

University Rover Challenge 2021 – Requirements and Guidelines

The Mars Society's University Rover Challenge challenges students to build remotely operated rovers that can accomplish a variety of tasks that might one day assist astronauts working on the surface of Mars. Rovers will compete in four missions: 1) a Science Mission to investigate a site for the presence of current or past life; 2) a Delivery Mission to deliver a variety of objects to astronauts in the field across rugged terrain; 3) an Equipment Servicing Mission to perform dexterous operations on a mock lander using a robotic arm; and 4) an Autonomous Navigation Mission to autonomously travel to a site and locate a marker.

The 2021 University Rover Challenge will be held June 3 – June 5, 2021 at the Mars Society's Mars Desert Research Station (MDRS) near Hanksville, Utah, USA. The competition is open to both graduate and undergraduate students, although teams are permitted to include secondary (high school) students.

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.

URC2021 is being planned and will occur in the midst of the global COVID-19 pandemic. At the time that these rules are being published it is uncertain what the state of the pandemic will be in June, 2021 for the URC2021 Finals. As such, it is possible that the URC2021 Finals may need to be modified, or even cancelled, based on conditions at that time. Please continue to monitor the URC website (<http://urc.marssociety.org>) for updates. Throughout the academic year teams are also strongly advised to follow the health and safety guidelines of their universities, local communities, and relevant public health officials (to include the World Health Organization (WHO) and United States Center for Disease Control and Prevention (CDC)).

1. Competition Rules

1.a. Schedule

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. Teams failing to qualify for the field competition are strongly encouraged to enter other Rover Challenge Series events. 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.a.i. Declaration of Intent to Compete

Teams are required to register and declare their intent to compete no later than Wednesday, October 28, 2020. No significant deliverables are required for this deadline, aside from team details requested via the URC web site.

1.a.ii. Preliminary Design Review

Teams are required to submit a Preliminary Design Review (PDR) document no later than Friday, December 4, 2020. 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 including the current state of development and prototypes are highly encouraged. Judges will be assessing each team's overall likelihood of being ready in time 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 4, 2020, and will be reviewed by judges on a rolling basis.

1.a.iii. **System Acceptance Review**

Teams are required to submit a System Acceptance Review (SAR) Package no later than Friday, March 5, 2021. 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. The 36 teams who score the highest in the SAR milestone will be invited to compete in the field.

1.a.iv. **Field Competition**

June 3 – June 5, 2021 at the Mars Society's Mars Desert Research Station (MDRS) near Hanksville, Utah, USA.

1.b. **Operations**

1.b.i. Teams will operate their rovers in real-time 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. The GPS standard shall be the WGS 84 datum. Coordinates will be provided in latitude/longitude format (e.g. decimal degrees; degrees decimal minutes; degrees minutes seconds).

1.b.ii. There should be radio communication line-of-sight from the command station to the rover for the Science and Equipment Servicing Missions. For the other missions, line of sight communication is not guaranteed for more than 50% of the courses. Rovers are not expected to travel more than 1 km from the command station.

1.b.iii. In the summer temperatures at MDRS can easily reach 100°F and winds frequently whip up dust. Rovers shall be able to withstand these conditions and also light rain, but will not be expected to compete in heavy rain or thunderstorms.

1.b.iv. **Testing will not be allowed at MDRS before, during, or after URC2021.** Teams may test in town or at other sites where off-road vehicles are allowed, but must follow local regulations regarding off-road activity. Land controlled by the Bureau of Land Management, that is not specifically designated for off-road use, is strictly not allowed for any URC purposes.

1.c. **Team Members**

1.c.i. There is no restriction on the number of team members allowed. 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.c.ii. Teams are encouraged to work with advisors. Advisors should limit their involvement to academic level advising only. Nontechnical management duties, including tracking finances, registration, submission of deliverables, and communication with URC staff, fall within the duties of the students. Advisors can spectate from the field, but may not spectate from within the control station.

1.c.iii. All team member operating the rover 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, non-operator team members, and other

spectators may only follow a rover at the judges' discretion. Team members following the rover may participate as runners in accordance with Section 2.d, or activate an emergency kill switch (in the event of an emergency), but may not otherwise participate in that mission.

- 1.c.iv. It is incumbent upon the student team leaders to ensure that their respective teams uphold the integrity of this competition.

1.d. **Finances**

- 1.d.i. Teams shall be required to track all finances as related to this project, and submit a final expense record no later than May 24, 2021 (if necessary, teams may submit an updated record on the first day of the URC event – June 3, 2021). 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 5, 2021).
- 1.d.ii. The maximum allowable cash budget to be spent on the project is **\$18,000 US**, which shall include 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.).
- 1.d.iii. The Director may allow certain sponsorships that are available to all teams to count as an extension of the budget limit.
- 1.d.iv. The budget limit shall not apply to spare parts, tools, travel expenses. Spare parts are defined as those that are replaced one-for-one in the case of damage to the original.
- 1.d.v. If used equipment is purchased commercially the as-bought price may be used. Re-used equipment from prior competitions must be valued at either the original as-bought cost, or the current cost for a new version of the same or equivalent item.
- 1.d.vi. Corporate sponsorship is encouraged. If equipment or services are donated to the team either free or at reduced cost, the full cost of a new or second-hand component must be used. Donations must be documented by the donor, but teams may use the cheapest rate commercially available for the same equipment or service.
- 1.d.vii. Shipping and taxes should be included in the cost since these are a standard part of the cost of any item.
- 1.d.viii. Any equipment rented must be valued at purchase cost (new or used).
- 1.d.ix. Non-US teams have an allowable budget equivalent to \$18,000 US based on the most advantageous documented currency conversion rate between August 1, 2020 and June 3, 2021.
- 1.d.x. Teams may be required to submit receipts as proof of budget upon request.

2. **Rover Rules**

2.a. **Size, Weight, Power**

- 2.a.i. The rover shall be a stand-alone, off-the-grid, mobile platform. Tethered power and communications are not allowed. A single connected platform must leave the designated start gate. 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.
- 2.a.ii. Rovers shall be weighed by the judges during the set-up time of each mission. For weighing the rover **must fit completely within a 1.2 m x 1.2 m box**. Rovers may articulate/fold/bend to fit within the “transport crate,” but may not be disassembled to do so. This includes wheels, antenna, and any other system protruding from the rover. There

is no vertical height limit for 2021, and the rover may be placed in any orientation.
Failure to fit within the specified dimensions at weigh-in will result in a 40% penalty.

- 2.a.iii. The maximum allowable mass of the rover when deployed for any competition mission 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, communication relays.
 - 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.a.iv. Rovers shall utilize power and propulsion systems that are applicable to operations on Mars. Air-breathing systems are not permitted: No power or propulsion system may ingest ambient air for the purpose of combustion or other chemical reaction that yields energy.
- 2.a.v. No airborne vehicles or lighter-than-air systems are allowed for 2021.
- 2.a.vi. **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 and cease all power draw from batteries in the event of an emergency such as a battery fire.
- 2.b. **Communications Equipment**
- 2.b.i. The rover shall be operated remotely using wireless communications with no time delay. The operators will not be able to directly view the rover or the site, and line-of-sight communications are not guaranteed for all of the missions. Internet is not available in the field or at MDRS. Teams are required to power down communications equipment at the event sites while not competing, so as not to interfere with other teams. Aerial devices are not allowed for communications at URC2021.
- 2.b.ii. Wireless communication methods used by teams shall adhere to all applicable FCC (United States Federal Communications Commission) standards and regulations. Teams must submit details regarding communication devices and operator licenses (when applicable) to the URC Director no later than Friday, April 30, 2021. 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.
- 2.b.iii. 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. 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.
- 2.b.iv. **Base station 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 30, 2021. 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 communications cable** to deal with this scenario.

2.c. **Restrictions on the 900 MHz and 2.4GHz bands**

Teams must notify the organizers of the communications standards they will be using, including frequency bands and channels, by April 30, 2021.

2.c.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 mission, 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.c.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 mission, 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.c.iii. **These restrictions apply to both the command station to rover communications and any local wireless network such as (but not limited to) on-board the rover between subsystems.**

2.c.iv. Teams may use spread spectrum or narrowband (fixed channel allocation) within the sub-band limits as they fit.

2.c.v. 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.

2.c.vi. 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. Teams are strongly encouraged to investigate interference-tolerant protocols but **in the event of interference outside of 900 MHz and 2.4 GHz, teams will not be granted additional time or special considerations.**

2.d. **Interventions**

If a rover suffers a critical problem during a mission 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.d.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. Spectating team members may carry tools and the command station may radio out to them to request an intervention.

2.d.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 mission will be considered terminated although the rover may compete in other subsequent missions. All points earned in a mission to this point are preserved, and in the Science Mission teams may still conduct their field briefing.

- 2.d.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 mission. Runners will still be permitted to retrieve or repair the rover in future interventions.
- 2.d.iv. Runners may fix the rover in the field without moving it, or return the rover to the command station, or return the rover to the start of that obstacle/mission 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.d.v. If the rover is returned to the command station, the operators may take part in the diagnostic and repair process, but runners and spectators may not communicate any details about the mission site to the operators.
- 2.d.vi. When an intervention is called, the team members in the field may communicate directly with their team members operating the rover to facilitate repairs. **If teams wish to use radios for this purpose they must bring their own radios, but they may be used only during an intervention. All radio communication must be in English so judges can properly monitor conversations.**
- 2.d.vii. Teams will be **penalized 20% of the total points in that mission for every intervention.** The mission clock will continue to run during an intervention. Multiple intervention penalties in a single mission are additive: e.g. two interventions would result in a score of 60% of points earned.

3. Competition Missions

- 3.a. The rover shall be judged in the four competition missions outlined below and also on the System Acceptance Review Package.
 - 3.a.i. 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. Missions are scored independently and it is not possible to score less than zero on a mission.
 - 3.a.ii. 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.** 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.a.iii. For the four competition events, the rover is not required to be in the same configuration so modular pieces can be swapped between missions. On days that teams compete in the Science and Extreme Retrieval and Delivery Missions, teams will only compete in one Mission. Teams may be required to begin on the Autonomous Traversal Mission as soon as 10 minutes after the completion of the Equipment Servicing Mission, operating from the same control station on an adjacent course.
 - 3.a.iv. **Teams do not need to return to the start gate, or collect any deployed items (radio repeaters, cameras, tools, etc) before the end of time for any of the missions.** However, they must be collected immediately after competing. The rover will be accessible throughout the competition and modifications can be made at any point.

3.b. Science Mission

The goal is to conduct in-situ analysis, including life-detection testing of samples to determine which would be the best to be cached for further analysis given a limited cache volume.

- 3.b.i. Teams will be given a field briefing by judges and will be missioned with investigating multiple sites of mineralogical and biological interest within a 0.8 km radius of the start gate. Teams will be given between 30 and 45 minutes to collect data with the rover.
- 3.b.ii. **Using the science package on-board the rover, teams should be able to determine the absence or presence of life, either extinct or extant, for designated samples.**
- 3.b.iii. The rover may use cameras or other passive instruments to investigate the area, and may dig using mechanical methods. **The rover must have a life detection capability instrument or assay** of the team's choosing. Samples must be investigated by the rover on-site, and may not be brought back to the crew for investigation. At each site (soil or rock) the rover will need to determine the absence or presence of life, extant, or extinct. Small amounts of soil may be removed from the sample site for analysis by on-board instrumentation, but rock samples must not be removed or altered. **There will be no laboratory analysis. All instruments/tests must be onboard on the rover.**
- 3.b.iv. Teams shall submit a written science plan by May 21, 2021, which will be factored into the judges' evaluation for the Science Mission. This will expand upon the science plan submitted in the SAR and will count towards the score. Specifications for the plan will be posted to the URC website.
- 3.b.v. Any chemicals used onboard, including water and any reaction products, must follow a no-spill policy of being contained on the rover and not spilled on the ground. Use of hazardous chemicals must be pre-approved prior to competition by submitting a plan of usage, transportation, 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.vi. Based on the onboard analysis teams will prepare a presentation for the judges to be given at the field site. Presentation and discussion with the judges will be between 10 – 15 minutes. The presentation and discussion with the judges is allowed even if the team was unsuccessful in collecting data with their rover. The presentation to the judges should include:
 - The team's conclusions for each site regarding the presence or absence of life. If life is present, distinguish between extant and extinct life.
 - Results of on-board rover tests performed including data and images.
 - 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 astrobiology and Mars based on responses to judges' questions.
- 3.b.vii. The score for this task will be based on the following components:
 - Correct identification of extant, extinct, or no life in the designated sample(s).
 - Quality and applicability of the onboard analysis and how well this supports the team's conclusions.
 - The completeness, correctness, and clarity of the science plan.

3.c. Extreme Retrieval and Delivery Mission

- 3.c.i. This will be a staged mission 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, no further than 1 km from the start gate. Teams will be given a fixed amount of time for each stage. Each stage will include multiple tasks as described below,

and teams must achieve a specified minimum score within a stage and the allotted time in order to proceed 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. Total on-course time will be between 30 and 60 minutes.

- 3.c.ii. The natural terrain around MDRS includes soft sandy areas, rough stony areas, rock and boulder fields, vertical drops and steep slopes. Terrain will range from flat close to the starting line, to exceedingly difficult obstacles at greater distances also involving navigation challenges. Portions of this mission, particularly in later stages, will be intentionally placed beyond direct line-of-sight of the control station antenna. A script giving a general description of the individual tasks will be given to the teams prior to the competition.
- 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 except the rocks 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.
- 3.c.iv. **The rover will be required to pull one object by a rope over relatively flat ground.** The rope will be lying on the ground, no more than 15mm diameter, and no more than 3 meters in length, and the object will be less than 5 kg. The rover will be expected to grab the rope near the end and pull the object (tool, etc) towards the rover, and then pick up the object. The rover may pull the object either by pulling the object towards the rover via the rope while the rover is stationary, or by grabbing the rope and moving the rover backwards, dragging the object via the rope, and then returning to the location on the course where the rope was grabbed originally.
- 3.c.v. Objects shall be picked up in the field and delivered to designated locations, which may include markers or astronauts identifiable by simulated space suits. Field science expertise may be useful for some tasks such as identifying a type of rock. 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.vi. 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 may be awarded for partial completion of any particular task.

3.d. **Equipment Servicing Mission**

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 mission will involve delivering a cached science sample to a lander and performing maintenance on the lander. It will include 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 10 cm long and not more than 5 cm in diameter. Cache will weigh less than 3 kg.
- Open a drawer on the lander. Insert cache into a close-fitting space in the drawer, and close the drawer.
- Tighten captive screw to secure drawer. Screw will be a 5/16" Allen (hex) head.
Teams may build the hex driver into the rover, or pick up the screwdriver provided.
- Undo a latch on a hinged panel of the lander and open panel.
- Type commands on a mechanical keyboard and follow directions on computer display.

- Operate a joystick to direct an antenna while observing a gauge.
- Pick up and insert a rugged USB memory stick into a USB (type A) slot on the lander.
- Push buttons, flip switches, turn knobs.

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

3.e. Autonomous Navigation Mission

- 3.e.i. Rovers shall be required to autonomously traverse to posts or between gates in this staged mission across easy and moderately difficult terrain. Teams must complete each 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 mission. Any time remaining at the completion of a stage is added to the allotted time of the subsequent stage, which begins immediately.
- 3.e.ii. Teams may be required begin on this mission possibly as soon as 10 minutes after the completion of the Equipment Servicing Mission, operating from the same control station on an adjacent course. Total time on course will be between 30 and 45 minutes, and the cumulative distance of all legs shall be no greater than 2 km.
- 3.e.iii. A leg is defined as the rover autonomously navigating to the next post or passing completely through the next gate.
- 3.e.iv. Each post will have a large (20cm x 20cm) marker 30 – 100 cm off the ground. Each gate will consist of a pair of posts 2 - 3 m apart. **Each marker will display a black and white AR tag (e.g. https://wiki.ros.org/ar_track_alvar?action=AttachFile&do=view&target=markers0to8.png).**
- 3.e.v. Legs will increase in difficulty:
- Stage 1. Autonomously drive to a post and stop within 3m of the post. Flat easy terrain.
- Leg 1: GPS coordinates of the post provided.
 - Leg 2: GPS coordinates of the post provided.
 - Leg 3: GPS coordinates up to 5m from the post. Rovers will need to autonomously detect AR tag on the post and drive to it.
 - Leg 4: Autonomously drive completely through a gate with posts 3 m apart. GPS coordinates between gate posts provided.
- Stage 2. Autonomously drive completely through a gate. Gate posts 2 m apart.
- Leg 5: GPS coordinates up to 10m from gate. A small autonomous search pattern may be required to locate the gate, if gate not initially detected by autonomous vision recognition.
 - Leg 6: GPS coordinates between posts provided. One or more obstacles will likely prevent a bee-line from the previous gate. Autonomous obstacle avoidance will be required to reach the gate.
 - Leg 7: GPS coordinates up to 10m from gate. Obstacles will complicate the search for the gate, requiring obstacle avoidance and/or autonomous route finding.
- 3.e.vi. **There must be an LED indicator on the back of the rover, visible in bright daylight (e.g. large LED or LED array), that will signal:**
- **Red: Autonomous operation**
 - **Blue: Teleoperation (Manually driving)**
 - **Flashing Green: Successful completion of leg.**
- 3.e.vii. **The rover's on-board systems are required to decide when it has reached a post or**

- passed through a gate. The rover must then stop and signal completion of a leg using the LED indicator on the back of the rover. It must also display a message or signal on the operator's display for the control station judge to observe.**
- 3.e.viii. Operators may at any point send a signal to the rover to abort the current attempt and autonomously return to the previous post/gate or GPS coordinate and stop within 10 m of it. **Operators may teleoperate back to the previous post or gate for a 50% penalty on the points available for that leg. Teleoperation should take the most direct reasonable route back and may not go scouting for the post/gate.** There is no penalty for an autonomous return.
- 3.e.ix. While stopped at any post/gate/coordinate to indicate successful completion, or from an abort return, teams may program the next leg and make any changes to the controls, but may not drive the rover.