



# 2005 SAE Robot Systems Challenge Rules

## Introduction

For 2005, the SAE Robot Systems Challenge rules have been significantly changed. In the past, the competition's primary focus has been mechanical walking with a secondary focus on autonomy. Starting this year your goal will be accomplishing tasks robotically by autonomous or remote control. It's now your decision, within some limits, how you create a robot system that will do the job. By making the competition task based rather than method based, the changes give you much greater design flexibility.

A few of the changes you will notice are:

**11.1 "Robot System Design Goal" – Major Change** – The goal for the competition is to develop a flexible robot system capable of performing a variety of tasks, such as research, retrieval or rescue in any environment including urban buildings, industrial plants, construction areas, mines, caves and archeological sites.

**21.2 "Motion System" – Major Change** – Walking is no longer required. Robots may move using any system, or combination of systems, that operate, primarily, in contact with the ground including wheels, treads, legs, arms, tentacles and springs – how the robot moves is entirely up to you. However flying, per se, is prohibited.

**21.6 Maximum Cross Section** – In keeping with the new objective of the Competition the width of the robots is limited to 0.66 m (26 in) so that they can go through a standard 30" door.

**21.7 Maximum Weight** – The maximum weight of the robot alone is limited to 50 kg (110 lb).

**21.8 Specialty Attachments – Major Change** – Teams may install and remove one (1) specialized attachment for use in each of the Challenges. The exact nature and functionality of the attachment is up to the team with the caveats that (a) attachments must comply with the same general design requirements and restrictions as the robot itself and (b) the weight of the robot plus any attachment must not exceed 60 kg (132 lb).

**23 "Robot Control Modes"** - Tethered has been eliminated as a control mode. The base control mode is now "Remote Tele-operated" although this mode allows remote operation through a cable, provided that the operator has no direct reference to the robot.

**Section 5 – Challenge Dynamic Events – Major Change** - They've all changed!



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# 2005 SAE Robot Systems Challenge Rules

## SECTION 1 – GENERAL INFORMATION

### 11. SAE ROBOT SYSTEMS CHALLENGE – OBJECTIVES

The SAE Robot Systems Challenge is an intercollegiate engineering design competition for undergraduate and graduate students. The competition gives students the opportunity to enhance their knowledge and skills in all fields of engineering related to robotics, including systems engineering and computer science through a difficult real-world design project. Participating students will become familiar with robotics engineering including the components and systems necessary for the construction and development of robots and other complex intelligent machines.

Disciplines addressed by the Robot Systems Challenge include: systems, dynamics, controls, materials science, structures, kinematics, kinetics, computer science, sensing technology and artificial intelligence. The design issues involve: safety, environmental changes caused by obstacles and terrain, the sensing of and interaction with static and moving objects, real-time control, human factors for operator control, artificial intelligence for autonomous control, and the response of the robots to natural language.

#### 11.1 ROBOT SYSTEM DESIGN GOAL

Each team's goal is to design, fabricate, test and compete with a prototype for a versatile, efficient robot system capable of performing all of the events in the Challenge.

Participants should view the competition as a simulation of an unmanned research, retrieval or rescue in any environment such as urban buildings, outdoor locations, industrial plants, construction areas, mines, caves and archeological sites.

Robot systems with high levels of autonomy are desired and receive higher scores under the scoring equations.

#### 11.2 COMPETITION CHALLENGES

The Robot Systems Challenge™ involves a four part design event followed by dynamic challengers of varying difficulty. The variety of challenges is intended to:

- Encourage participation by as many universities as possible. We do not want to limit the contest exclusively to those institutions that have extensive resources and/or experience. Schools should be able to compete to an extent consistent with their experience, resources, and goals. Actually, limitations might even provide for very creative solutions to



problems.

- ◆ Encourage interdisciplinary cooperation among students working in teams on specialized projects where communication and sharing of ideas and information are essential.
- ◆ Engage students with different areas of expertise, diverse skills and a variety of experience.
- ◆ Provide the students with a sense of what the future holds for robotic systems.

The rules for the Robot Systems Challenge™ are written to be clear and simple. The challenges themselves are defined in terms of objectives. Hopefully, this will give participants the opportunity to explore and evaluate several options for an efficient design to achieve the goals of the events. The liberal rules allow teams to develop creative solutions that reflect their experience and resources. The Robot Systems Challenge lends itself to imaginative approaches. Although the teams participating in past SAE robotics competitions have developed an astonishingly wide variety of robots, so far, no single best solution has appeared and fascinating new approaches continue to emerge.

### **11.3 GENERAL GUIDELINES FOR ROBOT SYSTEM DESIGN**

- ◆ Start with objectives and goals.
- ◆ Follow the KISS principle (Keep It Simple, Stupid!).
- ◆ Create a lightweight design in order to reduce power requirements.
- ◆ Allow plenty of time for testing. Take care of the details in the design.
- ◆ Consider the aesthetics of the design.
- ◆ Beware of Murphy's Laws —

If anything can go wrong, it will!  
Nothing is as easy as it looks!  
Everything takes longer than you think!



## 11.4 THE SPIRIT OF THE COMPETITION

In order to emphasize safety and to define the spirit of the Robotics Challenge™, we would like to quote Isaac Asimov's classic, "Three Laws of Robotics" from the Foreword of the Handbook of Industrial Robotics (S.Y. Nof, editor):

### 11.4.1 First Law:

A robot may not injure a human being, or, through inaction, allow a human being to come to harm.

### 11.4.2 Second Law:

A robot must obey the orders given it by human beings except where such orders would conflict with the first law.

### 11.4.3 Third Law:

A robot must protect its own existence as long as such protection does not conflict with the First or Second Laws.

## 12. REGISTRATION

The SAE Robot Systems Challenge is open to teams of undergraduate and graduate students from any university from any country. Registrations must be completed and paid for on-line through the SAE website. Registration fees are not refundable.

### 12.1 INDIVIDUAL PARTICIPANT REQUIREMENTS

Individual members of teams participating in this competition **must** satisfy the following requirements:

**(a) Student Status:** Team members must be enrolled as degree seeking undergraduate or graduate students. Team members who have graduated during the seven (7) month period prior to the competition remain eligible to participate.

**(b) SAE Membership:** Team members must be members of SAE. Proof of SAE membership is required at the event. Applications for membership will not suffice. This process must be complete and the original membership card must be presented at the competition.

**Comment:** Information on SAE student membership can be found at:  
<http://www.sae.org/students/walking.htm>

**(c) Liability Waiver and Insurance:** All on-site participants and faculty are required to sign a liability waiver upon registration.



**(d) Medical Insurance:** All participants must present proof that they have medical and accident insurance. Individual medical and accident insurance coverage is the sole responsibility of the participant.

## **12.2 ROBOT FABRICATION REQUIREMENTS.**

Robots entered in the competition must be designed, fabricated, tested, and operated entirely by the members of the student team. Teams are responsible for the production of all unique parts of their robot and its final assembly. Outside assistance with component manufacturing is permitted in cases where the university lacks the necessary tools and equipment or where the students do not have access to the tools and equipment. The use of commercially available robotics kits is prohibited.

## **12.3 LIMITS ON REUSE OF THE SAME DESIGN**

The organizers recognize that it may take more than one year to develop and perfect a robot. At the same time we want to encourage teams to rethink their robots and attempt new designs.

Teams may reenter robots **if** they have either (1) made changes to solve problems that prevented the successful operation in a previous year, or (2) made significant modifications and improvements to the mechanical systems, control systems or both. Section 33 “Robot Development Status” defines the categories of new and re-entered robots.

There are no limits on how many years a redesigned robot may be entered if it can be classified as an “Evolved Mechanical Design”.

However, a given robot may be entered for a maximum of two (2) years without significant mechanical modification. Specifically, a robot entered as “New Mechanical Design” in its first year is only eligible to be entered one year as “Same Mechanism Perfected”

## **12.4 FACULTY ADVISORS**

A team may have one or more faculty advisors representing the university. Faculty advisors serve as liaisons between the team and the university and competition officials. When consulting on the project faculty advisors may discuss alternatives and methods of analysis, but should not provide solutions. Faculty advisors may not design, build, prepare or repair any part of the robot system or provide any form of hands-on help.

Faculty advisors are invited to participate in the Robot Systems Challenge Rules Committee meeting that is held during the competition.



## **13. COMPETITION RULES**

### **13.1 RULES PHILOSOPHY**

The Robot Systems Challenge Rules are written to allow teams wide flexibility in the design of their robot consistent with safety. There are relatively few design requirements or limitations on the motion system. The rules, including those governing the challenges, are intended to favor the development of versatile robots. Robots may even consist of a “team” of small machines working simultaneously to complete an event and whose individual members are gradually “sacrificed” during the course of the competition.

### **13.2 RULES AUTHORITY**

The SAE Robot Systems Challenge Rules are issued under the authority of the SAE University Programs Committee. Official bulletins from SAE and/or the organizer shall be considered a part of, and shall have the same validity as these rules.

Infractions of these rules can lead to point penalties and, in extreme cases, the prohibition of the team and robot from the competition. Safety and good sportsmanship are expected at all times.

### **13.3 RULES EFFECTIVENESS**

The Robot Systems Challenge Rules posted on the SAE website and dated for the year of the event are the rules in effect for the competition. Rule sets dated for other years are invalid.

### **13.4 RULES COMPLIANCE**

By entering the SAE Robot Systems Challenge the team, faculty advisor, and the members of the team as individuals agree to comply with, and be bound by, these rules and any procedures issued by the event organizers and SAE.

### **13.5 VIOLATIONS OF INTENT**

The violation of the intent of a rule will be considered a violation of the rule itself.

### **13.6 RULES QUESTIONS**

Questions about the wording or intent of these rules should be directed to the organizer. The decision of the organizer, SAE and the SAE Robot Systems Challenge Rules Committee shall prevail and will be binding on all parties concerned except as provided under the protest and appeal procedures specified herein.



## **13.7 PARTICIPATING IN THE COMPETITION**

Teams, team members and faculty advisors are considered to be “participating in the competition” from the time they arrive on-site until they depart at the conclusion of the Robot Systems Challenge or otherwise withdraw from the event.

## **13.8 ORGANIZER AUTHORITY**

SAE and the Organizers of the competition reserve the exclusive right to revise the schedule of the competition and/or to interpret or modify the competition rules at any time and in any manner which is, in their sole judgment, required for efficient operation or safety of the competition.

## **SECTION 2 – ROBOT SYSTEM REQUIREMENTS**

### **21. ROBOT SYSTEM DESIGN REQUIREMENTS**

#### **21.1 DEFINITIONS**

**(a) Robot** – A “robot” is a self-propelled mobile unit capable of being controlled either remotely by a human operator and/or computer(s) or internally through computers and sensor systems.

**(b) Robot System** - A “robot system” can include any or all of the following (1) the robot, (2) any and all attachments, (3) the entire control and sensor system, (4) all beacons and (5) any other auxiliary devices including those used to recharge power systems.

#### **21.2 SOUND ENGINEERING PRINCIPLES**

All parts of the robot system must be designed and fabricated following sound engineering principles.

#### **21.3 MOTION SYSTEM**

Robots may move by any self-contained motion system or systems that operate primarily in contact with the ground including, but not limited to, the use of wheels, legs, treads, jumping systems, arms, suction grippers, tentacles or springs. Any and all combinations of motion systems are permitted.

Flying or systems involving internal combustion or flames are expressly prohibited.

#### **21.4 VERSATILITY**

The design of the robot system must be such that it is theoretically, if not as actually realized, capable of accomplishing all of the Challenges in the competition. Specifically, the design must not preclude the robot from attempting any of the



Challenges. For example, the design of the robot must theoretically permit it to climb the wall in Challenge 2 “Over and Under”.

## **21.5 ONBOARD POWER**

The power system, or systems, for the machine must be self-contained and carried entirely on-board the robot. Attachments, if powered, may contain their own power source or may be powered from the robot. Power systems must be safe, non-toxic and suitable for indoor use. Robots may not be attached to a power source separate from the machine.

## **21.6 MAXIMUM CROSS SECTION**

The robot equipped with any single attachment must be able to pass through a rectangular opening 1.0 m (39.37 in) high and 0.66 m (25.98 in) wide arranged vertically with the floor forming the lowest side. Once the robot has passed through the opening it may expand to any size or configuration provided such reconfiguration is done automatically.

**Comment:** The 0.66 m width limitation allows the robot to fit through a standard 30 in wide door.

## **21.7 MAXIMUM WEIGHT**

The weight of the robot in ready-to-run state including all batteries and pressure tanks but without any attachments must not exceed 50 kg (110 lb).

## **21.8 LIFT HANDLES/LIFT POINTS**

The robot must have either strong, dedicated handles, and/or lift points, that enable the team to securely lift, hold and move the robot. The robot must be designed to be readily carried by the use of the handles or lift points **alone**. The lift handles and/or lift points must be part of the main structure of the robot, exclusively designed for lifting, and may not be attached to wheels, legs or other moving components.

The team may be asked to lift and carry the robot as part of the technical inspection.

## **21.9 CONNECTION POINT**

Each robot must have a connection point along its rear longitudinal centerline to allow the attachment of the cable/chain in Challenge 4 “Tug of War”. Connection points may be eye bolts or plates meeting the following: minimum hole diameter of 19.05 mm (3/4 inch), maximum plate thickness 9.525 mm (3/8 inch).

The connecting hook must be located between 0.20 and 0.30 m (7.9 – 11.8 inches) above the ground with the robot in its operating position for the event.



## **21.10 LIFT POINT**

Each robot must have a lift point to allow the attachment of a device to lift and suspend the robot in Challenge 1 “Drop and Dash”. The lift point may be either (1) a forged eye bolt with a minimum eye diameter of 19.05 mm (3/4 inch) or (2) a plate with a minimum hole diameter of 19.05 mm (3/4 inch) and a maximum of 9.52 mm (3/8 inch) thick. The lift point must have a minimum of 10.4 cm (4 inch) radial clearance.

Note: The connection point (21.9) may also be designated the lift point.

## **21.11 SPECIALIZED ATTACHMENTS – OPTIONAL**

Definition: An “attachment” is any unit or device that attaches to the robot as a single system and does not require the removal of any operating part of the robot itself. Cover plates and other non-operational parts may be removed or repositioned to install the attachment. Attachments may contain their own power and control systems.

Teams may install and remove one (1) specialized attachment for use in each of the Challenges. The exact nature, control and functionality of such attachment is the team’s decision with the caveats that each (a) attachment must comply with the same general design requirements and restrictions as the robot itself and (b) the weight of the robot plus any single attachment must not exceed 60 kg (132 lb).

The exact design and use of specialty attachments is entirely at the team’s discretion. Possibilities include: equipment for wall climbing, object pick-up mechanisms, special sensors for object detection, defensive equipment, protective structures or gear for load retrieval. It may be possible to create an attachment that has multiple functions or that can be used for more than one event.

The attachment used during an event must be in place when the robot leaves the starting box/line.

Attachments may be abandoned during an event. That is, a robot may discard an attachment on the course at any time, however, any attachment that remains on the course after the robot is over the finish line is classified as “out of play” for all subsequent events. Such abandoned attachments may be reattached for a second attempt at the same event.

### **21.11.1 Defensive and Capture Attachments**

Defensive and capture attachments to protect the robot and its treasure and/or to capture treasure obtained by other robots during Challenge 3 “Treasure Hunt” are permitted. Defensive/capture attachments may either be integral to the robot itself or added, in



whole or in part, as a specialty attachment. Such attachments may not involve flame in any form, projectiles, high voltage current or anything else that could interfere with the prompt activation of the E-Stop by the judges.

### **21.12 REMOTE BEACONS – OPTIONAL**

At the team's option, the robot may use up to three (3) remote beacons that communicate with the robot for triangulation or other input. Such beacons may be active or inactive with the proviso that beacons that provide computer control may affect the robot's control category. Each beacon must be capable of passing through the same 1m x 0.66 m (39.37 x 25.98 inch) opening as the robot. Once passed through the opening the beacon may be rearranged or expanded into any safe configuration. Powered beacons must operate solely from a safe internal power source. In the "Remote Teleoperated" mode beacons may **not** be used to mount television cameras for input to a human operator.

The actual placement of the beacons is to be done by the team members at the locations specified in section 43.6 "Remote Beacon Locations"

## **22. TECHNICAL REQUIREMENTS AND RESTRICTIONS**

Each robot system must pass a technical inspection to determine its compliance with the rules before it is permitted to compete in the Robot Systems Challenge. Each team is responsible for providing the technical inspectors and organizers with sufficient documentation to establish the operational safety of their robot. Teams that can not provide proper documentation will be ineligible to compete.

All robots must comply with the following requirements and restrictions:

### **22.1 POWER SOURCE**

The robot may only be powered by the following, either singly or in any combination:

- (1) Batteries, photovoltaic cells or fuel cells suitable for indoor operation.
- (2) Pneumatic systems
- (3) Hydraulic systems

### **22.2 INTERNAL COMBUSTION ENGINES – PROHIBITED.**

The use of internal combustion engines of any type is specifically prohibited.

### **22.3 ELECTRICAL SYSTEMS**

Electrical systems must be properly isolated from all parts of the robot that are not part of the electrical system.



## 22.4 PRESSURE SYSTEMS

**Requirement** - All pressure vessels and pressure regulators must be properly certified and carry current and correct certification labels. All fittings and plumbing in the pressure system must be certified to meet or exceed the pressure requirements of the system.

**Documentation** – Teams must be prepared to present documentation of the pressure system components and/or any applicable certification.

**Protection**– All pressure vessels and pressure regulators must be contained within the frame of the robot and protected from damage or impact in the event the robot falls, overturns or collides with an object.

## 22.5 EMERGENCY STOP

**Requirement** – The robot must have a one or more emergency stops (E-Stop) that fully and irreversibly disconnect the power source from all drive systems. The E-Stop must directly disconnect the primary power, disconnecting computer control systems alone is insufficient. E-Stops must not require sustained action to operate.

**Location** – The E-Stop must be located (1) on the “top” of the robot in (2) a location that is easily seen and reached by the operator or event officials and (3) clearly identified. For the purpose of locating the E-Stop the “top” of the robot is defined as the portion of the main body of the robot that is uppermost at the time. Robots that operate with different body surfaces uppermost at different times may require more than one E-Stop.

**Documentation** – Teams must be prepared to demonstrate the E-Stop and provide the technical inspectors with the following documentation:

- 1) Schematic diagram – A detailed schematic diagram covering all motive components, all power systems and the E-Stop.
- 2) Component specifications – Manufacturer’s specifications for all purchased components of the power source and E-Stop arrangement.
- 3) Analysis – An analysis of the power source and E-Stop system and components that demonstrates their functionality.

### 22.5.1 Electrical Power System E-Stop – Requirements and Restrictions

**Fuse** – All robots using an electrical primary power source **MUST** have a fuse that interrupts the primary power to the drive systems.



**Restrictions** - The following E-Stop configurations for electrical power systems are **unacceptable**:

- 1) Switching off power to the computer
- 2) Switching off power to the motor/actuator drive circuits
- 3) Switching off power with a *Normally Closed* relay

### **22.5.2 Pressure System E-Stop – Requirements and Restrictions**

The E-Stop function for pressure systems must remove pressure from all components except the pressure tank itself.

**Manual Dump Valve** – All pressure systems must incorporate a manual dump valve.

**Required Analysis** – Documentation of the system must include an analysis substantiating that each component that is pressurized following actuation of the E-Stop is capable of withstanding a substantial pressure increase. For example, an actuator must be able to safely contain a pressure increase caused by the entire weight of the machine on the actuator or to demonstrate a substantial force margin as to not cause a pressure increase.

**Restrictions** – The following E-Stop configurations for pressure systems are **unacceptable**:

- 1) Switching off power to the computer
- 2) Switching off power to solenoid valves
- 3) Using a solenoid valve to drain pressure from the system

## **22.6 LASERS**

Lasers must conform to the CDR (United States Center for Devices and Radiological Health) Class II safety requirements. Teams must be in a position to furnish documentation in support of this upon the request of the judges.

## **22.7 PINCH POINTS**

All pinch points whether on drives, arms, legs, or other parts of the robot or the attachments must be clearly marked on the machine itself. Pinch points can include, but are not restricted to, the following: pivoting or sliding joints, rotating gears or pulleys, sharp protrusions of any type and autonomous trapping mechanisms.

## **22.8 ACTIVELY STABLE ROBOTS**

An “actively stable robot” is defined as a robot that is inherently unstable during some part of its motion and depends upon either, or both, its drive system or an



automatic control/correction system to maintain stability. Any robot that might fall over during some part of its motion if it loses its power, drive or control systems, either singly or in combination, is by definition “actively stable.”

If a robot is actively stable, then the team is required to (1) define the maximum fall radius of the robot as the “keep out” distance around the machine when it is operating, and (2) have a means of activating the E-Stop either remotely or by use of a lanyard.

## 23. ROBOT CONTROL MODES

Higher scores are awarded to robots that perform successfully in higher autonomy control modes.

Robots may operate in different control modes during different events. In some instances a robot is required to operate in a more autonomous mode when making a second attempt in an event.

The three (3) recognized control modes in order of increasing autonomy are:

### 23.1 REMOTE TELE-OPERATED

Remote tele-operated robots are remotely controlled by a human operator using only data received from vision systems and/or sensors on the robot. To be “remote tele-operated” the operator must **not** have any direct or indirect visual or auditory contact with the robot. All reference information used by the operator must come from systems mounted on the robot.

Control and sensor transmissions between the robot and the operator may be either by (a) a trailing cable or (b) radio or infrared (IR). Any type of computer system, either onboard the robot, at the operator’s station or located in a beacon, may be used to assist the operator.

Beacons that are part of a remote tele-operated robot system may only interact with the robot itself and not directly with the human operator. The beacons may **not** be used to mount television cameras for use by the human operator.

### 23.2 AUTONOMOUS LEVEL 1

“Autonomous Level 1” is computer controlled operation in which the robot follows an internal control strategy that does **not** use sensor input to analyze the surrounding environment and can not react to changes in that environment. Autonomous Level 1 robots typically rely on distance measurement, step counting, and/or the position of their components, to determine their location.



### **23.3 AUTONOMOUS LEVEL 2**

“Autonomous Level 2” robots use sensors to remotely analyze their environment and base their movement and actions on the information provided by these sensors. Autonomous Level 2 robots must be able to automatically compensate for changes in its position or the position of any component(s) of any event.

Autonomous Level 2 robots may, at the option of the officials, be started from any position or orientation along the front edge of the starting box/line.

The judges may require a demonstration to determine if the robot is operating at Autonomous Level 2.

## **24. IDENTIFICATION**

### **24.1 ROBOT NUMBER**

A number will be automatically assigned to each robot when the team completes on-line registration. This assigned number will appear next to the university name on the “Registered Teams” list on the Robot Systems Challenge portion of the SAE Collegiate Design Series website.

The number must appear on either, or both, (1) the left and right sides of the robot, or (2) the top of the robot, whichever positions are most easily visible. The number must be at least 10.2 cm (4 in) high in block numerals and in high contrast with the background color, i.e. black on white or white on black.

### **24.2 ROBOT NAME, UNIVERSITY NAME**

The name of the robot and the university, or the school initials if generally recognized, must appear prominently on each robot in roman characters.

The robot and university names may also appear on the robot in non-roman characters provided that the roman character version is uppermost and most prominent.

### **24.3 SAE LOGO**

An SAE logo sticker must be placed on the front of the robot to identify the primary direction of motion.



## **SECTION 3 – ROBOT SYSTEMS CHALLENGE EVENTS**

### **31. SCORING AND AWARDS**

The team with the highest number of total points, combining the static and dynamic events, will be declared the overall Challenge winner.

Awards will typically be presented for the following;

- Best Technical Paper
- Best Technical Presentation
- Best Design
- Best Poster Paper
- Overall Best Performance – 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> based on overall scores.

#### **31.1 AWARDS OF EXCELLENCE**

At the discretion of the judges Awards of Excellence may be presented in the following categories. Awards of Excellence have no point value and are presented only if the judges feel they are warranted.

1. Best New Design – including universities that have never entered, or universities that enter a totally new design from the previous year.
2. Best Analytical Approach to Design
3. Excellence in Autonomy – including sensors, computers and controls
4. Most Innovative Design
5. Value Engineering
6. Award of Excellence

### **32. TECHNICAL INSPECTION**

**NO POINTS**

#### **32.1 OBJECTIVE**

Each robot system must pass a technical inspection before it is permitted to operate. Technical inspection is conducted to determine if the robot system complies with the rules requirements and restrictions. It is each team's responsibility to produce such documents as the inspectors may request in connection with the technical inspection. Safety considerations are paramount at all time.

Technical inspectors may conduct any inspections or tests they, in their sole opinion, believe necessary to determine if the robot system satisfies the rules requirements. Inspectors may require any robot or other part of the robot system to be demonstrated.



Technical inspectors will not approve a robot if they, in their sole opinion, reasonably believe the machine could be unsafe for any reason including those not explicitly listed in the rules.

If any part of the robot system does not pass technical inspection then it must be modified to comply with the rules and pass a re-inspection before it is permitted to operate.

Inspectors may re-inspect any part of the robot system at any time and may withdraw operating approval from any robot system that is no longer in compliance with the rules.

### **32.2 ROBOT INSPECTION CONDITION**

Robots and attachments presented for inspection must be mechanically complete with operating drive systems, fully assembled and ready-to-run. Robots that are not mechanically complete can not be properly evaluated and will not be inspected.

We recognize the need to refine and modify computer control systems, sensors and software, and therefore technical inspection is based largely on the mechanical and general electrical systems and the E-Stop.

### **32.3 PROHIBITION ON MECHANICAL MODIFICATION**

Once a robot and its attachments has passed technical inspection and been approved for operation its mechanical systems may not be modified. Teams may repair malfunctioning robots including the addition and use of standard small components, e.g. fasteners, tape, connectors, wire etc, and the replacement of any components with substantially identical parts.

The replacement or recharge of batteries and pressure tanks and the installation or modification of software are not considered to be modifications. The removal or installation of cables, cover plates and connectors required to change control modes or connect attachments are not considered to be modifications.

## **33. DESIGN EVENT**

### **ALL PARTS OF DESIGN: 3500 POINTS TOTAL**

The Design Event is intended to assess both the robot's design and fabrication and each team's ability to explain and justify the design and development decisions to different audiences. The design event consists of four related parts:

Design Part 1 - Technical Paper	1000 Points
Design Part 2 - Technical Presentation	1000 Points
Design Part 3 - Design Evaluation	1000 Points
Design Part 4 - Poster Paper	500 Points



While the Technical Paper, Technical Presentation, Design Evaluation and Poster Paper are related, and there is naturally some overlap in their contents, they have different objectives and are aimed at different audiences. Your team's presented material should be consistent across the four parts of Design and should, in as much as possible, given the nature of an ongoing design and development process, match the robot itself.

### 33.1. ROBOT DEVELOPMENT STATUS

Robot systems are complex that may take a number of years to refine and perfect. To assist the design judges in understanding the development status of the robots each team is required to specify how their current entry differs from previous entries by their team or university.

Each entry will have one status for mechanical design and a second status for control system design. For example installing a new control system on last year's mechanism creates a robot described as "Same Mechanical Design – Perfected" and "New Control System". Teams are required to state the robot's development status during Design Events Part 2 "Technical Presentation" and Part 3 "Design Judging" and should be prepared to document and discuss their revisions with the judges.

The organizers and judges will rely on the integrity of the teams to properly classify both the mechanical and control states of their robots.

#### 33.1.1 Mechanical Design States

The three states of mechanical design are:

**(a) New Mechanical Design** – "New Mechanical Design" covers robot systems of a design that is new to the team and university even if similar designs have been entered in the past by other universities. A new mechanical design implies largely new fabrication of the robot.

To be classified as a "New Mechanical Design" no more than one-third (1/3) of the mechanical design may be based on an earlier robot system.

The reuse of parts stripped from previous robots, e.g. motors, actuators, pressure system components, sensors, electrical parts, is acceptable in a new mechanical design.

**(b) Evolved Mechanical Design** – An "Evolved Mechanical Design" is a robot whose mechanical design is based on a previous robot system entered by the team or university. Evolved mechanical designs include both (a) robots incorporating significant portions of an earlier robot in their fabrication and (b)



newly constructed robots based on an earlier design, but which have been corrected to eliminate the flaws in the earlier version.

Robots are classified as “Evolved Mechanical Design” if between one-third ( $1/3$ ) and two-thirds ( $2/3$ ) of the mechanical design is directly derived from an earlier design or uses mechanical systems taken from an earlier robot.

**(c) Same Mechanism - Perfected** – “Same Mechanism - Perfected” covers both (a) robot systems, including attachments, entered into a previous competition which, because of unanticipated problems or incompleteness, either did not work at all or did not complete all events and are being reentered with essentially the same mechanical systems, but which are now fully functional, and (b) newly built versions of an earlier design incorporating improvements to eliminate mechanical problems.

Robots are classified as “Same Mechanism - Perfected” if two-thirds ( $2/3$ ) or more of the mechanical design is directly derived from an earlier design or uses entire mechanical systems, including attachments, taken from an earlier robot.

### 33.1.2 Control System Design States

The three states of Control System Design are:

**(a) New Control Design** – “New Control Design” is any design for controls, computers, sensors and software that is new to the design team even if similar systems have been entered in the past by other universities. Since the control software may not be apparent to the design judges the team should be prepared to fully explain their system.

To be classified as a “New Control Design” no more than one-third ( $1/3$ ) of the system design may be based on an earlier robot.

The reuse of computers, sensors, electronic components and software, considered as individual items, is acceptable in a new control system.

**(b) Evolved Control Design** – An “Evolved Control Design” is a control and sensor system that is based on a previous system design entered by the team or university. Evolved control systems include both (a) robots incorporating significant portions of an earlier control/sensor system and (b) newly created control/sensor systems based on an earlier design, but which have been corrected to eliminate the flaws in the earlier version. Since the control



software may not be apparent to the design judges the team should be prepared to fully explain their system.

Robots are classified as having an “Evolved Control Design” if between one-third (1/3) and two-thirds (2/3) of the system is directly derived from an earlier design or robots that have been assembled from largely intact systems taken from an earlier robot.

**(c) Same Control Design - Perfected** – “Same Control Design - Perfected” covers both (a) systems incorporated into earlier robots which, because of unanticipated problems or incompleteness, either did not work at all or did not enable the robot to compete in all the events and are being reentered with minor modifications that make the system fully functional, and (b) newly built versions of an earlier control system slightly modified to eliminate earlier problems.

Robots are classified as having a “Same Control System - Perfected” if two-thirds (2/3) or more of the control system is directly derived from an earlier design or is composed of the control systems, including software, taken from an earlier robot.

## **33.2 DESIGN PART 1 - TECHNICAL PAPER**

**1000 POINTS**

### **33.2.1 Objective**

The objective of the technical paper is to explain the engineering objectives, solutions and analysis of the team’s robot system project. The technical paper should be considered the “resume” of your robot system.

### **33.2.2 Audience**

The technical paper should be written for engineers knowledgeable in mechanical engineering, systems, robotics, computers and electronics. Assume that the readers of the technical paper regularly read engineering publications such as SAE’s Journal of Automotive Engineering and the various IEEE Journals although they may not be experts in all aspects of robotics.



### **33.2.3 Technical Paper Format**

The technical papers must follow the format found in Society of Automotive Engineers (SAE) technical journals. The technical paper must be submitted electronically in .pdf or Word format.

Instructions for writing an SAE Technical Paper can be found at: <http://www.sae.org/events/volunteer/prepare.pdf>

### **33.2.4 Technical Paper Submission Deadline**

The technical paper must be submitted to the Challenge organizing committee at the address and by the date shown in Appendix 1 “Action Deadlines”. The technical paper must be submitted in electronic format. Acceptable formats are Adobe Acrobat .pdf format, and Microsoft Word documents. Any other formats must be approved by the organizing committee prior to the submission deadline.

It is the team’s responsibility to ensure that the technical paper is submitted on time.

Papers that are not received by the deadline will not be judged and the team will receive zero (0) points for Part 1 of the Design Event.

### **33.2.5 On-line Paper Publication**

To further the development of robotics technology we would like to release all of the technical papers as on-line accessible documents. Teams may elect to have their technical paper published as an on line document accessible through a website designated by the organizers. If your team wishes to have the document published on-line all the authors whose names appear on the paper must sign the waiver/release/authorization in the appendix and attach it to the paper itself or bring it to the competition.

Only teams that sign the document will have their papers released on-line.

### **33.2.6 Technical Paper Contents**

Technical papers must begin with an abstract and introduction and end with conclusions and references. Other than those sections there is great flexibility in the contents and emphasis placed on



different parts of the paper. Technical papers should contain at least the following basic contents:

**Project goal** – Define the goals of your current year’s robot system project.

**Starting point** – Review the starting considerations for the project including any previous robotics experience that influenced the process, either via the team members or the university. Cover any components, systems or designs that are being reused from previous robots.

**Innovation** – Describe any aspects of your design that you believe to be innovative.

**Constraints** – Every project operates under constraints. What were yours?

**Mechanical System and Analysis** – Cover the kinematics of motion, power systems and overall mechanical structure. Present your analysis of the motion and power system.

**Control System, Control Logic and Analysis** – Describe how the robot is controlled, why this control system was selected and, if applicable, the control system logic. For robots operating in either Autonomous 1 or Autonomous 2 modes describe the approach to autonomy. Present an analysis of the control and sensor system

**Attachments** – Discuss the design, use and testing of any attachments

**Fabrication** – Review the fabrication considerations and how they applied in practice.

**Verification and Testing** – Discuss how the entire robot system was verified and tested. What were the results of the design/fabrication process and testing?

**Conclusion** – This is the “bottom line” of your project.

**References** – Include references in the detail and format appropriate for a technical paper.



### 33.2.7 Technical Paper Judging

Technical Papers will be judged on the following:

**Scope** – Did the paper clearly and concisely explain both the team’s design and their design development process? How well does the paper covers the basic contents listed above? Was anything important left out? To what extent did the paper leave you with unanswered questions?

**Documentation and Data** – Did the paper include sufficient documentation and supporting data to enable you to assess the design arguments and conclusions? How well was the paper referenced?

**Graphics** – To what degree did the supporting graphics add value of the paper? Did the graphics improve your understanding of the design?

**Writing Style** – Is the paper written clearly and concisely? Was the structure of the paper logical and easy to follow?

**Accuracy** – Were there supported theoretical basis, or logical arguments, for the analysis in the paper? Were the analytical solutions adequate and accurate?

## 33.3 DESIGN PART 2 -TECHNICAL PRESENTATION      1000 POINTS

### 33.3.1 Objective

The technical presentation is a review of the design, analysis, development and testing of the team’s robot system at a technical seminar.

### 33.3.2 Audience

You may assume that the presentation audience consists of engineers knowledgeable in mechanical engineering, systems engineering, robotics, computers and electronics. Treat the audience as if it is attending a technical presentation at an SAE professional meeting. Members of the audience will be experts in some engineering areas concerned with robot design, but may be only slightly familiar with the other technologies involved in robotics. You may assume that some, but by no means all, of the audience members read your technical paper.



### **33.3.3 Presentation Contents**

The technical presentation may be based on the technical paper, but should **NOT** be a mere reading of the paper. Presenters should cover those parts of the paper, see “Technical Paper Contents” supra, and such additional material that they believe will give the presentation judges the best insight into your team’s decision making process and the design analysis for the various robot systems.

The presentation may cover material not included in the paper. By the end of your presentation the judges should understand why you designed the robot system as you did, what problems you encountered and solved and what the robot is expected to accomplish.

### **33.3.4 Presenters**

Any member of team may participate in the technical presentation. Only members of the team who are in the podium area and are introduced as part of the presentation team are permitted to respond to the judges’ questions. Team members who are part of this “presentation group” may answer questions even if they did not speak during the presentation itself.

### **33.3.5 Presentation Time Limit – 12 Minutes**

Technical presentations are limited to a maximum of twelve (12) minutes. The judges will stop any presentation exceeding twelve minutes and score the team only on the material presented in the allotted time.

### **33.3.6 Question Period**

Following the presentation there will be a question and answer period of up to five (5) minutes.

### **33.3.7 Projection Equipment**

Teams are responsible for providing their own data projectors or other audio-visual equipment. Although the host institution may have data projectors available do not depend on the availability or functionality of such equipment. It is each team’s responsibility to see that the equipment they need is available and working properly.



*Comment* – We suggest teams bring back-up CDs of their presentations.

### **33.3.8 Technical Presentation Judging**

The presentation will be evaluated on the following:

**Contents** – How adequately did the presentation cover the most important aspects of the project in relation to the contents of the paper outlined in Part 1 supra?

**Supporting Visuals** – How well did the visuals support the presentation? Were they easy to follow and not confusing?

**Audience** – How well was the presentation balanced for the different areas of expertise found in the audience? For example, did parts of the presentation cover design aspects in terms easily understood by only part of the audience without including an explanation in more general language?

**Design and Design Process** - Based on the presentation alone, how well did the team explain their design, how it functions and the process used to arrive at that design?

**Design Alternates** – Based on the presentation alone, to what extent did the team considered alternate approaches and the trade-offs involved in each?

**Analysis** - Based on the presentation alone, how good was the team's analysis of the different parts of their design and was the analysis sufficient to justify their design decisions?

**Understanding** – How well did the team convince you that they understand robot system design? Overall did the presentation explain their design decision making process in sufficient scope and detail to be easily understood?

**Response to Questions** – Did the team adequately respond to the judge's questions?

## **33.4. DESIGN PART 3 - DESIGN EVALUATION**

**1000 POINTS**

### **33.4.1 Objective**

The Design Evaluation assesses the engineering design, functionality and fabrication of the robot system.



### **33.4.2 Evaluation of the Design**

The judges will assess the overall design of the robot system including its theoretical capacity to accomplish all parts of the Challenge.

### **33.4.3 Presentation by the Team**

Design judging involves both an examination of the entire robot system by the judges and a discussion of the robot and the principles governing its design and fabrication with the team. Team members making the presentation to the judges and responding to the judge's questions are expected to be knowledgeable in the design process and engineering of the parts of the system they are discussing. Scores for teams that can (1) not adequately explain their design or their design process or who (2) do not display an understanding of the engineering principles affecting the design will be downgraded accordingly.

### **33.4.4 Design Judging**

Design judging will (1) assess the robot system, (2) specifically assess the robot and its attachments in relation to the tasks it is intended to accomplish, (3) assess the team's ability to explain their design decisions and (4) their understanding of the general engineering principles governing the design. Judging will include evaluation of the following aspects of the design along with such other areas as the judges may wish to address.

#### ***Part 1 – Mechanical System Design***

**Originality** – How original is the design? Originality will be assessed in comparison to (1) non-competition robots that are publicly known, (2) other robots in the competition and (3) robot designs that have been seen by the judges in the previous 2 competitions.

**Versatility** – Is the robot system at least theoretically capable of completing all of the event tasks? How well is it capable of accomplishing those tasks? Can the robot operate at sufficient speed to complete the Challenges within the required time limit?

**Functionality and system integration** – How well have the mechanical and control systems been integrated? How well do the attachments integrate with the main body of the robot to form a working system? The evaluation will consider such factors as response time to perform various actions and the smoothness of the various motions.



**Fabrication quality** – How well has the design been executed? The evaluation will assess both the (1) mechanical hardware and (2) operating, control and sensor systems.

**Serviceability** – How easily and effectively can the mechanical and control systems be repaired and/or revised during the competition? This evaluation will consider such factors as ease of disassembly, ease of parts replacement, access to sub-systems and the overall ease/difficulty of making repairs.

**Aesthetics** – Robots are expected to be carefully fabricated with a concern for craftsmanship and aesthetics.

### *Part 2 – Control System Design*

**Functionality** – How well is the system capable of controlling the robot at the operating level at which it is running? How easily can the control system be modified to compensate for failures in programming, mechanical or control systems? For example, if a high level system malfunctions can the robot easily compete at a lower level? (E.g. If a robot's Autonomous 2 sensor system fails can it continue in the Autonomous 1 or tele-operated mode?)

**System integration** – How well is the control and sensor system integrated into the overall robot system?

**Ease of Use** – How easily can the robot be prepared for each event and how easy is it to operate the robot during the events themselves? How easily are the attachments connected? Autonomous robots ease of operation during the actual events might be offset by difficult set-up procedures.

**Re-programmability** – How easily can the robot be reprogrammed to respond to, or compensate for, for mechanical malfunctions, initial programming errors or unanticipated aspects of the course?

**Serviceability** - How easily can the robot control and sensor systems be serviced and repaired?

### *Part 3 - Overall Design Assessment*

**How Good is It?** – This is the bottom line: How good do you feel this design is in relation to the tasks it has to accomplish within the allowed time? No matter how imaginative the design you need to be convinced that the robot can do its job. Fabrication and completeness must be considered in this assessment.

As part of the Design Evaluation the judges may, at their sole option, request that the machine, or any part of the machine, be started and demonstrated.



*Note: The Poster Paper (Design Part 4) may be used as supplemental material during the team's design evaluation, but is not, per se, part of that event and is judged separately.*

## **33.5. DESIGN PART 4 - POSTER PAPER**

**500 POINTS**

### **33.5.1 Objective**

The poster is intended to present a brief, basic overview of your robot system, how it operates, how it is controlled, how it will accomplish the Challenges, what it cost and the team members involved with the project.

### **33.5.2 Audience**

Educated, non-expert, readers with a general knowledge of science and engineering. The poster should be targeted to readers of Scientific American who understand science and technology in its broad scope, but who are probably not mechanical, systems, electronic or computer engineers.

### **33.5.3 Poster Format**

The poster papers must be presented on three 60.96 cm wide by 121.92 cm high (24 ins. x 48 ins.) sheets and do not have a specific format.

### **33.5.4 Poster Paper Topics**

The following basic topics must be covered in the poster paper. There are no specifications on the space devoted to each section, nor any constraints on the inclusion of other material the team feels is important.

**Goal** – A statement of the goal for your robotics project specifically including any innovative aspects of the design.

**Motion** – Describe the robot's motion system and how it is powered.

**Controls and Sensors** – Describe how the robot is controlled, the sensors and what they reveal (as applicable) and the control logic (as applicable). Posters on autonomous systems should cover the approach to autonomy.



**Attachments** – Describe the purpose, design and operation of the attachments.

**Budget** – Present a budget covering the total cost of the robot system and the cost of the various major systems and/or primary components. The budget should be based on the retail price of the components and the manufacturing price of the custom parts. Parts that were purchased on sale or at auction must also be priced at retail cost. For parts that were contributed, borrowed or reused from previous robots use the best estimate of current retail cost. The budget is expected to be truthful, accurate and mathematically correct. The judges are empowered to penalize budgets that are incomplete or inaccurate.

**Program Time Line** – Present the timeline for your project.

**Team** – List the team members and their areas of specialization or responsibility

### 33.5.5 Poster Paper Judging

The judging for the poster paper will consider at least the following aspects of the poster:

**Aesthetics** – Is the poster attractive and likely to capture and hold the attention of the audience?

**Basic Topics** – Does the poster adequately cover the “basic topics” of the design, operation, budget and team as outlined above?

**Additional Contents** - Has the team included additional material that adds to the audiences understanding of the design and/or overall project?

**Information Value** – Are the contents easy to understand? Is the audience likely to get a basic understanding of the key aspects of the robotics project from the poster?

**Graphics** – Do the graphics clearly present the relevant aspects of the robot system? Is there an apparent logic behind the flow of the poster?

**Clarity** – Is the poster easy to read and easy follow? Is the poster written to the knowledge level of the audience? Does the poster



avoid references and abbreviations that are obscure or probably unknown to the audience?

## **SECTION 4 – DYNAMIC EVENT PROCEDURES**

### **41. DYNAMIC EVENTS SCORING FORMULA**

In the dynamic events robots will earn points based upon their time or base score from the event relative to the overall fastest time or base score.

For judging and scoring purposes robots of all control modes, and design states, compete together and are eligible for the same scores based on their type of control system.

The dynamic events in the Robot Systems Challenge will be scored as follows:

#### **41.1 SCORING FORMULA**

The total score,  $S(n)$ , will be calculated by the following formula:

$$S(n) = [ (400 * t (1) / t (n)) + 600 / N ] * [\text{Performance Factor}]$$

#### **WHERE:**

$t(1)$  = fastest finisher's time including both the autonomous and tele-operated machines (in either trial)

$t(n)$  = "n"th place finisher's time including both the autonomous and tele-operated machines (better time if two trial are attempted)

$N$  = total number of finishers (both autonomous and teleoperated) for that event

#### **Performance Factor**

= 1 For remote tele-operated robots that successfully complete the event.

= 1.2 to 3 For robots operating in either Autonomous 1 or Autonomous 2 that complete the events. The exact performance factor depends on the operating mode and the event.

In general, this additional performance factor is to encourage the development of robust robots, especially those able to compensate for unforeseen circumstances such as wheel slip or misalignment in the initial placement of the machine within the starting box

## 41.2 SECOND TRIAL SCORE REDUCTION

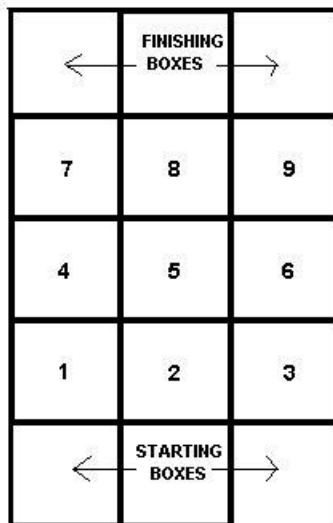
Any score obtained for a second trial at an event will be reduced by 100 points and the better score between the two trials, after the reduction, will count for the event.

## 42. BASIC COURSE LAYOUT

### 42.1 COURSE PATTERN

The basic course will consist of a grid of equal size squares each 3 m x3 m (9.84 ft x 9.84 ft) bordered by 5 cm (2 in) lines. The basic course pattern is rectangular, 3 squares wide and 5 squares deep (i.e. 9 m x 15 m), however the organizer may increase the number of squares and the overall size of the course to allow multiple robots to compete simultaneously. All the boxes along the front edge of the course are the “Starting Boxes” and the boxes along the back edge are the “Finish Boxes”.

For outdoor events the basic course pattern will be maintained, however the organizer reserves the right to alter the dimensions of the boxes, layout and width of the lines as may be required to suit the characteristics of the site.



## BASIC COURSE LAYOUT AND CHARACTERISTICS

### 42.2 COMPETITION SURFACE

The basic course will usually be constructed indoors on a flat, smooth, light colored, surface whose exact nature will be determined by the organizer. One likely indoor surface material is 1/2 inch unfinished sheet rock, placed white-side up, bonded on the edges by clear packing tape, however the organizer can not guarantee the texture, degree of flatness, exact color or reflectivity of the surface.



Any event may, at the organizers option, be held outdoors if a suitable venue is available and weather conditions permit. If an event is held outdoors then the course will still be relatively flat, but surface may be dirt, gravel, sand, asphalt, concrete, grass or whatever the organizer has available.

### **42.3 BOUNDARY LINES**

Indoor Courses: Boundary lines will be 2 inch wide black paint or duct tape. The boundary lines will be placed such that their centre-line coincides with the perimeter of the various boxes.

Numbers will be 24" high x 12" wide, centered in the squares. The numbers will be made out of 2" wide black paint or duct tape. The font for the numbers is not specified and will be selected by the organizer.

Outdoor Courses: Boundary lines and numbers for outdoor courses may be laid out using spray paint or sports field marking equipment. While the organizers will do their best to have lines and numbers approximately 2" wide the final width will depend on the equipment available and the surface being marked and is not guaranteed.

### **42.4 VERIFICATION OF THE COURSE**

Prior to the start of the dynamic events the judges will examine the dimensions and surface of the course and rule on any adjustments which need to be made to the course or any affected rules.

### **42.5 TEST AREA**

The organizer may make the course, or a test area with a similar surface, markings and lighting, available to the teams for testing their robots prior to the start of the dynamic events.

## **43. ROBOT PREPARATION**

### **43.1 EXPECTATION**

Teams are expected to have their robot complete, prepared and ready-to run when they are called for each event.

### **43.2 OPERATING CONFIGURATION**

Robots and attachments must remain in the condition in which they have passed technical inspection. The contestants may add or remove one (1) attachment prior to the start of any event, but, except for repairs, may not otherwise manually modify or reconfigure the robot.



### **43.3 OPERATING ORIENTATION**

Participants may choose to run certain events with the robot on its side or upside down. While this is permitted, variations in the initial orientation of the machine for certain events must be clearly described in the technical paper.

### **43.4 SPECIALIZED ATTACHMENTS**

Each robot may be equipped with one (1) attachment (see 21.9 “Specialized Attachments”) at the start of each event. Attachments that are discarded during an event may be reattached only for a second attempt at the same event, but may not be used in any subsequent event.

#### **43.4.1 Safety Lanyard**

Additionally a safety lanyard controlling an E-Stop may be attached to dynamically unstable robots.

Reminder: All attachments and their connection to the robot are subject to the approval of the technical inspectors.

### **43.5 OPERATOR CONTROL – TELE-OPERATED**

Manual control by an operator is permitted only if the system is “Remote Tele-operated”. Tele-operated systems may not be used as a supplement to autonomous operation.

### **43.6 SAFETY TETHERS**

Safety tethers attached to the E-Stop are allowed. A safety lanyard controlling an E-Stop must be attached to dynamically unstable robots

### **43.7 REMOTE BEACON LOCATIONS**

If beacons (see 21.10 “Remote Beacons”) are used they must be placed at: the lower left-hand corner of box 1, the lower right-hand corner of box 3 and the upper left-hand corner of box 7. Beacons may not be placed at any other location. The time required to place these beacons is not included in the elapsed time for the event but it is included in the Starting Period.

Teams may use a maximum of three beacons. If the team is using less than three beacons they may be placed in any of the locations specified above.

## **44. EVENT PROCEDURES**

Robots will be allowed a maximum of two (2) trials at each event under the terms specified in 44.10 “Second Attempts.”



Some events are run entirely against the clock while other events run competitively against other robots. The judges may run simultaneous trials on separate courses, or different parts of the same course, and may overlap the scheduling of events in order to keep the competition moving smoothly and rapidly.

#### **44.1 STARTING ORDER**

Robots will typically compete in the events in either numerical or reverse–numerical order based on their assigned robot number. However, organizers may use a starting order based on each team’s performance in an earlier event.

#### **44.2 STARTING LOCATION AND CONFIGURATION**

Events start with the robots completely within an assigned Starting Box or at a designated starting line. At the start each robot must be in its required configuration and facing forward. Some events end when the machine is completely within the Finishing Box or over the finish line. Other events end when the robot is completely within its original Starting Box and stationary. The organizer will designate which starting and finishing box or lines each team will use for each event

#### **44.3 CALLING THE TEAM**

Since some teams may not be able to run in every event, it is impossible to predict in advance exactly when within an event a team may be called to the line. Be prepared at all times.

Event officials will notify a team of its turn in an event either by (a) informing them at their work area, (b) making an announcement over the public audio or visual system or (c) placing a flag on the robot. The event times will appear in a schedule or be announced at the initial team meeting.

#### **44.4 STARTING PERIOD – 5 MINUTES**

After your team is notified that they are due for an event they will have a maximum of five (5) minutes to transfer their robot to the starting line/box, position it and be ready to run.

The starting period begins as soon as the team is called to the starting box/line. If the team either (a) does not place its robot in the starting box/line during Starting Period, or (b) places the robot in the starting box/line but for any reason has not started across the line before the end of the starting period; it will be classified as “Did Not Attempt” (DNA).

#### **44.5 STARTING BOX/LINE**

The team must place the machine completely within the Starting Box, or behind the starting line, with the designated front end of the machine directed towards the



finishing box/line and the machine in its initial configuration. Unless directed by the Judges, the robot may not be angled to provide a competitive edge during an event and the machine must be initially placed on the center-line. No part of the machine may be outside the Starting Box or over the starting line.

When the robot is ready, the team will so indicate to the judges. From that point the team may not touch the robot.

#### **44.6 ATTEMPT STARTING TIME**

The event clock starts either (1) when the team indicates it is ready and the official says “Go”, or (2) at the end of the 5 minute starting period, which ever occurs first.

#### **44.7 ATTEMPT TIME LIMITS**

The standard, i.e. default, time limit for most events is six minutes (360 seconds). The time limit for Challenge 3 “Tug-of-War” is two minutes (120 seconds) per match. The time limit for all three sections of Challenge 6 “Endurance” is twelve minutes (720 seconds). Events are timed from the point when the event clock starts until (a) the event is successfully completed, (b) the attempt fails or (c) time expires. Times will be recorded in minutes and seconds to the nearest tenth (1/10) second.

If during an attempt the judges concur that a robot has no chance of completing that event within the allotted time, then the judges may end the trial and score the attempt “DNF”.

#### **44.8 END OF ATTEMPT**

The judges will stop the timers when the final action specified for that event, such as having stopped in either the starting or finishing point, has occurred. *Important note* - Crossing the finish line or passing into the finish box does not by itself stop the clock – the robot must stop moving.

#### **44.9 SECOND ATTEMPTS**

Second attempts will be permitted under the following conditions:

- 1<sup>st</sup> Attempt unsuccessful – 2<sup>nd</sup> Attempt may be run in any mode at the team’s option.
- 1<sup>st</sup> Attempt successful in Remote Teleoperated mode – 2<sup>nd</sup> Attempt must be run either Autonomous 1 or Autonomous 2.
- 1<sup>st</sup> Attempt successful in Autonomous 1 or 2 mode – No 2<sup>nd</sup> attempt allowed.



The competition organizers and judges may decide to allow only one attempt for some events if allowing two trials will make the competition run too long

*Please keep in mind that any score obtained from a second attempt at an event will be reduced by 100 points.*

## **45. COURSE RULES**

### **45.1 ROBOT ISOLATION**

During the dynamic events, from the time the robot starts until it completes the event or the attempt ends, the robot must be treated as if it is beyond human reach. Specifically, neither the robot nor any attachment may be touched in any manner, nor may anyone carry anything connected to the machine. Attachments ejected from the robot during an event may not be touched. Touching the robot or attachment will result in the attempt being scored as “DNF”.

*Comment – Assume that the robot is completely inaccessible at the bottom of a mine shaft.*

### **45.2 TEAM LIMITATIONS**

For some events up to two (2) team members may be permitted on the course to accompany, but not touch or assist, the robot. For events involving multiple robots on the course simultaneously, for example Challenge 4 “Treasure Hunt” and Challenge 5 “Collect the Eggs”, team members are typically not allowed on the course. In all cases the organizer will decide how many team members are permitted on the course.

### **45.3 BOUNDARY RULES**

The robot must remain entirely within the boundary lines at all times during an attempt. If any part of the robot crosses, touches, or overhangs a boundary line, no matter how small the boundary intrusion, the attempt is ended. Specifically, it is permissible to overhang the “inside” edge of a tape, painted or otherwise marked boundary line, but it is **not** permissible to overhang the “outside” edge of the line. Inside and outside edges are defined with reference to the box the robot occupies.

Additionally, where it is specified below that the machine may not “enter” a box, the machine may not “touch,” step into or “overhang” that box.

The organizers will indicate which boundary lines are in effect for each Challenge.



## SECTION 5 – CHALLENGE DYNAMIC EVENTS

### 51. CHALLENGE 1 - DROP AND DASH

<b>Performance Factors</b>	<b>Remote Tele-operated</b>	<b>1</b>
	<b>Autonomous Level 1</b>	<b>1.5</b>
	<b>Autonomous Level 2</b>	<b>2.5</b>

#### 51.1 OBJECTIVE

The objective of “Drop and Dash” is to evaluate the robot’s durability and speed.

#### 51.2 EVENT SET-UP

The robot will be positioned 1m (39.37 in) +/- 5% above the impact surface either (a) by suspension or (b) by being positioned on a ledge. The impact surface will be solid and fairly horizontal. The composition of the impact surface is at the organizer’s discretion, but will most likely be concrete, gravel, rock, dirt or wood.

#### 51.3 PROCEDURE

The robot will be dropped, or pushed off a ledge, and allowed to free fall onto the impact surface. After impact the robot must right and orient itself and then dash down the course for a distance of 9.0 m (29.52 ft) to the finish box/line. The robot may be dropped/pushed from any orientation of the judge’s choice.

**Note:** Robots that roll or fall outside the starting box after impact, for any reason, must return to the designated starting box to begin their dash.

#### 51.4 PARTICIPATION REQUIREMENT

Durability is an essential requirement for Robot Systems competitors, therefore all robots must complete the 1 m drop portion of this event before they can participate in any other dynamic event. Robots not ready to compete during the scheduled time for this event will be dropped 1 m, for no score, to confirm their durability before they enter any other Challenge.

#### 51.5 SCORING

Base scoring for Drop and Dash is time to complete. Event time will begin when the robot is released for its fall and stop when the robot has stopped in the finish box.



## 52. CHALLENGE 2 - OVER AND UNDER

<b>Performance Factors</b>	<b>Remote Tele-operated</b>	<b>1</b>
	<b>Autonomous Level 1</b>	<b>1.5</b>
	<b>Autonomous Level 2</b>	<b>2.5</b>

### 52.1 OBJECTIVE

The objective of “Over and Under” is to evaluate the robot’s ability to climb over an obstacle and then pass under a horizontal, overhead obstruction.

### 52.2 EVENT SET-UP

A 61 cm (2 ft) +/- 10% high wall at least 8.9 cm (3.5” thick) wall will be erected at a right angle to the robot’s course at a position to be selected by the organizers. The wall will have solid surfaces of wood or metal. After the wall an overhead obstruction/bar mounted 61 cm (2 ft) +/- 10% above the floor will be set at a right angle across the course. The overhead obstruction/bar will be located at least 2.0 m (78.74 in) after the wall. The exact nature of the wall and the overhead obstruction will be determined by the organizer. The overhead obstruction may be in the form of a tunnel.

### 52.3 PROCEDURE

The robot will proceed from the starting box, climb the wall, go under the obstruction/bar and into the stop box. If desired the robot may gently touch the bar/obstruction with a feeler/sensor device solely for location purposes. If the robot either: (1) dislodges the obstruction/bar from its holder or (2) touches the overhead obstruction/bar with anything other than the feeler/sensor the attempt will be classified as “did-not-finish” DNF.

Robots must scale the wall. Breaking through or moving the wall other than as part of the climb will be classified as “DNF”.

### 52.4 SCORING

Base score for Over and Under is time to complete.



### 53. CHALLENGE 3 – TUG-OF-WAR

<b>Performance Factors</b>	<b>Remote Tele-operated</b>	<b>1</b>
	<b>Autonomous Level 1</b>	<b>1.2</b>
	<b>Autonomous Level 2</b>	<b>1.5</b>

#### 53.1 OBJECTIVE

The object of “Tug-of-War” is to evaluate each robot’s pulling ability in comparison to the pulling ability of the other robots. This is a multi-robot event in which two or more robots will compete simultaneously.

#### 53.2 EVENT SET-UP

A scoring line will be designated, or marked out, at a right angle to the pulling line of the robots. As many pairs of robots as possible, allowing for reasonable spacing between machines, will be positioned along the scoring line.

#### 53.3 TIME LIMIT

The time limit for “Tug-of-War” is one minute (60 seconds) per match.

#### 53.4 PROCEDURE

Robots will pull against each other in a series of one-on-one matches. Each robot will pull in at least six (6) matches. The number of matches per robot may be increased, at the organizers discretion, if time and facilities permit.

Robots will be positioned, in pairs, at least 0.5meter (19.68 inches) apart on each side of the scoring lines. The exact distance between the robots will be determined by the organizer but, in general will not exceed 3.5 meters. Once in position the robots will be coupled through their connecting points by a cable or chain. On the starter’s signal each robot will advance and attempt to pull its opponent backwards over the designated scoring line. The robot that succeeds in pulling any part its opponent over the scoring line is the winner of that match.

#### 53.5 FORFEITS

Teams may elect to forfeit any match if their robot is malfunctioning.

#### 53.6 SCORING

Base scoring for Tug-of-War is the number of matches each robot wins. .



## 54. CHALLENGE 4 – TREASURE HUNT

<b>Performance Factors</b>	<b>Remote Tele-operated</b>	<b>1</b>
	<b>Autonomous Level 1</b>	<b>2</b>
	<b>Autonomous Level 2</b>	<b>3</b>

### 54.1 OBJECTIVE

The objective of “Treasure Hunt” is to evaluate the robots ability to identify and collect specific items from a field containing a mixture of items. This is a multi-participant event in which two or more robots will compete simultaneously.

### 54.2 EVENT SET-UP

50 red wood cubes approximately 19mm ( $\frac{3}{4}$ ”) +/- 5% on an edge will be scattered randomly on the field along with 100 black wood cubes also approximately 19mm ( $\frac{3}{4}$ ”) +/- 5% on an edge. There may also be items of no point value and minor obstructions on the course.

### 54.3 PROCEDURE

This is a multi-robot competitive event. A robot must identify and collect as many red blocks as possible within the event time limit and return the blocks to the designated return box.

At the starter’s signal the robots will advance onto the field and start to collect red cubes. Robots may return, as frequently as the team decides, to their designated return box to deposit cubes they have collected. Once a cube has been deposited in a return box it is out-of-play and may not be collected by another team.

Cubes must be carried free of contact with the floor. Cubes may not be pushed, dragged, rolled or otherwise moved into a return box while in contact with the floor.

Robots may block or otherwise interfere with other robots during the collection process and may take blocks from other robots on the competition field.

### 54.4 SCORING

The base score will be based on the number of red blocks collected and returned to the collection box within the specified time, less the value of any black blocks that were also picked up. Red blocks are worth positive twenty (+20) points, black blocks are worth negative twenty (-20) points. At the start of the event the sum of the block values on the field will be minus one thousand points (-1000) points. The indiscriminate collection of blocks is very likely to result in a negative score.



**Note** – The blocks are sized so that they can be readily cut from standard 1” thick (i.e. ¾” actual) commercial lumber.

## 55. CHALLENGE 5 – “COLLECT THE EGGS”

<b>Performance Factors</b>	<b>Remote Tele-operated</b>	<b>1</b>
	<b>Autonomous Level 1</b>	<b>1.2</b>
	<b>Autonomous Level 2</b>	<b>2.5</b>

### 55.1 OBJECTIVE

The objective of “Collect the Eggs” is to evaluate the robot’s ability to quickly perform a delicate task. This is a multi-participant event in which two or more robots will compete simultaneously.

### 55.2 EVENT SET-UP

Chicken eggs will be placed randomly at various points on the course. At least five (5) eggs will be placed for every robot running simultaneously. The eggs may be raw or cooked, natural or colored, at the discretion of the organizers.

### 55.3 PROCEDURE

This is a multi-robot competitive event. Each robot will be positioned at the starting line. At the judge’s signal the robots will advance onto the course collect as many eggs as possible and transport them intact across the designated finish line within the event time. Eggs must be lifted and carried clear of the floor. Eggs may not be rolled, pushed or otherwise moved across the finish line while in contact with the floor.

It is permissible to block other robots during the event, but it is **not** permissible to attempt to capture eggs already in the possession of other robots.

### 55.4 PENALTIES

Teams are expected to carefully avoid damaging/braking eggs they are not attempting to pick up. Eggs may not be stepped on. Breaking an egg that your robot is not trying to pick up or carry will incur a twenty (20) point penalty.

### 55.5 SCORING

Base scoring will be based on the number of eggs successfully collected by each robot and carried across the finish line unbroken. “Unbroken” is defined as having an intact shell. Eggs with closed cracks of the sort sometimes found on eggs bought at the supermarket count for score. Eggs that are broken, badly cracked, leaking fluid or have compressed shell segments do not count for score.



### *Scoring Formula*

*“Collect the Eggs” Base Score – 1000 x Eyours / Emax*

Where: “Emax” is the greatest number of eggs collected  
“Eyours” is the number of eggs your robot collected

## **56. CHALLENGE 6 – ENDURANCE AND OBSTACLE CHALLENGE**

<b>Performance Factors</b>	<b>Remote Tele-operated</b>	<b>1</b>
	<b>Autonomous Level 1</b>	<b>1.5</b>
	<b>Autonomous Level 2</b>	<b>3.0</b>

### **56.1 OBJECTIVE**

The objective the “Endurance and Obstacle Challenge” is to evaluate the robot’s durability, versatility and capability of operating in difficult terrain in an unstructured environment.

### **56.2 EVENT SET-UP**

The Endurance and Obstacle course may be set-up either indoors or outdoors depending on site availability. Although the event will typically be run on the standard course layout organizers may at their option develop an alternate course on a different pattern. Whether run on a basic or alternate course the total travel distance for the robot will typically be between 20 and 30 meters (66 to 98 ft) and the track width in the area of 3 meters (9.84 ft).

Obstacles on the course are not restricted and can include things to be maneuvered around as well as things to be transited. The obstacles could consist of:

- Automobile tires either singly, roped together or piled.
- Inclined surfaces not exceeding +/- 25 ° with no particular orientation
- Lumber and logs
- Gravel, sand, stone and chunks of concrete
- Steps and low walls
- Other unknown objects and surfaces selected by the organizer

As general guidelines: (1) single obstacles the robot would need to cross will not exceed 0.33 m (13.12 inches) in height, (2) long inclined surfaces will exceed 0.33 m but will not exceed a +/- 25 ° slope, (3) sets of steps may exceed 0.33 m, but individual steps will not exceed 0.20 m (7.4 inches).



### **56.3 STANDARD COURSE LAYOUT**

The course is divided into 3 sections each of increasing difficulty. Section 1 is the first part of the basic course: boxes 1, 2 and 3. Section 2 is the middle part of the course: boxes 4, 5 and 6. Section 3 is the final part: boxes 7, 8, 9. If the event uses the basic course layout then the procedure will follow the “standard procedure” below.

### **56.4 ALTERNATE COURSE LAYOUT**

If an alternate course is used then it will be laid out in 3 bounded sections each of increasing difficulty and with a starting line at the beginning and finish line at the end. The boundary lines for all parts of the course will be clearly marked. The precise layout and structure of alternate courses will be determined by the organizers.

### **56.5 “NO-GOING-BACK” RULE**

Once a robot has crossed a section boundary it may not return to, or overhang, the section it has left. If a robot overhangs or moves into a section it has left it is declared DNF.

### **56.6 TIME LIMIT**

The time limit for completing all three sections of the endurance course is twelve minutes (720 seconds)

### **56.7 STANDARD PROCEDURE**

The robot will be placed in box 1 with the designated front end oriented toward box 3. After the start signal the robot will proceed from box 1 to box 3 while remaining within completely within section 1. From box 3 the robot will maneuver into box 6. Once the robot is entirely over the 3/6 boundary into Section 2 it has completed the first leg of the course.

At this point the “No-going-back” rule comes into effect. From box 6 the robot will proceed to box 4 while remaining entirely within Section 2. From box 4 the robot will maneuver into box 7 and pass into Section 3. Once the robot is entirely over the 4/7 boundary into Section 3 it has completed the second leg of the course.

From box 7 the robot will proceed to box 9 while remaining entirely within Section 3.

Once the robot has passed completely into box 9 it has completed the third leg of the course.



Obstacles may be placed anywhere in boxes 2 through 9 at the discretion of the organizers.

## **56.8 ALTERNATE PROCEDURE**

Robots will be staged at the starting line and on the starters signal will proceed along the course and over the finish line respecting all boundaries in the process. The “No-going-back” rule is effective as the robot passes the boundaries between sections.

Once the robot is entirely past the boundary into Section 2 it has finished the first leg of the course. Once the robot is entirely over the boundary into Section 3 it has finished the second leg of the course. Once the robot has completely passed the finish line it has finished the third leg of the course

Obstacles may be placed anywhere on the course at the discretion of the organizers.

## **56.9 SCORING**

Endurance is scored based on the time taken to complete each leg. Each Endurance leg is scored individually, so the maximum possible score is considerably higher than it is for other events.

If a robot fails during leg 1 no points are awarded. If a robot fails during leg 2, points are awarded for leg 1. If a robot fails during leg 3, points are awarded for legs 1 and 2.

Teams have a maximum of twelve (12) minutes to complete Endurance (i.e. 12 minutes to complete all three legs). Teams may make two trials as covered by rule 44.10 “Second Attempts”.

Robots are not required to come to a stop to signal they have completed the first or second legs; the judges will simply record the elapsed time at which the robot crosses the appropriate boundary

Operating modes may not be changed between legs. If a team attempts Endurance autonomously then all three legs must be run autonomously.

Rule 45.2 “Robot Isolation” applies throughout the event. Teams may not touch their robots between legs. For example, teams may neither change batteries, air tanks, or attachments nor make repairs.

The robot must come to a complete stop after passing into box 9, or crossing the finish line, to signal it has finished the attempt.



## **SECTION 6 - FUTURE SAE ROBOT SYSTEMS CHALLENGE HOSTS**

Future SAE Robot Systems Challenges are scheduled to be hosted by the following universities and organizers:

**2006** – Universidad Pan Americana, Mexico City DF – Alejandro Gonzalez Hernandez

**2007** – York College, York, Pennsylvania – Dr. James A. Kearns

**2008** – Universidad Panamericana, Guadalajara, Mexico - Víctor González Belmonte

**2009** – Union College, Schenectady, New York – Dr. Nicholas Krouglicof



APPENDIX 1

**Action Deadlines**

**2005 SAE Robot Systems Challenge  
ETS, Montreal, Quebec, Canada  
April 28 - 30, 2005**

**Note: All Submissions Must Be RECEIVED By the Deadline**

- **Registration – Opens October 4, 2004**  
Register online at: [www.sae.org/students/student.htm](http://www.sae.org/students/student.htm)
- **Early Registration Fee - US\$500.00**  
**Early Registration Deadline – January 31, 2005**
- **Late Registration Fee - US\$600.00**  
**Late Registration Deadline – March 5, 2005**

**Technical Paper submission deadline – Midnight Eastern Standard Time  
Tuesday, April 12, 2005**

**Technical Papers must be submitted electronically as .pdf or Word files  
See rules Section 33.2.3 “Technical Paper Format”**

**Submit Technical Papers to: .....To Be Announced**

**Rules questions and inquiries regarding the organization of the 2005 Robot Systems  
Challenge should be emailed to .....To Be Announced**



## APPENDIX 2

# SAE Robot Systems Challenge Technical Inspection Form

**University** \_\_\_\_\_ **Robot Number** \_\_\_\_\_

The robot system's design and fabrication must follow sound engineering principles.

**Functionality** – Must theoretically be capable of accomplishing all the challenges.

**Dimensions** – Maximum height 1.0 m (39.37 inches), maximum width 0.66 m (25.98 in)

**Weight** – Robot 50 kg (110 lb) max; Robot with one attachment 60 kg (132 lb) max

**Lift Handles/Lift Points** – Must have adequate and identifiable lift handles/lift points

**Power Source** – Internal combustion engines are prohibited

### **Electrical Systems** –

- (1) Source - Batteries or photocells
- (2) Isolation – The electrical system must be properly isolated from all components not part of the system.

### **Pressure Systems** –

- (1) Tanks & Regulators - All pressure vessels and pressure regulators must be certified and bear current and correct certification labels.
- (2) Fitting - All fittings and plumbing in the pressure system must be certified to meet or exceed the pressure requirements of the system.
- (3) Location - All pressure vessels and pressure regulators must be contained within the frame of the machine.
- (4) Documentation – Teams must be prepared to present documentation of the pressure system components and/or any applicable certification.

### **E-Stops** –

- (1) Location/Identification - Must be on the robot's upper surface, easily reached and clearly identified.
- (2) Functionality – Must comply with the E-Stop requirements

**Lasers** – Must conform to the CDR Class II safety requirements

**Pinch Points** – All pinch points must be properly identified and marked.

**Identification** – Must bear (1) assigned number, (2) school name and (3) robot name