The Eighth Annual

Autonomous Snowplow Competition

Rulebook

Revision 2018.1

Saint Paul Winter Carnival
Saint Paul, MN
25-28 January 2018

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1 Introduction

The Institute of Navigation (ION) and its Satellite Division are pleased to announce the **Eighth Annual Autonomous Snowplow Competition (ASC)**. This competition is operated and managed by the ION North Star Section based in Minneapolis, MN.

The competition is directly sponsored by ION's Satellite Division, as well as founding and current sponsors Lockheed Martin Corporation, Honeywell International Inc., ASTER Labs, Inc., Orbital ATK Inc, U.S. Bancorp, The Toro Company, SICK, Inc., Polaris Industries, Inc., John Deere and Company, UTC Aerospace Systems, Space Exploration Technologies Corp., Oshkosh Corporation, Left Hand Robotics, WESTERN Snow and Ice Control, ANSYS, Proto Labs, Inc., Nuts and Volts Magazine, Servo Magazine, Hitching Post Motorsports, and the Achievement Rewards for College Scientists (ARCS) Foundation..

The objective of the ASC is for teams to design an unmanned snowplow vehicle that will autonomously remove snow from pre-defined paths. The competition invites and challenges teams in the area of high-performance autonomous vehicle guidance, navigation, and control. The competition is also designed to encourage student interest in the areas of science, technology, engineering, and mathematics.

ASC teams are required to build snowplow vehicles to autonomously remove snow from two snowfields within a set amount of time. The two snowfields have straight 'I'-shapes. The first snowfield has a single 'I'-shaped path. The second snowfield has three parallel (side-by-side), or triple, 'I'-shaped paths. Teams can implement navigation-aiding systems surrounding the snowfields to aid the snowplow vehicle's navigation systems; however, there can be no direct human control of the vehicle during the plowing operation.

The Eighth Annual Autonomous Snowplow Competition will take place during a competition week held in conjunction with the annual Saint Paul Winter Carnival in January 2018 in Saint Paul, MN. The competition week will be composed of the following events:

- Thursday, 25 January 2018: Teams will present their final snowplow vehicle designs to a judge panel and the general public.
- Friday, 26 January 2018: Teams will demonstrate the operability and safety of their snowplow vehicles.
- Saturday, 27 January 2018: Teams will compete on the single straight 'I'-shaped snowfield.
- Sunday, 28 January 2018: Teams will compete on the triple straight 'I'-shaped snowfield.

Teams will be judged throughout the design phase of the ASC and all competition week activities. In the design phase of the competition, teams will be evaluated on their snowplow vehicle concepts and their presentation skills during a Preliminary Design Review (PDR). This PDR will be held in November 2017, approximately two months after all the entry applications have been received. During the competition week, teams will be judged on their snowplow vehicle design, presentation of their final designs, and their vehicle's performance removing snow from the two competition snowfields.

The Thursday night Final Student Presentation event will be held at:

The Science Museum of Minnesota
120 W. Kellogg Blvd.
St. Paul, MN 55102

The event will begin with a social hour, where ASC teams will have an opportunity to meet members of the other ASC teams, the ASC Officials, ASC Judges, the ION Executive Committee, and members of the public. Easels will be provided for teams if they would like to present a poster or similar display of their snowplow vehicle design during this social hour.

A Final Qualification Review (FQR) Vehicle Demonstration and Safety Inspection will be conducted on Friday of the competition week. This FQR demonstration and inspection is conducted prior to the dynamic competition to ensure the snowplow vehicles satisfy the ASC design, operability, and safety requirements defined within this rulebook.

The Friday snowplow vehicle FQR and the Saturday through Sunday dynamic competitions will be held at the snowplow competition field located at:

W. 4th St (between N. Washington St. and N Market St.)
Saint Paul, MN
(South of Rice Park and the Landmark Center, and in front of the Public Library)

The ASC will award prizes to teams in all phases of the competition. Teams that accumulate the most number of points during the PDR and competition week will be awarded cash prizes and trophies. The winning team will be invited to display their snowplow vehicle and present their winning snowplow vehicle designs at the annual ION Global Navigation Satellite System (ION GNSS+) Conference. The best student presentation during the Final Presentation event during the competition week will be awarded the Golden Shovel Award. The team demonstrating the most enthusiasm and spirit throughout the competition will be awarded the Dr. Nattu Golden Smile Award.

In addition to the competition prizes, student teams may apply for grants through the ION to support their travel costs to the competition week.

2 General Information

2.1 Team Rules

2.1.1 Team Composition

The ASC welcomes teams comprised of high school, college, university undergraduate and graduate students, and members of the general public. All team members must be 18 years or older.

All ASC teams, including teams comprised of members of the general public, must have at least one student member. The student members of ASC teams are entirely responsible for performing the PDR and Final Presentations. Teams comprised primarily of high school, college, or university students should have a faculty advisor. Student teams are encouraged to invite students from all technical or engineering programs, as well as students from business programs, to design and promote the snowplow vehicle, solicit funding, and perform program management responsibilities.

Colleges, universities, and institutions are welcome to enter more than one team into the ASC. Multiple teams may compete using the same snowplow vehicle. However, no team members may be in common between any competition team. Furthermore, each team's navigation aiding system must be designed independently and these unique designs must be clearly evident to the ASC Judges. Multiple teams from the same institution are required to independently prove their designs are unique. If multiple vehicles are entered from the same institution, then a different team must design each snowplow vehicle. Faculty advisors are allowed to advise more than one team. Each ASC team must submit a separate ASC Application Form accompanied with the full team entry fee.

2.1.2 Team Sponsorship

ASC teams are responsible for acquiring their own funding to design and build their snowplow vehicles. The competition organizers will work to gain sponsorship to provide partial funding for the competition week through travel grants; however, all ASC teams are responsible for their own travel to the competition venue. Therefore, ASC teams are encouraged to solicit sponsors to fund their team entry. Documentation from the ASC website can be used to provide potential sponsors with information about the ASC.

Sponsors are allowed to provide funding or hardware for teams. Furthermore, teams can place sponsor logos on their snowplow vehicle or navigation aiding sources, and can also place sponsor banners at the competition week's events.

2.1.3 Competition Application Procedures

Teams are required to enter the ASC by submitting a completed ASC Application Form. The ASC Application Form can be downloaded from the ASC website. Each ASC team entry must be documented by a separate ASC Application Form.

Each ASC Application Form must be accompanied by a non-refundable registration and entry fee of $100.00 made payable to: **Institute of Navigation**. For credit card payments, please contact the Institute of Navigation National Office at the phone number below. This entry fee includes a complementary one-year ION professional membership for the team's advisor.

The ASC Application Form must contain an **Indemnification Agreement** executed by an individual from the team's sponsoring institution who has authority to bind the institution for which he or she signs. Additionally, each team is required to provide a Certificate of Insurance to the ION North Star Section at the time the Application Form is submitted. This Certificate of Insurance may be supplied by the team's sponsoring institution or by a commercial insurance company, and it must show commercial general liability coverage in an amount not less than $1 million (US).

The completed ASC Application Form, the Application Fee, and the Certificate of Insurance are to be submitted to the ION National Office, as noted on the ASC Application Form, and must be received/postmarked no later than

15 September 2017.

This deadline is provided to support schools that start their semester in early September.

Please note that we highly recommend that all ASC teams apply as early as possible, and begin the design and development of their snowplow vehicles long before this deadline.

Each ASC team must inform **both** the ION National Office and the ION North Star Section of its intention to compete in the ASC. Mail, fax, or email a copy of the completed, signed ASC Application Form and Certificate of Insurance to **both** of the following:

Autonomous Snowplow Competition
The Institute of Navigation
Lisa Beaty, Executive Director
8551 Rixlew Lane, Ste. 360
Manassas, VA 20109-3701
lbeaty@ion.org
Phone: 703-366-2723
Fax: 703-366-2724

Dr. Suneel I. Sheikh
North Star Section Outreach Chair
ASTER Labs, Inc.
155 East Owasso Lane
Shoreview, MN 55126-3034
sheikh@asterlabs.com
Phone: 651-484-2084
Fax: 651-484-2085

2.2 Website

The main source for information about the ASC is via the competition website, which includes contact information for communication with the ASC Officials and Judges:

www.autosnowplow.com

This website contains general information about the competition, competition documentation, past event information, current sponsors and sponsorship information, and competition contact information.

The ASC documentation available on the website includes the ASC Application Form, the ASC Rulebook, and ASC flyers. Outlines of the PDR Presentation format and Final Presentation format are available on the website, and will also be sent directly to ASC teams during the competition.

2.3 Timeline

The timeline for the ASC is provided in Table 1. The timeline is designed to give teams time to design and build their snowplow vehicles culminating with the competition week held in conjunction with the Saint Paul Winter Carnival, 25-28 January 2018.

The Saint Paul Winter Carnival will be celebrating its 132nd anniversary in 2018. ASC teams are encouraged to enjoy and participate in the Saint Paul Winter Carnival activities as much as time permits.

Table 1. Competition Timeline

Entry Application Deadline	15 September 2017
Kickoff Meeting With Teams	11 October 2017, 6:00 PM
PDR Presentation Slides Due	2 November 2017, 9:00 PM
PDR Presentations By Teams	4 November 2017, 9:00 AM
PDR Scores To Teams	2 December 2017
Interim Status Meeting with Teams	13 December 2017, 6:00 PM
Final Status Meeting with Teams	10 January 2018, 6:00 PM
Final Presentations By Teams	25 January 2018, 4:30 PM
FQR Vehicle Demonstration and Safety Inspection	26 January 2018, 1:00 PM
Saint Paul Winter Carnival Grand Day Parade	27 January 2018, 2:00 PM
Single Straight ‘I’-Shaped Snow Path Competition	27 January 2018, 8:00 AM
Triple Straight ‘I’-Shaped Snow Path Competition	28 January 2018, 9:00 AM
Competition Awards Ceremony	28 January 2018, 4:00 PM

*Note: All times listed are U.S. Central Time Zone

2.4 Document Revision History

The ASC Rulebook is provided to teams as soon as the competition has been defined. ASC Officials reserve the right to update the Rulebook during the competition.

Revisions to the rules will be provided based upon competitor feedback and contest limitations. Teams are encouraged to monitor the ASC website for the latest competition information and versions of the ASC Rulebook.

ASC Rulebook Versions

- Version 2018.1
    - Initial Draft released to competitors
    - New Sponsors list
    - Collaborative Operational Challenge introduced

3 Autonomous Snowplow Contest

3.1 Overview

The objectives of the ASC are to design and operate an autonomous, unmanned snowplow vehicle to quickly and accurately clear snow from two rectangular snowfields using the art and science of guidance, navigation, and control. ASC teams are judged based upon their cumulative scores earned throughout the competition phases:

- 75% of the total score is based upon the dynamic plowing competitions; and
- 25% of the total score is based upon the presentations.

3.2 Rules and Regulations

3.2.1 Snowplow Vehicle Design

The ASC is designed to challenge teams in the areas of high-performance autonomous vehicle guidance, navigation, and control. In addition to these challenges, the ASC also provides teams with interaction and feedback from industry experts throughout the entire design process from initial concept design through to the dynamic snowplow competition.

The ASC welcomes all innovative designs for a snowplow vehicle. However, as in any industry design of a concept vehicle, the vehicle must satisfy certain requirements for design, cost, and marketing purposes. Therefore, the ASC Officials have imposed several constraints on the snowplow vehicle design that would exist for vehicles used to remove snow from sidewalks or driveways, as well as to satisfy safety and practicality constraints:

1) Snowplow vehicles shall be autonomous and unmanned, and they shall not be remotely controlled during the competition. During the dynamic snowplow competitions, the snowplow vehicle may be moved from the snowplow staging area to the competition snowfields with human assistance. However, the snowplow vehicle must not receive human assistance while it is removing snow from a snowfield. Any team whose snowplow vehicle receives human assistance while removing snow from a snowfield will be disqualified from that portion of the competition and receive zero points for that portion of the competition. *Remotely controlled* includes, but is not limited to: commands to modify or reset the snowplow vehicle's computers, commands to reinitialize the snowplow vehicle, commands to adjust a plowing route, etc.

2) For safety reasons, each snowplow vehicle has a speed limit of **2 m/s** that shall be strictly enforced.

3) The snowplow vehicle must be equipped with an Emergency Stop System (ESS), which consists of both a physical power-off switch and a wireless remote power-off switch that independently removes power from the vehicle's drive system. The physical, or manual, power-off switch must be easily identifiable and easily accessible to a person walking behind the snowplow vehicle. This switch must be located on the top surface of the vehicle and there shall not be any other protruding objects within a **30 cm** radius of the switch. This emergency stop switch shall be **red** in color and have a diameter of at least **40 mm**. The wireless remote power-off switch shall remove power from the vehicle's drive system when a signal from the wireless control unit switch is received. The wireless remote power-off switch must have a minimum range of **50 m**. The snowplow vehicle shall cease operation and come to a complete stop within **3 meters** upon activation of either the physical or wireless remote power-off switch. The ESS shall not have a single point of failure, such that no single failure in the ESS or the vehicle shall inhibit the ESS from removing power from the vehicle's drive system. It is recommended that the ESS not process data through or require computer operation for the emergency stop. The ESS power cut-off capabilities of the snowplow vehicle must be demonstrated at the competition FQR Vehicle Demonstration and Safety Inspection. Snowplow vehicles that are determined to be unsafe or fail to meet the ESS requirements, as specified herein and as determined by the ASC Judges, shall not be allowed to participate in the competition.

4) The snowplow vehicle and any of its attachments must not exceed **2 m** in any dimension.

5) The plowing action may be completed using a fixed plow blade and/or rotating brushes. Rotating brushes must operate such that no hard object (ice, pebble, etc.) can be ejected at a speed that will harm a person. No *snowblowing* – using an auger to ingest snow and shoot to eject snow – implements are allowed.

6) The ASC will take place on a downtown city street that has a ground surface made of brick. The City of Saint Paul has added the following constraints on the design of the snowplow vehicle tires to preserve the brick surface: the tires shall not be augmented with metal rivets, spikes, or chains to gain traction. Knobby, rubber winter tires are allowed. Other plastic or rubber augmentations to the tires are allowed. For example, metal wire coated with plastic or vinyl insulation may be wrapped around tires for traction. However, if the insulation jacket becomes damaged exposing the underlying wire, then the coated wire must be replaced prior to operating on the snowfield.

7) The snowplow vehicle must be self-powered and contain no power source external to the vehicle. Power shall either be by combustible fuel, batteries, or both. Other power sources must be cleared with the ASC Officials prior to the competition.

8) The plowing action shall be accomplished through direct contact with the ground surface.

9) The snowplow vehicle must be equipped with an electrical ground.

3.2.2 Final Qualification Review Vehicle Demonstration and Safety Inspection

The Final Qualification Review (FQR) Vehicle Demonstration and Safety Inspection is an opportunity for ASC teams to display their snowplow vehicles to the ASC Judges and demonstrate that their snowplow vehicles satisfy the design requirements and constraints. ASC teams must demonstrate the following at the FQR:

- Their snowplow vehicle and navigation-aiding sources satisfy the ASC design constraints including vehicle dimensions, power, and electrical ground.
- The operability of both the physical power-off switch and remote power-off switch of the ESS.
- Their snowplow vehicle satisfies the ASC speed limit requirements by displaying their speed limit software, speed control hardware, and by running their snowplow vehicle at its maximum speed.
- Their snowplow vehicle can operate autonomously.

ASC teams are allowed to modify their snowplow vehicles or navigation-aiding sources should they fail their initial FQR Vehicle Demonstration and Safety Inspection and resubmit their vehicle or aiding sources for review. Any physical modifications to the vehicle require a new review to verify that vehicle safety and other requirements are met. Once a snowplow vehicle and navigation-aiding sources have passed the FQR Vehicle Demonstration and Safety Inspection, ASC teams are not allowed to modify their vehicle's speed limit software or speed control hardware. ASC teams are allowed to modify their guidance, navigation, and control software any time during the competition subject to competition time limits.

The FQR Vehicle Demonstration and Safety Inspection will take place on Friday of the competition week at the competition field in downtown Saint Paul. The FQR Vehicle Demonstration and Safety Inspection will begin as noted in Table 1 with a schedule published by the ASC Officials in advance of the competition week. Each team will be given an initial 15 minute time period during which the ASC Safety Judges will ensure that the snowplow vehicle and navigation-aiding sources satisfy the competition rules. If a team initially does not pass the FQR Vehicle Demonstration and Safety Inspection, then the team will be given as many inspections as needed until 6:00 pm on Friday evening to satisfy the ASC Safety Judges that the snowplow vehicle and navigation-aiding sources satisfy the competition rules. The decisions of the ASC Judges are final.

During the FQR Vehicle Demonstration and Safety Inspection period, all ASC teams will be given the opportunity to view the competition snowfields and test their snowplow vehicles on a practice area at the competition site. ASC teams may not test their vehicles within the dynamic competition area during the FQR Vehicle Demonstration and Safety Inspection period.

3.2.3 Competition Plowing

1) The snowplow vehicles will be required to start autonomous operation in the Vehicle Starting Zone (Garage) and plow within the Snow Path areas.

2) The timer to begin each plowing run will be started from zero when the snowplow vehicle is within the Vehicle Starting Zone and the ASC teams and ASC Safety Officials declare they are ready.

3) The Snow Path has buffer zones extending from their outer boundaries called the Vehicle Starting, Maneuvering, and Plowed Snow Zones. A snowplow vehicle must stay within these boundaries at all times once it begins to clear snow from the Snow Path.

4) If any part of the snowplow vehicle extends outside the prescribed Vehicle Starting, Maneuvering, or Plowed Snow Zones, the ESS power-off switch shall be activated, and the vehicle must be moved back into the nearest plowed square-meter section of the Snow Path before a plowing run may be resumed. A penalty will be assessed for this boundary infraction as detailed in the scoring section below.

5) Teams are permitted restarts during each competition run. The snowplow vehicle must be repositioned back into the Vehicle Starting Zone for a restart. If an ASC team chooses to restart, then a penalty will be assessed as detailed in the scoring section below.

6) Teams have a maximum of 20 minutes to clear snow from the Snow Path. The 20 minutes refers to the total plowing time allowed, and it includes the initial navigation-aiding sources set up, the initial competition plowing run, and possible plowing run restarts.

7) Team members, snowplow vehicles, or navigation-aiding sources may not touch any snow in the Snow Path prior to beginning a competition plowing run.

8) The snowplow vehicle should be designed to operate in any weather condition. In the event of severe weather, the competition may be postponed. The decision to postpone an event shall be made by the ASC Officials.

9) The snowplow vehicle may be equipped with eye-safe (Class 1) lasers. However, the lasers must be affixed to the snowplow vehicle and pointed towards the ground, with an angle at or below the local horizontal plane of the laser device. If lasers are used on the snowplow vehicle, then the laser harness and mounting to the vehicle must be displayed during the FQR Vehicle Demonstration and Safety Inspection. If requested by ASC Officials, then the team is obligated to provide proof (sensor's certification sticker is sufficient) that the laser complies with Class 1 regulations.

10) Teams may place multiple navigation-aiding sources surrounding the Snow Path, but the sources must remain within the Maneuvering Zones and/or Plowed Snow Zones. These navigation-aiding sources must be stationary following their placement within the competition area.

11) Teams that choose to place navigation-aiding sources surrounding the Snow Path must begin their competition run with all aiding sources and team members who are placing the aiding sources located within the Team and Navigation Aids Starting Zone prior to the start of their plowing run. Once the timer starts for the team's plowing run, the team members may move out of the Team and Navigation Aids Starting Zone and place their navigation-aiding sources around the Snow Path. A maximum of six team members are allowed in the Team and Navigation Aids Starting Zone at the start of their run and for placement of the navigation-aiding sources. The placement of these aiding sources and any associated field surveys must be completed within the 20-minute allotted competition time.

12) A secondary navigation-aiding source zone will be provided to teams for placement of remote navigation aids requiring longer set up time (e.g. differential GPS stations). This secondary navigation-aiding source zone will be located on the competition event site, but not directly within the snowfield boundaries. Teams cannot be assured of direct line of sight between this zone and a competition field, as this zone may be blocked by competition structures, competition volunteers, other competitors, or other aids. Set up for these remote navigation-aiding sources will not count towards the 20-minute allotted competition time.

13) The navigation-aiding sources may be actively emitting signals (e.g. radio, ultrasonic). If active, these navigation-aiding sources must be self-powered.

14) The ESS must be operational and active anytime the snowplow vehicle is in operation at or near the site of the competition.

15) Neither the snowplow vehicle nor the navigation-aiding sources may expel any fluids or objects of any kind within the snowfield competition boundaries. This ensures the road surface and snowfield conditions will remain identical for all teams. Snowplow vehicle plow blades may not be heated, as this will cause plow snow to melt and act as an expelled liquid.

16) At the end of a competition plowing run, the snowplow vehicle must autonomously return and park within the Vehicle Starting Zone (Garage) on the snowfield. A penalty will be assessed if no portion of the snowplow vehicle is parked within this zone. The snowplow vehicle must remain within the snowfield boundaries as it returns to the Vehicle Starting Zone (Garage).

17) No team member, snowplow vehicle, or navigation-aiding source is allowed on the competition field after hours of operation, as posted by ASC Officials. This limitation is for safety and insurance reasons.

3.2.4 Competition Procedures

Prior to a competition run, ASC team members may move their snowplow vehicle directly into the Vehicle Starting Zone on the competition snowfield, with the assistance of ASC Safety Officials. Teams can use the vehicle's power supply to maneuver their vehicle into the Vehicle Starting Zone. The vehicle can be turned off (unpowered) until the competition run officially begins, unless necessary for vehicle operation (e.g. provide heat to systems, keep navigation aids active). If the vehicle is turned on, then teams must have their ESS system active to ensure the vehicle can be turned off immediately by an ASC Safety Official as necessary. Teams should notify ASC Safety Officials of their intent of powered operation prior to starting a competition run.

For those ASC teams who place navigation-aiding sources around the snowfield prior to their competition run, team members and their navigation-aiding sources must move into the Team and Navigation Aids Starting Zone and remain there until the run begins.

Each ASC team is given a total of 20 minutes for their entire snowfield set up and competition run. An ASC team's run commences upon notification by the ASC Marshal. Snowplow vehicles can then be powered on (started) and ASC team members can leave the Team and Navigation Aids Starting Zone and relocate their navigation-aiding sources within the Maneuvering Zones and/or the Plowed Snow Zones as required by the team's design. Teams may initiate plowing operation at any time during their allotted 20 minutes to enable their snowplow vehicle to clear snow from the Snow Path.

Once an ASC team's 20 minute plowing window is completed, the team must take their snowplow vehicle and navigation-aiding sources back to the staging area. The ASC Judges will then assess the performance of the snowplow vehicle on the Snow Path, and the ASC Snow Pit Crew will prepare the Snow Path for the next ASC team.

The ASC Marshal will oversee the snowplow vehicle competition schedule to ensure that the ASC events begin and end as scheduled.

Before an ASC team turns on their snowplow vehicle within the competition snowfield, the team must show the ASC Safety Official the operation of the remote power-off switch. A single member of the ASC team will then maintain control and operation of the remote power-off switch. Along with an ASC Safety Official, this single member will remain outside but adjacent to the snowfield boundaries while a team's snowplow vehicle is clearing snow from a Snow Path to operate the power-off switch or declare a restart. After a boundary zone infraction, a power shut down, or a declared restart, the remaining ASC team members are allowed within the snowfield boundaries to assist with repositioning the vehicle to either the nearest plowed square-meter section of the Snow Path or back to the Vehicle Starting Zone. ASC team members must minimize the amount of uncleared snow disturbed while repositioning their vehicle at the direction of the ASC Marshal. The ASC Safety Officials have the authority to engage either the physical power-off switch or remote power-off switch if the snowplow vehicle should travel outside the Vehicle Starting, Maneuvering, or Plowed Snow Zones. The decisions of the ASC Marshal and Safety Officials are final.

3.3 Snowfield Specifications

The ASC will take place in downtown Saint Paul, MN. The snowfield competition location is W. 4th Street on the south end of Rice Park between N. Washington and N. Market streets. This street will be closed to traffic from Friday through Sunday of the competition week to facilitate the FQR Vehicle Demonstration and Safety Inspection and the dynamic plowing competitions. The street has a brick surface and the ASC Officials will make every attempt to ensure that the snowfield paths are evenly constructed and fair for all ASC teams. This street is located in an urban environment with tall city buildings surrounding the snowfields.

The ASC has two competition snowfields, which include a **single straight 'I'-shaped** path, shown in Figure 1, and a **triple straight 'I'-shaped** path, shown in Figure 2. The dimensions of the two Snow Paths as well as the Vehicle Starting, Team and Navigation Aids Starting, Maneuvering, and Plowed Snow Zones are provided in these figures.

For both Snow Paths, the snow depth will vary between **5.0 to 15.0 cm**. The decision of the snow depth variation is strictly up to the ASC Marshal's and Judge's discretion and will be implemented as part of the competition day setup. ASC teams should anticipate this variation during their snowplow vehicle design and development. The ASC Officials will make every effort to ensure that the snowfield paths have the same total quantity of snow for each ASC team, but the snowfield path depth and the snow consistency cannot be guaranteed to be exactly the same for each ASC team.

The external boundaries of the Vehicle Starting, Maneuvering, and Plowed Snow Zones will be marked with PVC pipe, wood strips, metal bars, web strapping, or markings on brick pavement. These boundaries and zone markings will be obvious to ASC team members, Officials, and the viewing public.

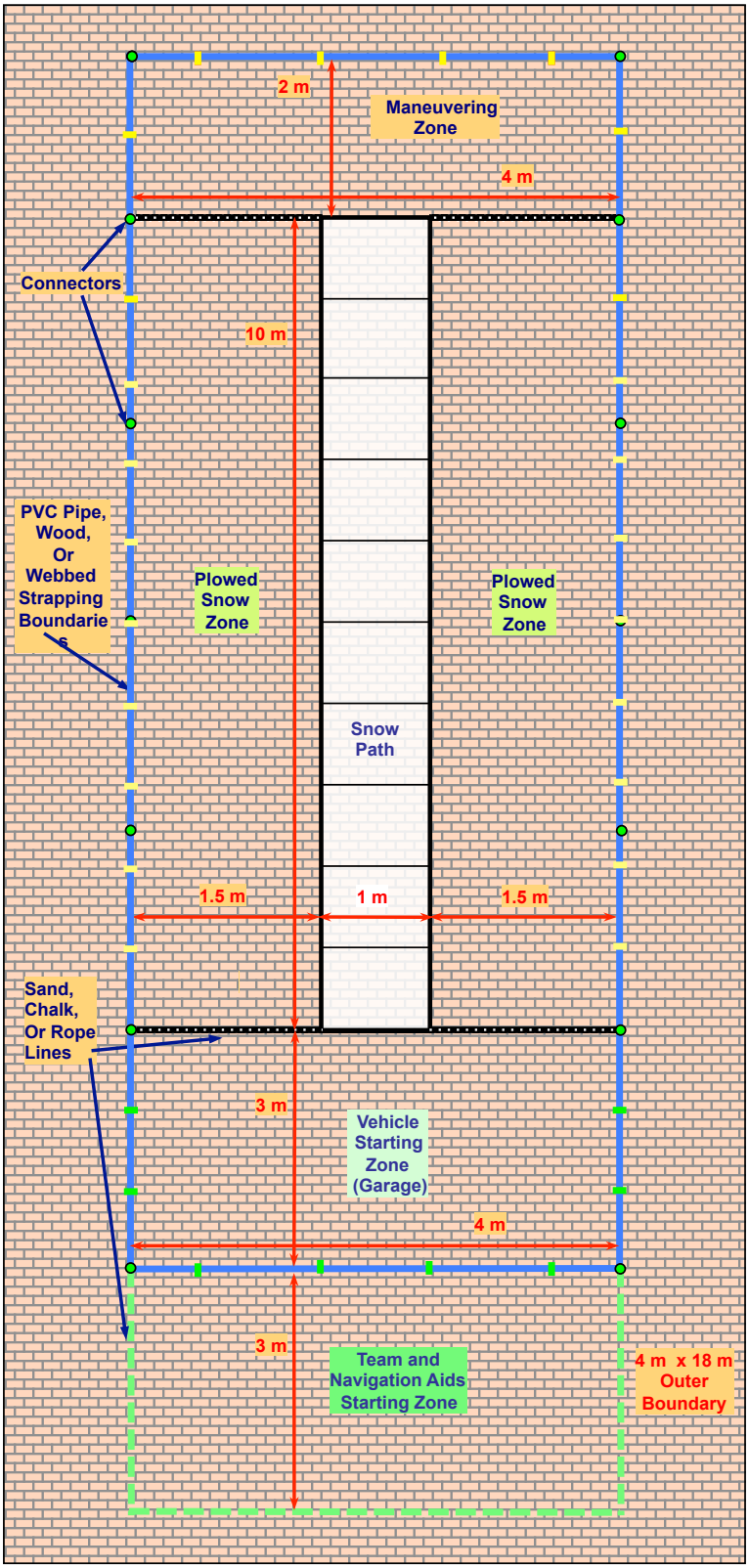

Figure 1. Single straight 'I'-shaped competition path snowfield diagram.

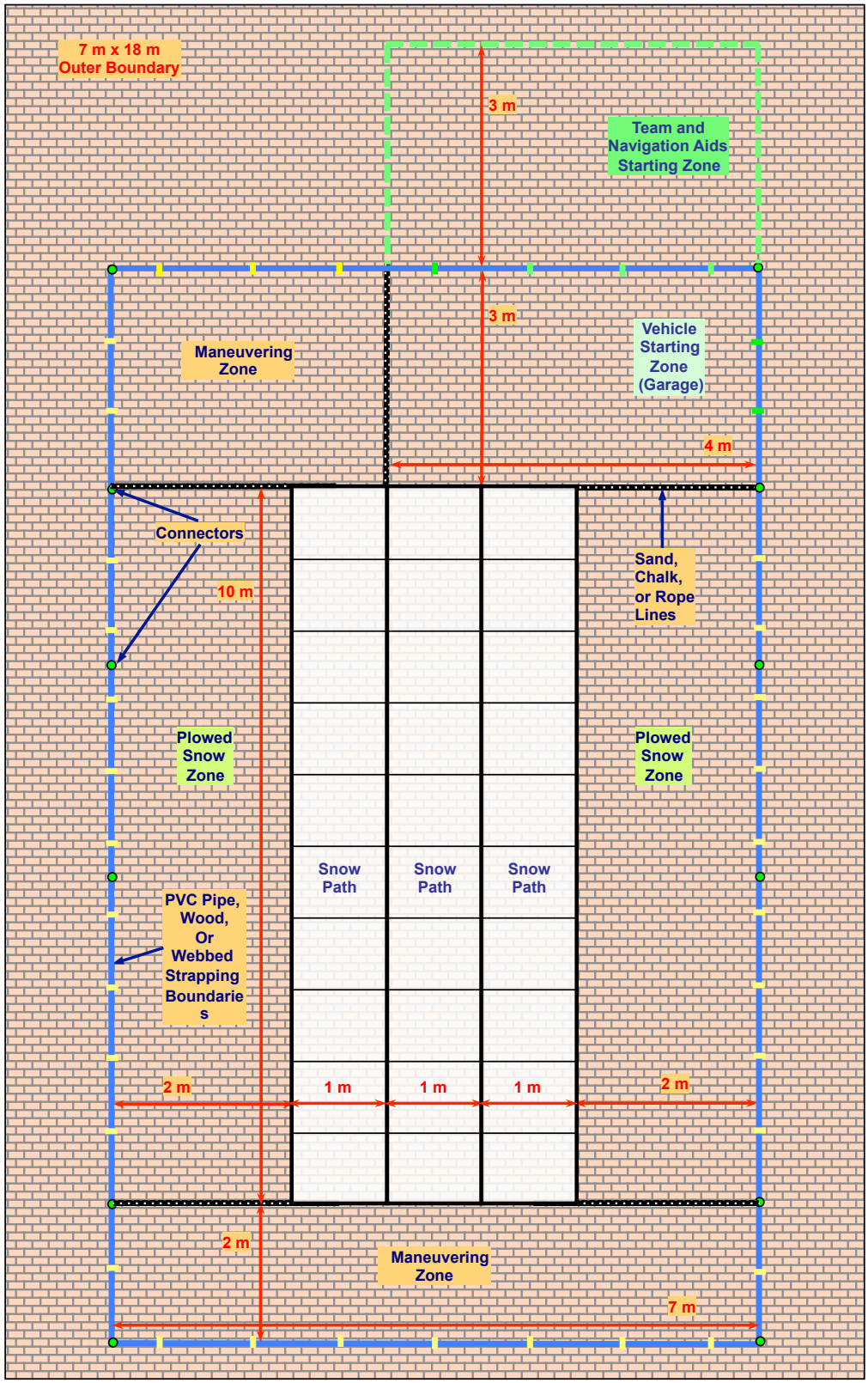

Figure 2. Triple straight 'I'-shaped competition path snowfield diagram.

3.3.1 Simulated Posts

Many house driveways have adjacent trees and city sidewalks typically have parking meters. Some of these objects are located near but do not interfere with a snowplow vehicle when plowing a path or driveway. Other objects that are located on a sidewalk or driveway will interfere with the snowplow vehicle's path, and must be avoided by a snowplow vehicle.

To simulate fixed objects within the competition snowfield, two fixed posts, approximately **1.5 m high by 0.2 m** wide, will be placed within the boundaries of the competition field during both dynamic competition runs. These fixed posts will be included within both the single straight 'I'-shaped (Saturday) and the triple straight 'I'-shaped (Sunday) snowfields. Random locations for these posts for each ASC team run will be chosen by the ASC Marshal and Judges. The placement of these fixed posts will occur immediately prior to a team's 20-minute competition run.

The first fixed post will be placed directly within the Snow Path. The 1-m^2 section in which the first fixed post is placed will not have any snow, so it does not need to be plowed by the snowplow vehicle. The second fixed post will be placed within the Maneuvering or Plowed Snow Zones outside of the Snow Path.

The fixed posts are considered part of the competition snowfield and no objects, such as navigation aids, may be physically attached to these posts by the ASC teams during their plowing run.

Snowplow vehicles must avoid each fixed post, and ASC teams will be assessed a penalty if any part of their snowplow vehicle hits, moves, or topples over a post during their run or if the post is moved from its original location in the snowfield by any other action, including the action of plowed snow being pushed by the snowplow vehicle. This penalty will reduce the team's overall score.

Moved or fallen snow from the snowplow vehicle is allowed to touch either post, and no points for hitting a post will be deducted if only snow (and no part of the vehicle) touches or remains on the post and does not move the post from its original location on the snowfield.

3.3.2 Moving Obstacle

A critical function of autonomous vehicles is to detect and avoid any obstacles within their path. This especially includes those obstacles that are moving and crossing the intended path of the vehicle. These obstacles could indicate a pet, child, adult, other vehicle, or another important item has moved into the snowfield and in the way of the snowplow vehicle. The purpose of this obstacle in the ASC is to encourage competitors to design a snowplow vehicle system that will prevent any part of the vehicle from impacting a moving obstacle.

To simulate moving obstacles within the competition snowfield, a single flat object approximately **0.5 m high by 0.5 m wide by 0.03 m thick**, will enter the boundaries of the competition field during the dynamic competition runs. This moving obstacle will occur in both the single straight 'I'-shaped (Saturday) and the triple straight 'I'-shaped (Sunday) snowfields. The moving obstacle event will occur at a random time during each of the ASC team's 20 minute plowing run, at a time chosen by the ASC Marshal and Judges.

The moving obstacle will enter and stop directly within the Snow Path. The moving obstacle will travel in a straight line perpendicularly across the field (+/- 90° with respect to the long axis of each Snow Path). The obstacle will move at a maximum of 3 m/s. The Moving Obstacle will come to rest, at least 0.5 m above the snow within the Snow Path. The moving obstacle's motion will be coordinated such that when entering the competition snowfield it will not impact any part of the snowplow vehicle before coming to rest along the Snow Path.

Snowplow vehicles must avoid the moving obstacle by coming to a complete stop once the obstacle is detected by the vehicle. All snowplow vehicle wheels and/or tracks must stop turning, and the vehicle will not have forward, backward, or rotating motion, which will indicate a complete stop. Once the snowplow vehicle comes to a complete stop, the moving obstacle will be immediately removed from the competition snowfield, and the snowplow vehicle can resume its snow removal from the Snow Path.

Once the Moving Obstacle has entered the snowfield and become visible to the snowplow vehicle, ASC teams will be assessed a penalty if the snowplow vehicle does not come to a complete stop or if any part of the snowplow vehicle hits, moves, or topples over the obstacle during their plowing run. This penalty will reduce the ASC team's overall score.

3.3.3 Collaborative Operational Challenge

The Collaborative Operational Challenge (COC) is a new, independent competition event that is being added to the ION's Autonomous Snowplow Competition. The objective of this challenge is for a snowplow vehicle to autonomously operate in tandem with other snowplow vehicles on the same snowfield to remove as much snow as possible in the shortest period of time. This cooperative task must be done safely and without collision between snowplow vehicles.

As there is a certain risk to any team's snowplow vehicle, the COC is considered a side competition event within the overall ASC. Teams can elect to enter, participate, and compete in the COC or elect to not participate in the COC without penalty. Additional awards will be provided to COC participants and winners outside of the ASC award structure. COC participation will not in any way affect a team's standing or performance within the overall ASC.

The COC will be conducted on the single straight 'I'-shaped snowfield. The first four 1-m^2 sections from each end of the 10 m long snowfield path will be filled with snow. The two middle 1-m^2 sections will be clear of any snow.

Each COC event will involve a 20-minute competition. Two snowplow vehicles will be initially placed at each end of the straight 'I'-shaped snowpath in their respective starting garages. At the beginning of the run, each snowplow vehicle will commence plowing the first four 1-m^2 sections directly in front of the vehicle, with the objective of plowing these four sections and returning to the starting garage as fast as possible. Unlike the normal ASC competition runs, any snowplow vehicle requiring external navigation aids may have these set up prior to the 20-minute COC competition run.

During the COC competition, snowplow vehicles must not collide with each other. If either snowplow vehicle detects a threat of a collision, it must take evasive action to avoid colliding with the other vehicle.

Points will be awarded to each team based upon the amount of snow is removed, the time required to plow the four 1-m^2 sections of snow and return to the starting garage. Teams that score the highest points will be declared the winner of their competition run. If a Safety Officer must engage the emergency stop because an unsafe condition develops, then that snowplow vehicle will automatically lose their head-to-head competition.

The winner of each competition run will compete with other COC competition run winners, and progressively compete until an overall winner is determined.

3.4 Competition Scoring

ASC teams are ranked based upon their total score throughout the competition. The total score is a composite of the points earned on the team's presentations and the plowing competition. The ASC events and total scoring methods are provided in this section.

The ASC team's final point total is based on the following composite total of the ASC events:

Table 2. Overall Competition Scoring

PDR Presentation	10 %
Final Presentation	15 %
Snowplow Competition: Single 'I'-Shaped Snow Path	25 %
Snowplow Competition: Triple 'I'-Shaped Snow Path	50 %
Total Competition Points	**100 %**

The scores awarded by ASC Judges in all phases of the snowplow competition are final. Competitors must be aware that all decisions by the ASC Judges are final.

3.4.1 Technical Presentation Scoring

ASC teams are required to present their snowplow vehicle designs in oral presentations at the PDR and the Final Presentation. Outlines of the PDR presentation format and Final presentation format can be downloaded from the ASC website. The exact procedure for document submission will be provided to the ASC teams well in advance of the submission deadlines.

The PDR presentation slides are due as shown in the ASC Timeline in Table 1. Teams are not allowed to modify their PDR slides once they have been submitted, as ASC Judges will begin reviewing them immediately. The maximum allowable time for a PDR presentation is 16 minutes, followed by a 4-minute question and answer period, and an 8-minute Judge's feedback period. The entire PDR presentation must be delivered by the student members of the ASC team and will be conducted either using a video- or tele-conference. The PDR presentations will be attended only by ASC Judges, and any submitted materials will be held in confidence by the ASC Officials and Judges.

The late submission of the PDR slides will be penalized at 25% per day.

The Final Presentations of the ASC teams will be scheduled for Thursday evening of the competition week, as shown in the ASC Timeline in Table 1. The Final Presentation slides are due at the time of the presentation event. The maximum allowable time for a Final Presentation is 15 minutes followed by a 5-minute question and answer period. Teams are strongly encouraged to produce original presentation work each year, as ASC Judges will reduce scores for non-original work. The entire Final Presentation must be delivered by student members of the ASC team. In both the PDR and Final Presentation, all questions posed by ASC Judges must only be answered by student team members.

The Final Presentations will be attended by the ASC Officials and Judges and are open to other ASC teams, as well as the general public. Teams should bring posters or displays describing their snowplow vehicle designs and operation for show prior to the presentations, as ASC Judges and the audience will review these posters when meeting the teams during the social hour. This team and Judge interaction can often improve a team's score.

The PDR and Final Presentations scores will be based on the following scoring system:

Table 3. Presentation Scoring System

Technical Assessment and Quality of Presentation Slides	80
Ability to Engage Audience	20
TOTAL Points	**100**

3.4.2 Plowing Competition Scoring

During the dynamic snowplow competition, ASC teams earn points when their snowplow vehicles clear snow from the snowfield paths. Snow is considered cleared from a snowfield path if the vehicle plows the snow out of the Snow Path into the Plowed Snow Zones. An ASC team's vehicle performance in clearing snow from a Snow Path will be evaluated and assessed by a distinguished panel of ASC Judges, who will score this event by determining the percentage of the path cleared of snow within each 1-m^2 section of the snowfield path.

ASC teams are penalized if their snowplow vehicle requires a restart after their vehicle begins to plow snow from a snowfield path or if any part of their vehicle extends out of the Vehicle Starting, Maneuvering, or Plowed Snow Zones. ASC teams will be assessed a **10% penalty** for each snowplow vehicle restart and a **20% penalty** for any snowfield Vehicle Starting, Maneuvering, or Plowed Snow Zone boundary infraction by the snowplow vehicle.

It is important that plowed snow be moved to areas that do not impede foot or vehicle traffic. Thus, ASC teams are penalized for allowing any plowed snow to remain in the wrong zones along the competition snowfield. Snow must be plowed out of the Snow Path and moved into the Plowed Snow Zones, as marked on the snowfield diagrams. ASC teams may use the Maneuvering and Vehicle Starting Zones to maneuver their vehicle or move snow between zones. If more than 50% of the snow plowed from the Snow Path remains in either the Maneuvering Zones or Vehicle Starting Zones at the end of their run, then ASC teams are assessed a **10% penalty**.

Snowplow vehicles must maneuver to avoid both posts located within the competition snowfield. No part of the snowplow vehicle may strike a post during a run. Snow may fall up against a post without loss of points for hitting the post. However, any snow remaining on the Snow Path will reduce the overall score, and snow on the post will be considered as snow remaining on the Snow Path. If any part of a snowplow vehicle strikes a fixed points post, then a **15% penalty** will be assessed for that post.

Snowplow vehicles must come to a complete stop to avoid hitting a moving obstacle that randomly enters and comes to rest within the competition field. No part of the snowplow vehicle may strike the obstacle that travels into the snowfield during a run. If a snowplow vehicle fails to come to complete stop after the moving obstacle has entered the competition field or if any part of a snowplow vehicle strikes the moving obstacle, then a **15% penalty** will be assessed. The obstacle will be immediately removed from the competition field after the snowplow vehicle comes to a complete stop or if a penalty is assessed for striking the obstacle. The snowplow vehicle must resume snow clearing autonomously from its stopped position after the obstacle is removed from the snowfield, without any human interaction, otherwise a snowplow vehicle restart penalty will be incurred.

Snowplow vehicles are required to park inside the Vehicle Starting Zone (Garage) at the end of their run. If any portion or all of the snowplow vehicle crosses the zone lines, the vehicle will be considered parked within the garage. Teams will be assessed a **20% penalty** if the snowplow vehicle fails to autonomously park inside the Vehicle Starting Zone at the end of the competition run. A team may not declare a restart to gain the advantage of locating in the Vehicle Starting Zone at the end of their plowing run.

To encourage timely completion of the plowing the snowfield paths, ASC teams can also earn extra points by completing each snowfield course in a time shorter than the allotted 20-minute competition time. Thus, ASC teams could earn up to a total of 7.5 extra points for clearing both snowfield courses in a timely manner. At least 50% of the snowfield path must be cleared to be eligible to earn these time related points. Any time stopped for the moving obstacle will count towards an ASC team’s overall plowing run time.

For each snowfield path, the points awarded for the snow clearing performance will be scored using the following formula:

$$P_{SC} = FSC\left[\begin{array}{l} W_{SF}\left(0.9^{N_R}\right)\left(0.8^{N_{BZ}}\right)\left(0.9^{(1-D)}\right)\left(0.85^{(1-M_1)}\right)\left(0.85^{(1-M_2)}\right)\left(0.85^{(1-MO)}\right)\left(0.8^{(1-G)}\right) \\ + \quad \dfrac{W_{SF}}{10}\left(\dfrac{20-t_{SC}}{20}\right) \end{array}\right]$$

where,

P_{SC} = points for snow clearing
FSC = fraction of snow cleared from path as determined by judges
W_{SF} = weight for each snowfield course (= 25 for single 'I', and = 50 for triple 'I')
N_R = number of full run restarts
N_{BZ} = number of snowfield buffer zone boundary infractions
D = drift snow remaining (= 1 if > 50% plowed snow in Plowed Snow Zones, otherwise = 0)
M_1 = simulated fixed snow path post (= 1 if avoided, and = 0 if struck)
M_2 = simulated fixed snow zone post (= 1 if avoided, and = 0 if struck)
MO = simulated moving obstacle (= 1 if vehicle stops & avoids, and = 0 if not stopped or struck)
G = garage parking (= 1 if successful, and = 0 if unsuccessful)
t_{SC} = total snow clearing competition run time (rounded up to the next whole minute)

3.5 Awards and Prizes

The ASC will award prizes to competition teams in multiple categories. The amounts of the monetary awards are subject to change depending on the availability of sponsorship funds. The cash amount for each prize will be posted on the ASC website:

www.autosnowplow.com

The ASC will award the prestigious Golden Shovel trophy and cash prize to the best student presentation. ASC teams will be considered for the Golden Shovel award based on the average of the total points accumulated from the ASC Judges after the judging of the PDR and the Final Presentation. The ASC team with the highest accumulated score in these events will win the award.

The ASC will award the Dr. Nattu Golden Smile trophy and cash prize for the team exhibiting the best sportspersonship throughout the competition. The ASC Committee will select a team for this award based upon team's participation, enthusiasm, and support of their own and other competitor's team. This award is named in honour of Dr. Narasimhamurthi Natarajan (often called "Nattu" for short) from the University of Michigan, Dearborn, who led over ten competition teams at the ASC, including three teams in the 2014 ASC year, and led a number of teams at the ION's past Robotic Lawnmower Competitions. Although Dr. Nattu passed away from a lung illness in 2016, his leadership and true camaraderie during the ASC event serves as the inspiration for this award.

The ASC will award cash prizes to the teams that accumulate the highest point totals throughout the entire competition. ASC teams will be ranked based on the average of the total points accumulated from the ASC Judges during the different phases of the competition.

All trophies and prizes will be announced during the Awards Ceremony at the close of the ASC on Sunday afternoon of the competition week.

To qualify for the total dollar prize amounts, a snowplow vehicle must plow at least 50% of the snowfield path during their competition run as scored by the ASC Judges. If less than 50% of the snowfield path is plowed, then the ASC team will only receive 50% of the total prize.

4 Appendix

4.1 Acronyms

The contents of Table 4 provide a list of commonly used acronyms for the ASC, including those used within this rulebook.

Table 4. Autonomous Snowplow Competition Acronyms

ASC	Autonomous Snowplow Competition
ESS	Emergency Stop System
FQR	Final Qualification Review
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
ION	Institute of Navigation
PDR	Preliminary Design Review

4.2 Definitions

For the purposes of this competition, the following terms are defined as follows:

Guidance: The determination of the desired path or trajectory of travel from a vehicle's current position and velocity to a specified destination, including the necessary changes in vehicle velocity or attitude to follow the path.

Navigation: The determination at a specific instance in time of a vehicle's position, velocity, and attitude relative to a known reference frame.

Control: The manipulation of control surfaces, thrusters, or motors necessary to track the specific guidance commands, while maintaining vehicle stability, along the trajectory to a specified destination.

4.3 Obstacle Images

Images or diagrams of obstacles used within the ASC are provided. These obstacles include the fixed posts and the moving obstacle. These images are representative of the kind of obstacles that teams should expect, and these can be utilized for design and development of the snowplow vehicle and its navigation, guidance, and control system for obstacle avoidance.

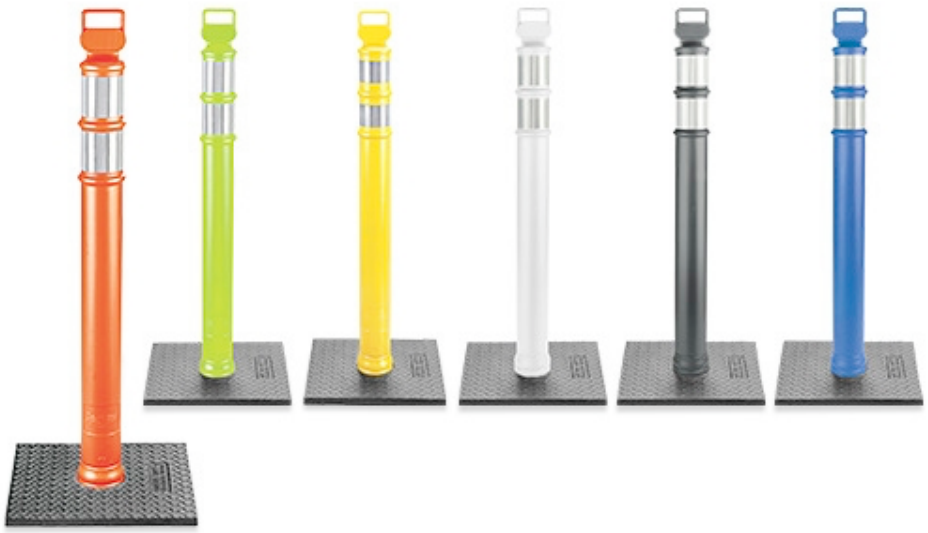

Figure 3. Representative fixed post obstacles.

Figure 4. Representative moving obstacle stop sign.