for the rover, rover modules, rover power sources, rover communications equipment, and base station equipment including the antenna and transceiver, and all command and control equipment (i.e. base station computers, monitors, controllers, etc.). The budget limit shall not apply to tools, travel expenses, or volunteer labor. Volunteer labor applies to any work done helping out with menial labor and should not make a significant contribution to the rover.
- 1.j.ii. Spare parts that are replaced one-for-one in the case of damage to the original are not counted against budget or mass limits.
- 1.j.iii. Corporate sponsorship is encouraged. Teams may acquire donations of equipment and services. However, such donations will count towards the cash budget, except for specific exemptions granted by the URC Director for donations made available to all URC teams.
- 1.j.iv. Teams may be required to submit receipts as proof of budget upon request (donations must be documented by the donor). For donated equipment or services teams may use the cheapest rate commercially available for the same equipment or service. Shipping and taxes should be included in the cost since these are a standard part of the cost of any item.
- 1.j.v. If used equipment is purchased commercially the as-bought price may be used. If used equipment is donated to the team and no used market exists for a component then the cost of a new component must be used.
- 1.j.vi. Non-US teams have an allowable budget equivalent to \$17,500 US based on the most advantageous documented currency conversion rate between August 1, 2017 and May 31, 2018.

2. Rover Guidelines

- 2.a. Rovers shall utilize power and propulsion systems that are applicable to operations on Mars. Air-breathing systems (such as internal combustion engines and certain fuel cells) are permissible, but must be implemented as fixed-supply systems. No power or propulsion system may ingest ambient air for the purpose of combustion or other chemical reaction that yields energy. Teams implementing such systems are required to understand and follow all applicable safety regulations at their university. Teams are required to document their adherence with these safety regulations during the design phase, and submit this documentation to the URC Director prior to implementation. The URC Director further reserves the right to ban any system deemed unsafe from competition.
- 2.b. The maximum allowable mass of the rover when deployed for any competition task is 50 kg. The total mass of all fielded rover parts for all events is 70 kg. For example, a modular rover may have a robotic arm and a sensor that are never on the rover at the same time. The combinations of rover plus arm and rover plus sensor must each be under 50 kg, but the total rover plus arm plus sensor must be less than 70 kg. The weight limits do not include any spares or tools used to prepare or maintain the rover, but does include any items deployed by the rover such as sub-rovers, cameras, relays. Rover wheelbase width or length may not exceed 2m.
 - 2.b.i. For each event in which the rover is overweight, the team shall be assessed a penalty of 5% of the points scored, per kilogram over 50.
 - 2.b.ii. Rovers over 70 kg in any given configuration must be cleared with the URC Director by email prior to April 27, 2018 to be eligible to compete.
 - 2.b.iii. If a gas-consuming engine is used, the rover shall weigh-in with all tanks full.
- 2.c. The rover is only required to be autonomous for the Autonomous Traversal Task. In the other tasks autonomy is not required, although some level of autonomy may be beneficial, such as the

ability to backtrack to the last good communications location. Besides the Autonomous Traversal Task, the rover shall be operated remotely by a team which will not be able to view the rover on the site or the site itself directly, and line-of-sight communications are not guaranteed for all of the tasks. The rover may be commanded by the team using a wireless link, with information needed for guiding the rover acquired by the rover's own on-board systems and transmitted to the team wirelessly. There shall be no time delay in communications, as the URC is based on the assumption that the rovers in question are telerobots, being operated by astronauts on or orbiting Mars. Refer to rule 2.f regarding the impacts of a loss of communications. **Teams may use tethered communications instead of wireless, but will be penalized 50% of the points earned during that task. When operating in tethered mode, teams cannot progress beyond the first stage of any staged task.**

- 2.d. Wireless communication methods used by teams shall adhere to all applicable FCC (United States Federal Communications Commission) standards and regulations. The 900 MHz and 2.4 GHz bands are further regulated in their use at URC as described in section 2.e. Other bands are not further regulated. Teams may utilize multiple bands at the same time. Teams must submit details regarding any wireless communication devices being implemented and operator licenses (when applicable) to the URC Director no later than Friday, April 27, 2018. Team members are permitted to obtain and utilize any relevant licenses, and must document the license, applicable regulations, and devices as part of the communications documentation deadline. Teams must notify the URC Director immediately of any changes after this date. Teams may be required to power down communications equipment at the event sites while not competing, so as not to interfere with other teams.
- 2.d.i. Internet is not available in the field or at MDRS, but is available at nearby businesses in Hanksville.
- 2.d.ii. Both omnidirectional and directional antennae are allowed, but communications equipment must not rely on the team's ability to watch and track the rover first hand. Steered directional antennae may use a mechanized antenna mounted outside that is controlled via an electronic signal from the command station or operates autonomously. Signal strength, relayed GPS, or other strategies may be used to give feedback on antenna direction, but it is not allowed to mount a camera on top of the antenna for visual feedback. However a camera may be deployed by the rover in the field.
- 2.d.iii. Antenna height is limited to 3m, and shall adhere to all applicable regulations. Any antennae must be documented as part of the communications documentation submitted by April 27, 2018. Antenna bases must be located within 5 meters of the team's command station, and any ropes or wires used for stability purposes only may be anchored within 10 meters of the command station. The exception to this is the use of structures at the MDRS where allowable antennae locations will be given by the judge and may be located up to 20m away from the Hab to avoid underground pipe and cables, and other structures which may block radio signals. **All teams should bring at least 25m of antenna cable** to deal with this scenario.
- 2.d.iv. Lighter-than-air devices are not allowed for communications at URC.
- 2.e. Teams must notify the organizers of the communications standards they will be using, including frequency bands and channels, by April 27, 2018. **The URC restrictions on the 900 MHz and 2.4GHz bands are as follows:**
- 2.e.i. 900 MHz frequency band (902-928 MHz): Teams shall not use frequency bandwidths greater than 8 MHz. **Teams must also be able to operate exclusively within each of the following three sub-bands: "900-Low" (902-910 MHz), "900-Mid" (911-919 MHz), and "900-High" (920-928 MHz). The competition schedule will notify teams which**

- sub-band may be used for each task, and teams must be able to shift to another sub-band as required.** There is no limit on the number of 900 MHz channels a team uses, so long as they are all within the designated sub-band.
- 2.e.ii. **2.4 GHz frequency band (2.400-2.4835 GHz): Teams shall use center frequencies that correspond to channels 1-11 of the IEEE (Institute of Electrical and Electronics Engineers) 802.11 standard for 2.4 GHz.** Teams shall not use frequency bandwidths greater than 22 MHz. **The competition schedule will notify teams which channels may be used for each task, and teams must be able to shift to other channels as required. Teams shall be limited to using no more than three channels in the 2.4 GHz band.**
 - 2.e.iii. Teams may use spread spectrum or narrowband (fixed channel allocation) within the sub-band limits as they fit.
 - 2.e.iv. There will be spectrum monitoring on-site to ensure that teams are not interfering with channels outside those allotted. Teams should anticipate being within signal range of other teams operating on different 900 MHz sub-bands and different 2.4GHz channels and be able to operate their rover under these conditions. Teams must also be able to deconflict communications as specified above (the URC Director will mediate as necessary). Beyond this requirement a 0.5 km minimum separation between competition areas will be guaranteed, which will include large terrain barriers, and event scheduling will avoid communication interference to the greatest extent possible.
 - 2.e.v. Teams are allowed to operate in bands outside of 900 MHz and 2.4 GHz, but should implement spread spectrum, automatic channel switching, frequency hopping, or other interference-tolerant protocols. **In the event of interference outside of 900 MHz and 2.4 GHz, teams will not be granted additional time or special considerations.**
- 2.f. If a rover suffers a critical problem during a task that requires direct team intervention (including a loss of communication that requires the team to move the rover to reestablish communications), that intervention shall be subject to the following:
- 2.f.i. **A request for an intervention can only come from the team members operating the rover, not any team members spectating in the field.** They may designate any number of team members who may go to repair or retrieve the rover (hereafter referred to as “runners”). Spectating team members may be asked to act as runners, and also rover operators may leave the command station and become runners.
 - 2.f.ii. **If a spectating team member intervenes with the rover without request from the operators, it counts as an emergency stop.** This is allowed such as to rescue the rover to prevent a fall or a fire. The current task will be considered terminated although the rover may compete in other subsequent tasks.
 - 2.f.iii. If a team member leaves the command station to become a runner they will not be permitted to return to the command station to participate in operating the rover, or analysis of any data, after this point for the current task. Runners will still be permitted to retrieve or repair the rover in future interventions.
 - 2.f.iv. Runners may fix the rover in the field without moving it, return the rover to the command station, or return the rover to the start of that obstacle/task as defined by the judge in the field. However, the judge may require the rover to be moved for the safety of the team members or preservation of the course.
 - 2.f.v. If the rover is returned to the command station runners and spectators shall not communicate any details about the task site to the team members operating the rover (judges will monitor conversation), however all team members are permitted to take part in the diagnostic and repair process.
 - 2.f.vi. Spectating team members may carry tools and the command station may radio out to them to request an intervention.

- 2.f.vii. Teams will be penalized 20% of the total points in that task for every intervention. The task clock will continue to run during an intervention. Multiple intervention penalties in a single task are additive: e.g. two interventions would result in a score of 60% of points earned, not $0.8 \times 0.8 = 64\%$.
- 2.g. All rovers shall have a “kill switch” that is readily visible and accessible on the exterior of the rover. This switch shall immediately stop the rover’s movement in the case of emergency. Teams are encouraged to configure their rover such that the kill switch immediately ceases power draw from batteries in the event of a dangerous exothermal runaway event.

3. Competition Tasks

- 3.a. The rover shall be judged in the four competition tasks outlined below in 3.b to 3.e. and also on the System Acceptance Review Package.
- 3.a.i. For the four competition events, the rover is not required to be in the same configuration so modular pieces can be swapped between tasks. On days that teams compete in the Science Cache and Extreme Retrieval and Delivery Tasks, teams will only compete in one Task. Teams will begin on the Autonomous Traversal Task 10 minutes after the completion of the Equipment Servicing Task, operating from the same control station on an adjacent course. The rover will otherwise be accessible throughout the competition and modifications can be made at any point.
- 3.a.ii. Each event and the SAR shall be worth 100 points, for a total of 500 points. Penalties for overweight rovers, interventions, and other penalties are additive: e.g. penalties of 10% and 20% would result in a score of 70% of the points earned, not $0.9 \times 0.8 = 72\%$. Tasks are scored independently and it is not possible to score less than zero on a task.
- 3.a.iii. From the time teams are given access to their command station, they shall be able to set up all necessary systems, including all communications systems, and be ready to compete in no more than 15 minutes for all tasks except the Extreme Retrieval and Delivery Task where 20 minutes will be allowed. Teams shall be able to fully disassemble all equipment in no more than 10 minutes at the end of the event, and may be asked to switch off radio equipment immediately.
- 3.b. Science Cache Task:
The goal is to collect samples at sites selected in the field, perform basic science evaluation of these samples with onboard instrumentation, and store at least one sample in a cache for further scientific analysis. A single or multiple sites can be sampled. Sites shall be analyzed for their likelihood to support microbial life using the geological context such as evidence of water flow, minerals present and soil structure in addition to the data obtained from the on-board instrumentation.
- 3.b.i. Teams shall submit a written science plan by May 11, 2018, which will be factored into the judges’ evaluation for the Science Cache Task. Specifications for the plan will be posted to the URC website.
- 3.b.ii. Teams will be given a field briefing by judges to discuss the tasks at the science site. Through the information relayed by the rover, teams shall then select sites of potential biological interest within a 0.5 km radius of the command station.
- 3.b.iii. Teams shall document each site investigated by:
- A wide-angle panorama showing the full context of the site. The panorama must indicate cardinal directions, and have some indication of scale;
 - A close up, well focused, high-resolution picture with some indication of scale (scale can be indicated post-capture) at the sampling site;

- Teams will be required to take a stratigraphic profile using the on-board cameras to determine the depositional environment and history of water in the sedimentary structures;
 - GPS coordinates of each site, to include elevation and accuracy range. Thorough documentation is especially crucial for the sample that is returned onboard the rover.
- 3.b.iv. Based upon investigation of the selected sites, teams shall then collect a sub-surface sample from a depth of 10 cm or deeper. Sample(s) must be at least 5 g and may consist of a single rock, loose soil, or anything in between. Sample(s) may return the full depth including the topsoil but teams must be able to distinguish the soil depth for any sample. The portion of the sample from below 10 cm will be used to determine the sample mass.
- 3.b.v. After collection of the sample, the rover must then store and seal it in a cache container onboard the rover, and return the sealed cache to the command station.
- 3.b.vi. **Onboard equipment at a minimum should include a science capability of the team's choice, and also test the soil moisture (relative humidity) and subsurface temperature at least 10 cm below the surface.** Additional sensors, subsystems, and test procedures are left to the discretion of the teams to meet the science-driven objectives of this task.
- 3.b.vii. Any chemicals used onboard, including water and any reaction products, must follow a no-spill policy of being contained on the rover and not spilt on the ground. Use of hazardous chemicals must be pre-approved prior to competition by submitting a plan of transportation, usage, safety precautions, and accident plan. Teams should consider that URC takes place in a remote desert location with very limited water supplies and no quick access to emergency medical care.
- 3.b.viii. Teams will be given between 20 and 30 minutes to collect data and the sample with the rover. Teams may investigate as many sites as time allows.
- 3.b.ix. After return of the rover to the command station, teams shall remove the cached sample from the rover, while minimizing any possibility of contamination. Teams will have the opportunity to use these samples for subsequent laboratory analysis at a later time in the competition.
- 3.b.x. At a later time the cache will be returned to the teams and they will be given 15-30 minutes for analysis and preparation of data for a 10 minute discussion with the judges. **The lab analysis portion shall include at least one life detection method (i.e. biological assay) of the team's choosing.** The lab science analysis and discussion with the judges is allowed even if the team was unsuccessful in obtaining samples with their rover. The discussion should include:
- The stratigraphic profile and evidence of water in the profile;
 - Results of on-board rover and laboratory tests performed;
 - Method used to ensure sample was collected at least 10 cm below the surface and transferred to the judges without contamination;
 - Reasoning for sample site selection and documentation of each site;
 - Meaning of data collected with respect to the habitability potential, the geology of the site (past and present) and implications of the site being suitable for life;
 - Scientific knowledge of Mars based on responses to judges' questions.
- 3.b.xi. The score for this task will be based on the following components:
- Thoroughness of the investigation of sites (panoramas, site selection, stratigraphic profile);
 - Quality and applicability of the onboard and laboratory analysis (moisture, temperature, science capability of choice, laboratory analysis);
 - Quality of the sample returned (weight, depth, possible contamination);
 - Scientific knowledge of astrobiology.

3.c. Extreme Retrieval and Delivery Task:

This will be a staged task in which rovers shall be required to pick up and deliver objects in the field, and deliver assistance to astronauts, all while traversing a wide variety of terrain. Teams will be given a fixed amount of time for each stage. Each stage will include multiple objectives as described below, and teams must complete each component of a stage within the allotted time in order to proceed to the next stage. Failure to complete a stage will result in the end of the task. Teams will NOT be allowed to survey the course ahead of time.

- 3.c.i. Terrain may include soft sandy areas, rough stony areas, rock and boulder fields, vertical drops potentially in excess of 1 m, and steep slopes in excess of 45°. There is no limit placed on the steepness of slopes or size of drops or boulders that may be encountered. Terrain may include routes indicated by visual markers. Terrain will range from very easy and close to the starting line, to exceedingly difficult obstacles at greater distances also involving navigation challenges. Portions of this task, particularly in later stages, will be intentionally placed beyond direct line-of-sight of the control station antenna.
- 3.c.ii. Rovers will be required to complete a set of objectives not more than 1 km from the start gate. In some areas a set path may be defined. All paths will be at least 2 m wide. Teams will be given approximate GPS coordinates of the object retrieval and delivery locations and any required waypoints.
- 3.c.iii. Objects to be retrieved in the field will consist of small lightweight hand tools (e.g. screwdriver, hammer, wrench), supply containers (e.g. toolbox, gasoline can), or rocks up to 5 kg in mass. All items will have graspable features (such as a handle) no greater than 5 cm in diameter. The maximum dimensions shall be no larger than 40 cm x 40 cm x 40 cm, but teams should expect a variety of sizes and weights. Rovers may pick up multiple items at a time, but are not required to do so.
- 3.c.iv. Objects shall be picked up in the field and delivered to designated locations, which may include markers or astronauts identifiable by simulated space suits. Approximate GPS coordinates will be provided for each pickup/delivery location, although accuracy may vary. In certain cases, specific instructions will be provided for each object in advance, and in other cases, the object to be delivered will be indicated at the delivery location (e.g. on a small sign held by the astronaut).
- 3.c.v. Teams must successfully complete the objectives of a stage in order to advance to the next stage. Any time remaining at the completion of a stage is added to the allotted time of the subsequent stage, which begins immediately. A more complete description of the stages, specific objectives within them, and requirements for passing to the next stage will be given to the teams at a later date before the competition.
- 3.c.vi. Certain objectives of this task may require field science proficiency in order to complete. This can include picking a specified type of rock from an assortment for the pickup / delivery.
- 3.c.vii. Teams will be scored on their ability to pick up and deliver the correct objects to the correct locations, and how close the object is placed to the objective within the allotted time. Points will be awarded for partial completion, and will be deducted for failure to stay within marked routes.
- 3.c.viii. This task will allow 20 minutes for set-up time and time on course will be no greater than 70 minutes. Teams do not need to return to the start line as part of the task, but are expected to leave the field immediately after their time on course is over in consideration of the next contestants.

3.d. Equipment Servicing Task:

Rovers shall be required to perform several dexterous operations on a mock-up equipment system.

The rover shall have to travel up to 0.25 km across relatively flat terrain (minimal slope) to reach the equipment. The equipment servicing task will involve delivering a cached science sample to a lander and performing maintenance on the lander. It will include but not be limited to some subset of the following sub-tasks:

- Pick up the cache container and transport to the lander rocket. Cache will have a handle at least 10cm long and not more than 5cm in diameter. Cache will weigh less than 3 kg. The equipment servicing cache will be provided and may be partially buried;
- Open a drawer on the lander. Insert cache into a close-fitting space in the drawer, and close the drawer;
- Undo a latch on a hinged panel of the lander and open panel;
- Type commands on a keyboard and follow directions on computer display;
- Push buttons, flip switches, turn knobs;
- Turn a hand crank;
- Replace an electronics board using a rugged board-to-board connector such as a multi-pin power molex connector;
- Picking up and using a screwdriver or wrench.

3.d.i. Teams will receive points for every sub-task completed successfully. Teams will have between 20 and 45 min to complete the task.

3.e. Autonomous Traversal Task:

Rovers shall be required to autonomously traverse between markers in this staged task across moderately difficult terrain. Teams will be given a fixed amount of time for a given stage. Each stage will have one or more legs as described below, and teams must complete each leg of a stage within the allotted time in order to proceed to the next stage. Failure to complete a stage will result in the end of the task.

3.e.i. Teams will begin on this task 10 minutes after the completion of the Equipment Servicing Task, operating from the same control station on an adjacent course.

3.e.ii. A leg is defined as the rover autonomously traversing from a start marker to a finish marker. Markers will be a standard tennis ball elevated 10 – 50 cm off the ground and GPS coordinates close to the markers will be provided. The finish marker of one leg may be used as the start marker of a subsequent leg.

3.e.iii. Stages will increase in difficulty and may or may not include legs of the following levels of difficulty:

- Level 1: Teleoperated scouting of the route will be allowed between markers which will be very close to the GPS coordinates provided.
- Level 2: Marker will not be very close to the GPS coordinates requiring a search for the marker once the GPS coordinates have been reached.
- Level 3: Teleoperated scouting is not allowed. Purely autonomous navigation to the GPS coordinates and an autonomous search around the GPS coordinates to find the marker will be required.
- Level 4: No teleoperation allowed and significant obstacles may lay between the markers requiring pre-planning or autonomous route finding. Approximate bearing and distance to the next marker may be provided, instead of GPS coordinates.

3.e.iv. To complete a leg, teams must start with their rover within 2 m of the designated start marker. Before proceeding, teams must formally announce to judges that they are entering autonomous mode. In autonomous mode team members may monitor video and telemetry information sent from the rover, but may not transmit any commands that would be considered teleoperation.

3.e.v. The rover shall autonomously navigate from the start marker to the finish marker. **The rover's on-board systems are required to decide when it has reached the finish**

marker, and transmit a message back to operators that is displayed for the judge to observe. It must also provide a visual signal on the rover that can be observed by a judge following the rover. A 2 m radius from the marker to the closest point on the rover will be considered successful.

- 3.e.vi. In stages where teleoperation is allowed, operators may abort autonomous operation and revert to teleoperation at any time, but the time will continue to run and teams shall be required to resume that leg in autonomous mode from the start marker. Interventions that require the physical intervention of runners are still penalized as in rule 2.f. In legs where teleoperation is not allowed, operators may only abort autonomous operations and request the physical intervention of runners, which is still penalized as in rule 2.f.
- 3.e.vii. Teams may resume teleoperation mode when the rover indicates it is at a marker and conduct any operations prior to attempting the subsequent leg but competition time will not stop. In stages where teleoperation is not allowed teleoperation at a marker shall not include driving of the rover, but programming of the next leg is allowed.
- 3.e.viii. Teams must successfully complete each leg of a stage in order to advance to the next stage. Any time remaining at the completion of a stage is added to the allotted time of the subsequent stage, which begins immediately.
- 3.e.ix. It is anticipated that there will be a total of four stages in this task at increasing levels of difficulty, however judges may revise this number for the final schedule. Total time on course will be no greater than 60 minutes, and the cumulative distance of all legs shall be no greater than 2000 m.