The 30th Annual Intelligent Ground Vehicle Competition (IGVC) & Self-Drive

June 2nd – 5th, 2023
Oakland University
Rochester, Michigan

New in 2023

AutoNav remains on asphalt

Self Drive Practice Course added

Stand alone Self Drive Award re-established.

Cyber Security Challenge re-established for 2023

Sec VII Awards updated Self Drive and AutoNav awards separated

6 Minutes of minutes of AutoNav run-time clarified

Design rules will be updated by 15 November

19 October 2022 version

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I. COMPETITION INFORMATION

I.1 TEAM ENTRIES

Teams may be comprised of undergraduate and graduate students, and must be supervised by at least one faculty advisor. Interdisciplinary (Electrical, computer, mechanical, systems engineering, etc.) teams are encouraged. Students must staff each team. Only the student component of each team will be eligible for the awards. Faculty supervisor will certify that all team members are bonafide students on application form and will also provide contact information (telephone number and e-mail address) for him and the student team leader on the form. Business/Non-Engineering students are encouraged to join teams to promote marketing, sponsorships, and other program management functions. For a student to be eligible to compete as a team member, they are required to have attended at least one semester of school as a registered student between June 2022 and June 2023.

Team sponsors are encouraged. Sponsors' participation will be limited to hardware donation and/or funding support. Sponsors logos may be placed on the vehicle and may be displayed inside of the team maintenance area. Teams should encourage sponsor attendance at the IGVC.

Schools are encouraged to have more than one entry; but are limited to a maximum of three per school, and each vehicle must have a separate team of students and a design report in a defined format. See design rules for format. Each entry must be based on a different chassis and software and must be documented by a separate application form and design report, submitted in accordance with all deadlines. All entries must have a team name and each application will be accompanied with a $500.00 non-refundable (after 1 March) registration.

Registrations will be accepted on a first come first served basis. Register early to assure a confirmed team entry. Registrations are being accepted beginning 15 October and not later than *February 28, 2023****, by registering online at*** *Oakland University to provide registration URL.* ***Questions regarding registration should be directed to OU PACE at Professional and Continuing Education (PACE) <oupace@oakland.edu***

International Teams Note

International (non-United States Teams) requiring Visa invitation letters must limit team participation to a maximum of twelve students and two faculty. Changes and additions to original submission entry are not permitted after March 30th, 2023

I.2 VEHICLE CONFIGURATION for Autonomous Navigation (AutoNav)

The AutoNav competition is designed for a small semi-rugged outdoor vehicle. Vehicle chassis can befabricated from scratch or commercially bought. Entries must conform to the following specifications:

- **Design**: Must be a ground vehicle (propelled by direct mechanical contact to the ground such as wheels, tracks, pods, etc. or hovercraft.
- **Length**: Minimum length three feet, maximum length seven feet.
- **Width**: Minimum width two feet, maximum width four feet.
- **Height**: Not to exceed 6 six feet (excluding emergency stop antenna).
- **Propulsion**: Vehicle power must be generated onboard. Fuel storage or running of internal combustion engines and fuel cells are not permitted in the team maintenance area

(tent/building).

- **Average Speed:** Speed will be checked at the end of a challenge run to make sure the average speed of the competing vehicle is above one (1) mph over the course completed. Vehicle slower than the minimum average speed will be disqualified for the run.
- **Minimum Speed:** There will be a stretch of about 44 ft. long at the beginning of a run where the contending vehicle must consistently travel above 1 mph. A vehicle slower than this speed is considered to “hold-up traffic” and will be disqualified.
- **Maximum Speed:** A maximum vehicle speed of five miles per hour (5 mph) will be enforced. All vehicles must be hardware governed not to exceed this maximum speed. No changes to maximum speed control hardware are allowed after the vehicle passes Qualification.
- **Mechanical E-stop location**: The E-stop button must be a push to stop, red in color and a minimum of one inch in diameter. It must be easy to identify and activate safely, even if the vehicle is moving. It must be located in the center rear of vehicle at least two feet from ground, not to exceed four feet above ground. Vehicle E-stops must be hardware based and not controlled through software. Activating the E-Stop must bring the vehicle to a quick and complete stop.
- **Wireless E-Stop:** The wireless E-Stop must be effective for a minimum of 100 feet. Vehicle E-stops must be hardware based and not controlled through software. Activating the E-Stop must bring the vehicle to a quick and complete stop. During the competition performance events (Autonomous Challenge and Navigation Challenge) the wireless E-stop will be held by the Judges.
- **Safety Light:** The vehicle must have an easily viewed solid indicator light which is turned on whenever the vehicle power is turned on. The light must go from solid to flashing whenever the vehicle is in autonomous mode. As soon as the vehicle comes out of autonomous mode the light must go back to solid.
- **Payload**: Each vehicle will be required to carry a 20-pound payload. The shape and size is approximately that of an 18" x 8" x 8" cinder block. Refer to section I.3 Payload.

I.3 PAYLOAD

The payload must be securely mounted on the vehicle. If the payload falls off the vehicle during a run, the run will be terminated. The payload specifications are as follows: 18 inches long, 8 inches wide, 8 inches high and a weight of 20 pounds.

I.4 QUALIFICATION

All vehicles must pass Qualification to receive standard award money in the Design Competition and compete in the Auto Nav performance events. To complete Qualification the vehicle must pass/perform all of the following criteria.

- **Length**: The vehicle will be measured to ensure that it is over the minimum of three feet long and under the maximum of seven feet long.
- **Width**: The vehicle will be measured to ensure that it is over the minimum of two feet wide and under the maximum of four feet wide.
- **Height**: The vehicle will be measured to ensure that it does not to exceed six feet high; this excludes emergency stop antennas.
- **Mechanical E-stop**: The mechanical E-stop will be checked for location to ensure it is located on the center rear of vehicle a minimum of two feet high and a maximum of four feet high and for functionality.
- **Wireless E-Stop:** The wireless E-Stop will be checked to ensure that it is effective for a minimum of 100 feet. During the performance events the wireless E-stop will be held by the Judges.
- **Safety Light:** The safety light will be checked to ensure that when the vehicle is powered up the light is on and solid. When the vehicle is running in autonomous mode, the light goes from solid

to flashing, then from flashing to solid when the vehicle comes out of autonomous mode.

- **Speed:** The vehicle will have to drive over a prescribed distance where its minimum and maximum speeds will be determined. The vehicle must not drop below the minimum of one mile per hour and not exceed the maximum speed of five miles per hour. Minimum speed of one mph will be assessed in the fully autonomous mode and verified over a 44 foot distance between the lanes and avoiding obstacles. No change to maximum speed control hardware is allowed after qualification. If the vehicle completes a performance event at a speed faster than the one it passed Qualification at, that run will not be counted.
- **Lane Following:** The vehicle must demonstrate that it can detect and follow lanes.
- **Obstacle Avoidance:** The vehicle must demonstrate that it can detect and avoid obstacles.
- **Waypoint Navigation:** Vehicle must prove it can find a path to a single two meter navigation waypoint by navigating around an obstacle.

During the Qualification the vehicle must be put in autonomous mode to verify the mechanical and wireless E -stops and to verify minimum speed, lane following, obstacle avoidance and waypoint navigation. The vehicle software cannot be reconfigured for waypoint navigation qualification. It must be integrated into the original autonomous software. For the max speed run the vehicle may be in autonomous mode or joystick/remote controlled. Judges will not qualify vehicles that fail to meet these requirements. Teams may fine tune their vehicles and resubmit for Qualification. There is no penalty for not qualifying the first time. Vehicles that are judged to be unsafe will not be allowed to compete. In the event of any conflict, the judges' decision will be final.

I.5 INDEMNIFICATION AND INSURANCE

Teams will be required to submit an Application Form prior to **February 28, 2023**. The Application Form can be downloaded from www.igvc.org.

Each Team's sponsoring institution will also be required to submit a Certificate of Insurance at the time the Application Form is submitted. The certificate is to show commercial general liability coverage in an amount not less than $1 million.

In addition, each individual participating at the competition will be required to sign a Waiver of Claims when they arrive at site and before they can participate in the IGVC events.

NOTE: *The IGVC Committee and Officials will try to adhere to the above official competition details, rules and format as much as possible. However, it reserves the right to change or modify the competition where deemed necessary for preserving fairness of the competition. Modifications, if any, will be announced prior to the competition as early as possible.*

II AUTO-NAV CHALLENGE COMPETITION

All teams must pass Qualification to participate in this event.

II.1 OBJECTIVE

A fully autonomous unmanned ground robotic vehicle must negotiate around an outdoor obstacle course under a prescribed time while maintaining a minimum of speed of one mph over a section and a maximum speed limit of five mph, remaining within the lane, and avoiding the obstacles on the course.

Judges will rank the entries that complete the course based on shortest adjusted time taken. In the event that a vehicle does not finish the course, the judges will rank the entry based on longest adjusted distance traveled. Adjusted time and distance are the net scores given by judges after taking penalties, incurred from obstacle collisions and boundary crossings, into consideration.

II.2 VEHICLE CONTROL

Vehicles must be unmanned and autonomous. They must compete based on their ability to perceive the course environment and avoid obstacles. Vehicles cannot be remotely controlled by a human operator during competition. All computational power, sensing and control equipment must be carried on board the vehicle. No base stations allowed for positioning accuracy is allowed. Teams are encouraged to map the course and use that information to improve their performance on the course.

II.3 Auto-Nav COURSE

The Auto-Nav Challenge is on asphalt pavement. The Course will be approximately 450 feet long inan area 120ft wide and 100 feet deep. This distance is identified so teams can set their maximum speed to complete the course pending no prior violations resulting in run termination. Track width will vary from ten to twenty feet wide with a turning radius not less than five feet.

Outer boundaries will be designated by continuous or dashed white lines approximately three inches wide, taped on the asphalt. Track width will be approximately ten feet wide. ~~Alternating side-to-side dashes will be 15-20 feet long, with 10- 15 feet separation.~~ A minimum speed will be required of one mph and will be a requirement of Qualification and verified in each run of the Auto-Nav Challenge. If the vehicle does not average one mph for the first 44 feet (30 seconds) from the starting line, the vehicle run will be ended. The vehicle will then need to average over one mph for the entire run.

Competitors should expect natural or artificial inclines (ramps) with gradients not to exceed 15% and randomly placed obstacles along the course. The course will become more difficult to navigate autonomously as vehicle progresses. Obstacles on the course will consist of various colors (white, orange, brown, green, black, etc.) of construction barrels/drums that are used on roadways and highways. Natural obstacles such as trees or shrubs and manmade obstacles such as light posts or street signs could also appear on the course. The placement of the obstacles may be randomized from left, right, and center placements prior to every run. Simulated potholes of 2 foot diameter solid white circles may be inserted. These simulated pot must be avoided or an end of run will occur.

There will be a minimum of five feet clearance, minimum passage width, between the line and the obstacles; i.e., if the obstacle is in the middle of the course then on either side of the obstacle will be five feet of driving space. Or if the obstacle is closer to one side of the lane then the other side of the obstacle must have at least five feet of driving space for the vehicles.

The Course will be primarily sinusoidal curves with series of repetitive barrel obstacles. Two waypoint pairs for the course will be provided prior to competition. One waypoint pair will be the entrance and exit of the course in No Man's Land. The two additional waypoints in No-Man's Land will guide the vehicles to the ramp entrance in either direction.

Five (5) minutes will be allowed for course negotiation.


Chicane
N
Start
S
Ramp
+ Navigation
Waypoint-4
Barricade
Min Speed barrel

II.4 COMPETITION RULES & PROCEDURES

- The competition will take place in the event of light rain or drizzle but not in heavy rain or lightning.
- Each qualified team will have up to two runs (time permitting) in each of three heats.
- Starting order will be based on order of qualification. Teams will setup on-deck in that order. Failure to be on-deck will place you at the end of the order for the run and may forfeit you final (second) run in a heat based on heat time completion.
- No team participant is allowed on the course before the team's first run, and only one student team member is allowed on the course during a run. This shall in no case be the faculty advisor.
- At the designated on-deck time, the competing team will be asked to prepare their vehicle for an attempt. On-deck teams start in the order they arrive in the starting area unless they give way to another team.
- A Starting Official will call teams to the starting line. The Starting Official's direction is final. The Starting Officials may alter the order to enhance the competition flow of entries; e.g. slower vehicles may be grouped together to allow successive running of two vehicles on the course simultaneously.
- A team will have one minute in the starting point to prep the vehicle at the starting line and point out to the Competition Judges the buttons to start and stop the vehicle,
- The Competition Judge will start the vehicle by a one touch motion; i.e. pushing a remote control button, hitting the enter key of a keyboard, a left mouse click, lifting the e-stop up, flipping a toggle switch, etc. The Competition Judge will also carry the E-Stop.
- An attempt will be declared valid when the Competition Judge initiates the start signal at the designated competing time. An attempt will continue until one of the following occurs:
- The vehicle finishes the course.
- The vehicle was E-Stopped by a judge's call.
- The team E-Stops the vehicle.
- The vehicle has not started after one minute after moving to the start line or at the judges' discretion.
- Time for each heat will be strictly observed.
- Tactile sensors will not be allowed.
- Based on the above allowable run times, if the vehicle has not completed the course in the **6** minute time period, the attempt will be ended by a judge's choice E-stop, with no additional penalty for that run.
- Each vehicle must navigate the course by remaining inside the course boundaries and navigating around course obstacles. Crossing internal lines is not allowed and will be judged an E-Stop end of run with penalty. For the following Traffic Violations, the appropriate ticket will be issued and deducted from the overall distance or time score. Refer to section II.5 Traffic Violation Laws.

II.5 TRAFFIC VIOLATION LAWS

	Traffic Violations	Ticket Value	E-Stop	Measurement
1	Hold-up Traffic	End of Run	Yes	>60 secs. to 88 ft
2	Leave the Course/Scene	- 10 Feet	Yes	Yes
3	Crash/Obstacle Displacement	- 10 Feet	Yes	Yes
4	Careless Driving	- 5 Feet	No	No
5	Sideswipe/Obstacle Touch	- 5 Feet	No	No
6	Student's Choice E-Stop	- 10 Feet	Yes	Yes
7	Judge's Choice E-Stop	0 Feet	Yes	Yes
8	Blocking Traffic	- 5 Feet	Yes	Yes
9	Loss of Payload	0 Feet	Yes	Yes
10	Too slow, did not average 1 mph	Disqualified	No	No

- **Hold-up traffic:** Must maintain 1 mph, there will be a speed check at 44/88 foot mark of the course, will result in end of run with time recorded
- **Leave the scene\course**: All portions of the vehicle cross the boundary. The overall distance will be measured from the starting line to the furthest point where the final part of the vehicle crossed the boundary edge.
- **Crash**: The overall distance will be measured from the starting line to the collision point with the obstacle.
- **Careless Driving**: Crossing the boundary while at least some part of the vehicle remains in bounds.
- **Student E-Stop**: Student e-stop is used if the team feels that there may be damaged caused to their vehicle or they know that it is stuck and want to end their time.
- **Judge E-Stop**: The overall distance will be measured from the starting line to the front of the vehicle or where the final/furthest remaining part of vehicle if stopped, crossed the boundary outside edge.
- **Obstacle Displacement**: Defined as displacing permanently the obstacle from its original position. Slightly rocking/Tilting an obstacle with no permanent displacement is not considered obstacle displacement. An obstacle that rocks or tilts significantly but with no displacement will still be considered a end of run. Judges calls are final.
- **Blocking Traffic**: Vehicles stopping on course for over one minute will be E-Stopped and measured.
- **Loss of Payload**: If the payload falls of the vehicle the run will be ended.
- **Too Slow:** If the vehicle does not maintain 1 mph minimum average speed limit throughout the course this run is disqualified.

II.6 HOW COMPETITION WILL BE JUDGED

- A team of judges and officials will determine compliance with all rules.
- Designated competition judges will determine the official times, distances and ticket deductions of each entry. At the end of the competition, those vehicles crossing the finish line will be scored on the time taken to complete the course minus any ticket deductions. Ticket values will be assessed in seconds (one foot = one second) if the vehicle completes the course within the run time.
- The team with the adjusted shortest time will be declared the winner.
- In the event that no vehicle completes the course, the score will be based on the distance traveled by the vehicle minus the ticket deductions. The team with the adjusted longest distance will be declared the winner.
- For standard award money consideration, entry must exhibit sufficient degree of autonomous mobility by completing the Auto-Nav course. If a tie is declared between entries, the award money will be split between them.
- If your vehicle is overtaken by a faster vehicle you will be commanded to stop and your time will be recorded and allowed to be restarted with remaining time after the faster vehicle passes. Total distance will be assessed at the 6 minute mark of runtime.

II.7 GROUNDS FOR DISQUALIFICATION

- Judges will disqualify any vehicle which appears to be a safety hazard, degrades the course or violate the safety requirements during the competition.
- Intentional interference with another competitor's vehicle and/or data link will result in disqualification of the offending contestant's entry.
- Damaging the course or deliberate movement of the obstacles or running over the obstacles may result in disqualification.
- Actions designed to damage or destroy an opponent's vehicle are not in the spirit of the competition and will result in disqualification of the offending contestant's entry.

III. DESIGN COMPETITION for AutoNav and Self Drive

All teams must participate in the Design Competition and submit design report in mandatory format.

III.1 OBJECTIVE

Although the ability of the vehicles to negotiate the competition courses is the ultimate measure of product quality, the officials are also interested in the design strategy and process that engineering teams follow to produce their vehicles. Design judging will be by a panel of expert judges and will be conducted separate from and without regard to vehicle performance on the test course. Judging will be based on a written report, an oral presentation and examination of the vehicle.

Design innovation is a primary objective of this competition and will be given special attention by the judges. Innovation is considered to be a technology (hardware or software) that has not ever been used by this or any other vehicle in this competition. The innovation needs to be documented, as an innovation, clearly in the written report and emphasized in the oral presentation.

III.2 WRITTEN REPORT

The IGVC report (15 page maximum) shall follow a modified version of the American Astronautical Society (AAS) paper format that is used by the Association for Unmanned Vehicle Systems International (AUVSI). The report must follow the outlined format provided in section III.6 **(DESIGN REPORT FORMAT – MANDATORY)** located at the end of this Written Report section. Each vehicle must have a complete report in defined format below of its own (a report cannot cover more than one vehicle). All reports, both for new vehicles and for earlier vehicles with design changes, must include a statement signed by the faculty advisor certifying that the design and engineering of the vehicle (original or changes) by the current student team has been significant and equivalent to what might be awarded credit in a senior design course.

Participants are required to submit an electronic copy in PDF format along with a scanned copy of the statement in PDF format by **May 15, 2023.** Everything must be e-mailed along with any questions to IGVCquestions@yahoo.com. Reports arriving after that date will lose 10 points in scoring for each day late, statements arriving after that date will lose 5 points in scoring for each day late. Teams are encouraged to submit reports even several weeks early to avoid the last minute rush of preparing vehicles for the competition, and there will be no penalty for last minute changes in the vehicle from the design reported. The electronic copy of the report will be posted on the competition's web site in PDF format after the completion of the competition.

The paper should present the conceptual design of the vehicle and its components. Especially important to highlight are any unique innovative aspects of the design and the intelligence aspects of the vehicle. Also included must be descriptions of:

Electronics	Design Planning Process
electrical system	signal processing
actuators	plan for path following (both solid & dashed lines)
software strategy	failure point & mode
sensors	plan for control decisions
computers	system integration plan
mapping	high speed operations

Design of the lane following and obstacle detection/avoidance systems must be specifically described. Along with how the vehicle uses mapping techniques to perceive and navigate through its environment. Describe how the system uses GPS for waypoint navigation and localization.

Components acquired ready-made must be identified, but their internal components need not be described in detail. The steps followed during the design process should be described along with any use of Computer-Aided Design (CAD). How considerations of safety, reliability, and durability were addressed in the design process should be specifically described, as well as problems encountered in the design process and how they were overcome. Identification of Failure Points and Modes of hardware is required. Furthermore, description of how failure points are addressed and resolved if they should occur during the days of the competition. The analysis leading to the predicted performance of the vehicle should be documented, specifically:

- Speed
- Ramp climbing ability (Self-Drive N/A)
- Reaction times
- How the system uses GPS for waypoint navigation and localization
- Battery life
- Distance at which obstacles are detected
- How the vehicle deals with complex obstacles including switchbacks and center islands dead ends, traps, and potholes)
- How the team identifies and addresses vehicle failure points and modes (Not an FMEA)
- Accuracy of arrival at navigation waypoints
- Comparison of these predictions with actual trial data is desirable.

Although cost itself is not a factor in judging (these are considered research vehicles), the report should include a cost estimate (not counting student labor) for the final product if it were to be duplicated. A breakdown of the cost by component is helpful.

The team organization and the names of all members of the design team, with academic department and class, should be included along with an estimate of the project's total number of person-hours expended.

Vehicles that have been entered in IGVC in earlier years and have not had significant changes in design are ineligible in either the design or performance events. Vehicles that have been changed significantly in design (hardware or software) from an earlier year are eligible, but will require a completely new design report treating both the old and new features, thus describing the complete vehicle as if it were all new.

Judges will score the written reports as follows:	**Maximum Points**
1. Conduct of the design process and team organization (Including decision-making & software development)	50
2. Failure points identification and resolution methods to be used if this failure occurs. (Not an FMEA)	100
3. Quality of documentation (English, grammar, completeness, and style)	50
4. Effective innovation represented in the design (as described above)	150
5. Description of mapping technique	100
6. Description of mechanical design	100
7. Description of electronic design	100
8. Description of software strategy	150
9. Description of systems integration Descriptions to include: lane following, obstacle detection/ avoidance, and waypoint navigation (GPS or other)	150
10. Efficient use of power and materials	50
11. Attention given to safety, reliability, and durability and failure modes	50
Total	**1050**

III.3 ORAL PRESENTATION

The technical talk should relate the highlights of the written report described above and include any updates of the design since the written report. Audio or video tape presentations of the text are not allowed, but graphic aids may be presented by video, slide projection, computer projection, overhead transparencies, or easel charts. The presentation must be made by one or more student members of the team to the judges and other interested members of the audience and should last not more than 10 minutes. A penalty of 5 points will be assessed for each minute or fraction thereof over 11 minutes. After the presentation, judges only may ask questions for up to 5 minutes. The audience should be considered as a senior management group of generally knowledgeable engineers upon whom the project is dependentfor funding and the team is dependent for their employment. Scoring will be as follows:

Judges will score the oral presentations as follows:	**Maximum Points**
1.Clear, well planned and understandable explanation of the innovations	50
2. Logical organization and subject knowledge of the talk	50
3. Effective use of graphic aids	30
4. Articulation and eye contact during presentation	40
5. Demonstrated simulation of vehicle control in performance events	10
6. Response to questions	10
7. Salesmanship	10
Total	**200**

Effective use of graphic aids includes not blocking the view of the screen by the presenter and simple enough graphics that are large enough to read (block diagrams rather than detailed circuit diagrams). Articulation refers to the clarity and loudness of speaking. Eye contact refers to speaking to the audience and judges (not reading notes or screen or looking above audience heads). Response to questions means short answers that address only the question. Salesmanship refers to the enthusiasm and pride exhibited (why this vehicle is the best).

Participants are responsible for providing their own visual aids and related equipment (the vehicle itself may be displayed). A computer-connected projector will be made available. Projectors may also be supplied by the participants.

During the oral presentation, the following question period and the examination of the vehicle, team members sitting the audience may participate by assisting the oral presenters, but at no time is the faculty advisor to participate in this part of the design competition.

III.4 EXAMINATION OF THE VEHICLE

The vehicle must be present and will be examined by the judges preferably immediately after the oral presentation or at another convenient time the time during the competition. Software is not included in this judging. Judging will be as follows:

Judges will score the vehicle examinations as follows:	**Maximum Points**
1. Packaging neatness, efficient use of space	20
2. Serviceability	20
3. Ruggedness	20
4. Safety	20
5. Degree of original content in the vehicle (as opposed to ready-made)	50
6. Style (overall appearance)	20
Total	**150**

EXAMINATION OF THE VEHICLE (Self-Drive specific)

The vehicle must be present and will be examined by the judges after the oral presentation or at another convenient time during the competition. Software is not included in this judging.

Judging will be as follows:

Scoring Criteria		Presented	Passed	Penalty Points
Vehicle	4 wheels, front and rear bumpers, fire extinguisher			
	4 manual E-stops			
	1 actuator easily accessible and labeled			
	no design elements harmful to surroundings			
Navigation System	GPS			
	IMU			
	Etc.			
Integrated Sensor Fusion System	camera(s)			
	lidar(s)			
	radar(s)			

	ultrasonic			
	infrared			
Safety	audible and visible warning devices in RUN mode			
	rear brake lights work in autonomous mode			
Safety E-stop	wireless E-stop system with stop/restart of the vehicle			
	E-stop actuation is smooth and controlled (no swerving, skidding, excessive delay)			
Delay before start	5-10 seconds pause after entering into RUN mode and before moving			

Table 6: Vehicle Examination Scoring Sheet

III.5 FINAL SCORING

The number of points awarded by the individual judges will be averaged for each of the 23 judging areas above, and these results will be offered to each participating team for their edification. The total of the average scores over all 23 areas (max 1300) will be used to determine the ranking.

When two (or three) teams of judges are used (due to a large number of entries) each judging team will determine the top three (or two) winners in their group, and the resulting six contestants will participate in a runoff of oral presentations and vehicle examinations judged by all judges to determine an overall Design Winner. The six teams will be judged in random order.

For the Finals competition four criteria from the written report judging will be added to the normal oral presentation scoring shown above for preliminary judging. Thus, the Finals Oral presentation scoring will have maximum points as below:

Judges will score the final presentations as follows:	Maximum Points
1.Clear explanation of the innovations	50
2. Description of mapping technique	30
3. Description of Electronic Design	30
4. Description of Software Strategy	30
5. Description of System Integration	30
6. Logical organization of the talk	50
7. Effective use of graphic aids	25
8. Articulation	25
9. Demonstrated Simulation of Vehicle Control	10
10. Response to questions	10
11. Salesmanship	10
Total	**300**

The vehicle examination scoring will be the same as in the preliminary judging, as shown above.

III.6 DESIGN REPORT FORMAT - MANDATORY

1. Title Page
    - University/College Name
    - Vehicle/Team Name
    - Vehicle Photo/Sketch/Symbol
    - Date Submitted
    - Team Captain's Name and E-Mail
    - Team Members Names and E-Mails
    - Faculty Advisors Name and Statement of Integrity
2. Conduct of design process, team identification and team organization
    - Introduction
    - Organization
    - Design assumptions and design process
3. Effective innovations in your vehicle design
    - Innovative concept(s) from other vehicles designed into your vehicle
    - Innovative technology applied to your vehicle
4. Description of mechanical design

- Overview
- Decision on frame structure, housing, structure design
- Suspension
- Weather proofing

5. Description of electronic and power design
    - Overview
    - Power distribution system (capacity, max. run time, recharge rate, additional innovative concepts)
    - Electronics suite description including CPU and sensors system integration/feedback concepts
    - Safety devices and their integration into your system
6. Description of software strategy and mapping techniques
    - Overview
    - Obstacle detection and avoidance
    - Software strategy and path planning
    - Map generation
    - Goal selection and path generation
    - Additional creative concepts
7. Description of failure modes, failure points and resolutions
    - Vehicle failure modes (software, mapping, etc) and resolutions
    - Vehicle failure points (electronic, electrical, mechanical, structural, etc) and resolutions
    - All failure prevention strategy
    - Testing (mechanical, electronic, simulations, in lab, real world, etc.)
    - Vehicle safety design concepts
8. Simulations employed
    - Simulations in virtual environment
    - Theoretical concepts in simulations
9. Performance Testing to Date
    - Component testing, system and subsystem testing, etc.
10. Initial Performance Assessments
    - How is your vehicle performing to date

V.C6 SELF-DRIVE DESIGN REPORT FORMAT - MANDATORY

1. Title Page
    - University/College Name
    - Vehicle/Team Name
    - Vehicle Photo/Sketch/Symbol
    - Date Submitted
    - Team Captain's Name and E-Mail
    - Team Members Names and E-Mails
    - Faculty Advisors Name and Statement of Integrity
2. Conduct of design process, team identification and team organization
    - Introduction
    - Organization
    - Design assumptions and design process
3. Effective innovations in your vehicle design
    - Innovative concept(s) from other vehicles designed into your vehicle
    - Innovative technology applied to your vehicle
4. Description of mechanical design
    - Overview
    - Description of drive-by-wire kit
    - Suspension
    - Weather proofing
5. Description of electronic and power design
    - Overview
    - Power distribution system (capacity, max. run time, recharge rate, additional innovative concepts)
    - Electronics suite description including CPU and sensors system integration/feedback concepts
    - Safety devices and their integration into your system
6. Description of software strategy and mapping techniques

Overview

- Obstacle detection and avoidance
- Software strategy and path planning
- Map generation
- Goal selection and path generation
- Additional creative concepts

7. Description of failure modes, failure points and resolutions
    - Vehicle failure modes (software, mapping, etc) and resolutions
    - Vehicle failure points (electronic, electrical, mechanical, structural, etc) and resolutions
    - All failure prevention strategy
    - Testing (mechanical, electronic, simulations, in lab, real world, etc.)
    - Vehicle safety design concepts
8. Simulations employed
    - Simulations in virtual environment
    - Theoretical concepts in simulations
9. Performance Testing to Date
    - Component testing, system and subsystem testing, etc.
10. Initial Performance Assessments
    - How is your vehicle performing to date
11. Mandatory Unit Tests up to date (see V.B3 section 4)
    - **Unit test 1: Emergency stop**

- **Unit test 2: Emergency stop remote**
- **Unit test 3: Speed limit test**
- **Unit test 4: Right Lane boundary is crossed.**
- **Unit test 5: Left Lane boundary is crossed.**
- **Unit test 6: Object detection**
- **Unit test 7: Backing up operation. Speed in reverse should never exceed 2 mph (0.89 mps).**

IV. INTEROPERABILITY PROFILES CHALLENGE (Robotics Architecture) on-hold for IGVC 2022

V.

Self Drive Challenge

The purpose of Self Drive is to develop student, faculty and university skills and experience which encompasses those required to develop automotive smart driving cars or defense intelligent vehicle systems compatible with current roadways and future intelligent highway systems. Those capabilities include camera vision systems, lane following obstacle and pedestrian avoidance, roadway and parking driving maneuvers, road network navigation, road sign understanding and other traffic functions. Components and subsystems currently used in smart driving vehicles are the preferred approach.

V.A1 TEAM ENTRIES

Teams in accordance with I.1

V.A2 VEHICLE CONFIGURATION

1.2.1 The Self-Drive competition is designed for FMVSS-500/EU Quadricycle type electrical vehicles (EV) equipped with automotive drive-by-wire systems. The primary Side by Side 2-Person EV vehicles are John Deere, Cub Cadet, Honda, Kawasaki, Arctic Cat, Polaris, Yamaha, Kubota.

Figure 1: FMVSS-500 Vehicle Example - Polaris GEM e2

Teams may build their own drive-by-wire kits or use off the shelf drive-by-wire solutions sold by various companies such as TORC Robotics, Dataspeed, AutonomousStuff and Clearpath Robotics.

1.2.2 Design Specifications. Entries must conform to the following specifications :

- Design: Side by Side 2-person four-wheel ground vehicle
- Type of Vehicle: Electrical, no gas
- Maximum Length: 115 in (as reference, Polaris Gem e2 is 103 in, Renault Twizy is 91 in)
- Maximum Width: 60 in (as reference, Polaris Gem e2 is 55.5 in, Renault Twizy is 47 in)
- Maximum Height: 75 in (as reference, Polaris Gem e2 is 73 in, Renault Twizy is 57 in)
- Maximum Weight: 1500 lbs
- Maximum Speed: Speed is limited to 5 mph in 2022 as safety features of Self-Drive course are developed.
- Mechanical E-stop Location: The E-Stop button must be a push to stop, red in color and a minimum of one inch in diameter. It must be easily identifiable and activate safely, even if the vehicle is moving. It must be located inside the cabin, as well as outside on sides and rear of vehicle. Vehicle E-Stops must be hardware based and not controlled through software. Activating the E-Stop must bring the vehicle to a quick and complete stop.

- Wireless E-Stop: The wireless E-Stop must be effective for a minimum of 100 feet. Vehicle E-stops must be hardware based and not controlled through software. Activating the E-Stop must bring the vehicle to a quick and complete stop. During the competition performance events the wireless E-stop will be held by the Judges.
- Safety Light: the vehicle must have easily identified brake lights red in color and reverse lights yellow in color. A strobe light must be mounted on roof and activated when the vehicle is under robotic control. During an autonomous mode the light must be blinking and otherwise be turned off.

V.A3 QUALIFICATION

On the first day of competition all vehicles must pass Qualification to receive standard award money in the Self-Drive Design Competition and compete in Self-Drive performance events. During the Qualification the vehicle must be put in autonomous mode to verify the mechanical and wireless E-Stops and to verify minimum speed, lane following, obstacle avoidance and waypoint navigation. The vehicle software cannot be reconfigured for waypoint navigation qualification, and must be integrated into the original autonomous software. For the maximum speed run, the vehicle may be in autonomous mode or joystick/remote controlled. Judges will not qualify vehicles that fail to meet these requirements.

Teams may fine tune their vehicles and resubmit for Qualification. There is no penalty for not qualifying the first time. Vehicles that are judged to be unsafe will not be allowed to compete. In the event of any conflict, the judges' decision will be final.

To complete Qualification the vehicle must pass or perform all of the following criteria:

- **Length**: The vehicle will be measured to ensure that length does not exceed specifications.
- **Width**: The vehicle will be measured to ensure that width does not exceed specifications.
- **Height**: The vehicle will be measured to ensure that height does not exceed specifications.
- **Weight:** The vehicle weight shall not exceed 1500 lb.
- **Mechanical E-stop**: The mechanical E-stop will be checked for locations:
    - inside the vehicle at the instrument panel.
    - outside the vehicle located on two sides and rear.
- **Wireless E-Stop**: The wireless E-Stop will be checked to ensure that it is effective for a minimum of 100 feet.
- **Passenger(s) Safety:** seat belts and helmets are required.
- **Safety Light**:
    - The Safety Light should be located on the roof of the vehicle.
    - The Safety Light is on and solid when vehicle is powered up or comes out from autonomous mode.
    - The Safety Light is flashing when vehicle is running in autonomous mode.
- **Speed**:
    - minimum speed 1 mile per hour.
    - maximum speed 5 miles per hour.
    - Maximum speed in reverse is 2 miles per hour.
- **Lane Following**: The vehicle must demonstrate that it can detect and follow lanes.
- **Obstacle Avoidance**: The vehicle must demonstrate that it can detect and avoid obstacles.
- **Waypoint Navigation**: Vehicle must prove it can find a path to a single two meter navigation waypoint by navigating around an obstacle.

During the Qualification the vehicle must be put in autonomous mode to verify the mechanical and wireless E -stops and to verify minimum speed, lane following, obstacle avoidance and waypoint

navigation. The vehicle software cannot be reconfigured for waypoint navigation qualification. It must be integrated into the original autonomous software. For the max speed run the vehicle may be in autonomous mode or joystick/remote controlled. Judges will not qualify vehicles that fail to meet these requirements. Teams may fine tune their vehicles and resubmit for Qualification. There is no penalty for not qualifying the first time. Vehicles that are judged to be unsafe will not be allowed to compete. In the event of any conflict, the judges' decision will be final.

Please see section VI.1. Appendix A: Qualification Testing for further information.

V.A4 INDEMNIFICATION AND INSURANCE see section I.5

V.B1 OBJECTIVE

A fully autonomous unmanned ground robotic vehicle must negotiate around an outdoor obstacle course under a prescribed time while maintaining a minimum of speed of one mph over a section and a maximum speed limit of five mph, remaining within the lane, and avoiding the obstacles on the course. Judges will rank the entries that complete the course based on shortest adjusted time taken. In the event that a vehicle does not finish the course, the judges will rank the entry based on longest adjusted distance traveled. Adjusted time and distance are the net scores given by judges after taking penalties, incurred from obstacle collisions and boundary crossings, into consideration.

V.B2 VEHICLE CONTROL

Vehicles must be unmanned and autonomous. They must compete based on their ability to perceive the course environment and avoid obstacles. Vehicles cannot be remotely controlled by a human operator during competition. All computational power, sensing and control equipment must be carried on board the vehicle. No base stations allowed for positioning accuracy is allowed. Teams are encouraged to map the course and use that information to improve their performance on the course.

V.B3 SAFETY REQUIREMENTS AND UNIT TESTS

1. Overview

The Self Drive Safety Requirements had been derived from "Automated Driving Systems 2.0: A vision for safety", published by U.S. Department of Transportation [1]. The safety guidelines are aimed at guiding Self-Drive teams to analyze, identify, and resolve safety considerations prior to deployment at the Self-Drive Proving Ground.

2. Scope and Purpose

This compliance is mandatory and required for teams to participate.

3. Safety Elements

3.1 System Safety

The design and validation processes include a hazard analysis and safety risk assessment for vehicle overall design. Design decisions shall address risks that could impact safety-critical system functionality.

Design safety considerations should include:

- Design architecture
- Sensors
- Actuators
- Communication Failure
- Potential software errors
- Reliability
- Potential inadequate control
- Undesirable control actions
- Potential collisions with environmental objects and other road users
- Potential collisions that could be caused by vehicle's actions
- Leaving the roadway
- Loss of traction or stability
- Violation of traffic laws
- Deviations from normal (expected) driving practices

All design decisions shall be tested, validated, and verified as individual subsystems and as part of the entire vehicle architecture. It is suggested to document all changes, design choices, analysis, associated testing and etc.

3.2 Operational Design Domain (ODD)

Roadway Type: local road with 2 lanes – 8 ft per lane, 20 ft minimum turning radius

Geographic Area: Self-Drive proving ground, flat paved area with some slopes at Oakland University

Speed Range:

- Speed limit – 5 mph
- Speed in Reverse - 2 mph

Environmental Conditions:

- Weather: sunny, cloudy, rainy
- Daytime

3.3 Object and Event Detection and Response (OEDR)

The vehicle is expected to operate in normal and pre-crash scenarios.

Normal Driving relates to:

- Keeping the vehicle in lane
- Obeying traffic laws (as outlined in the Self-Drive manual)
- Responding to barrels and mannequins (stopping and/or avoiding)

Hazardous Driving relates to:

- Vehicle's control loss
- Crossing-path crashes
- Lane change/merge
- Road departure
- Backing up
- Parking maneuvers

3.4 Fallback (Minimal Risk Condition)

Self-Drive teams are encouraged to have a documented process for transitioning to a minimal risk condition or safe state when a problem is encountered, or a vehicle cannot operate safely. Detections may include the following features: vehicle has malfunctioned, operating in a degraded state or operating outside of ODD.

3.5 Tester and Judge Safety

- All judges must wear orange reflective vests
- Observing judges must maintain safety distance from the Vehicle Under Test
- No standing forward or behind the vehicle on the test track. Minimum side distance observation is 20 ft.
- Vehicle Testing Procedure: trained team member shall be seated at the driver's seat and be proficient at vehicle shutdown during malfunction. The judge shall be seated at the passenger's seat. The second judge, holding the remote E-stop, will observe vehicle from the test ground. Either judge must activate E-stop (manual or remote) if vehicle starts to perform outside of the scope of the function or route, or if the vehicle exhibits danger for environment.
- Judges will practice shutdown before vehicle tests begin

3.6 Human Machine Interface

The vehicle shall be capable of informing the human operator or occupant through various indicators, such as warning displays, blinking lights or sounds, that the system is:

- Functioning properly
- Currently engaged in Autonomous Mode
- Currently "unavailable" for use
- Experiencing a malfunction; and/or

- Requesting control transition from the vehicle to the operator

3.7 Crashworthiness

1. Occupant Protection

- Occupants must wear helmets
- Seat belts should be buckled up during the test
- Doors or side vehicle webbing will protect students and judges from extending outside of the vehicle envelope. Doors or webbing must be easily opened, released for occupant exit.

2. Surroundings at the test track

- Vehicle must apply safe-following behavior when approaching other vehicles behind in a traffic lane, and maintain safe-following distance
- Vehicle must apply safe check-and-go behavior when pulling around a stopped vehicle, pulling out of parking spot, moving through intersections, and in situations where collisions are possible

3.8 Post-Incident Vehicle Behavior

- Turn off the system (disengage electrical power)
- Move vehicle off the test track to the safe location

3.9 Data Recording

During the run, the log file must be recorded. The recorded data must be immediately available upon judges' request.

The minimum logged data must include:

- Timestamps
- Vehicle Speed
- Braking
- Steering angle or yaw rate
- Detected Object (relative to your system)
- Maneuver related input (relative to your system)

4. Mandatory Safety Unit Tests

For each test, provide time plot documenting vehicle movement.

4.1 Requirements

1. Test in autonomous mode
2. All vehicle speeds are in m/s
3. Stopping time is in mps (meters per second)
4. All other time is in seconds

4.2. Unit Tests

Unit test 1: Emergency stop

Provide plot of speed vs time

Unit test 2: Emergency stop remote

Provide plot of speed vs time

Unit test 3: Speed limit test

Provide plot of speed vs time. **Accelerate until speed limit of 5 mph is reached.** Plot should continue at least for 20 seconds after the speed limit had been reached. Test your system with the following speeds:

1) Speed is 3 mph (1.34 mps)
2) Speed is 5.2 mph (2.28 mps)
3) Speed is 6.0 mph (2.68 mps)

Unit test 4: Right Lane boundary is crossed. Apply brakes if line had been crossed.

Provide the following plots:

1) Plot speed vs time
2) Plot lateral velocity vs time

Unit test 5: Left Lane boundary is crossed. Apply brakes if line had been crossed.

Provide the following plots:

1) Plot speed vs time
2) Plot lateral velocity vs time

Unit test 6: Object detection

Apply brakes if the object is at the certain distance.

Provide the following plots:

1) Plot speed vs time
2) Plot speed vs distance to object, brake active

Unit test 7: Backing up operation. Speed in reverse should never exceed 2 mph (0.89 mps).

Please test the system with the following speeds:

1) Speed limit is 1 mph
2) Speed limit is 3 mph

Provide the following plot:

1) Plot speed in reverse vs time

V.B4 SELF-DRIVE COURSE

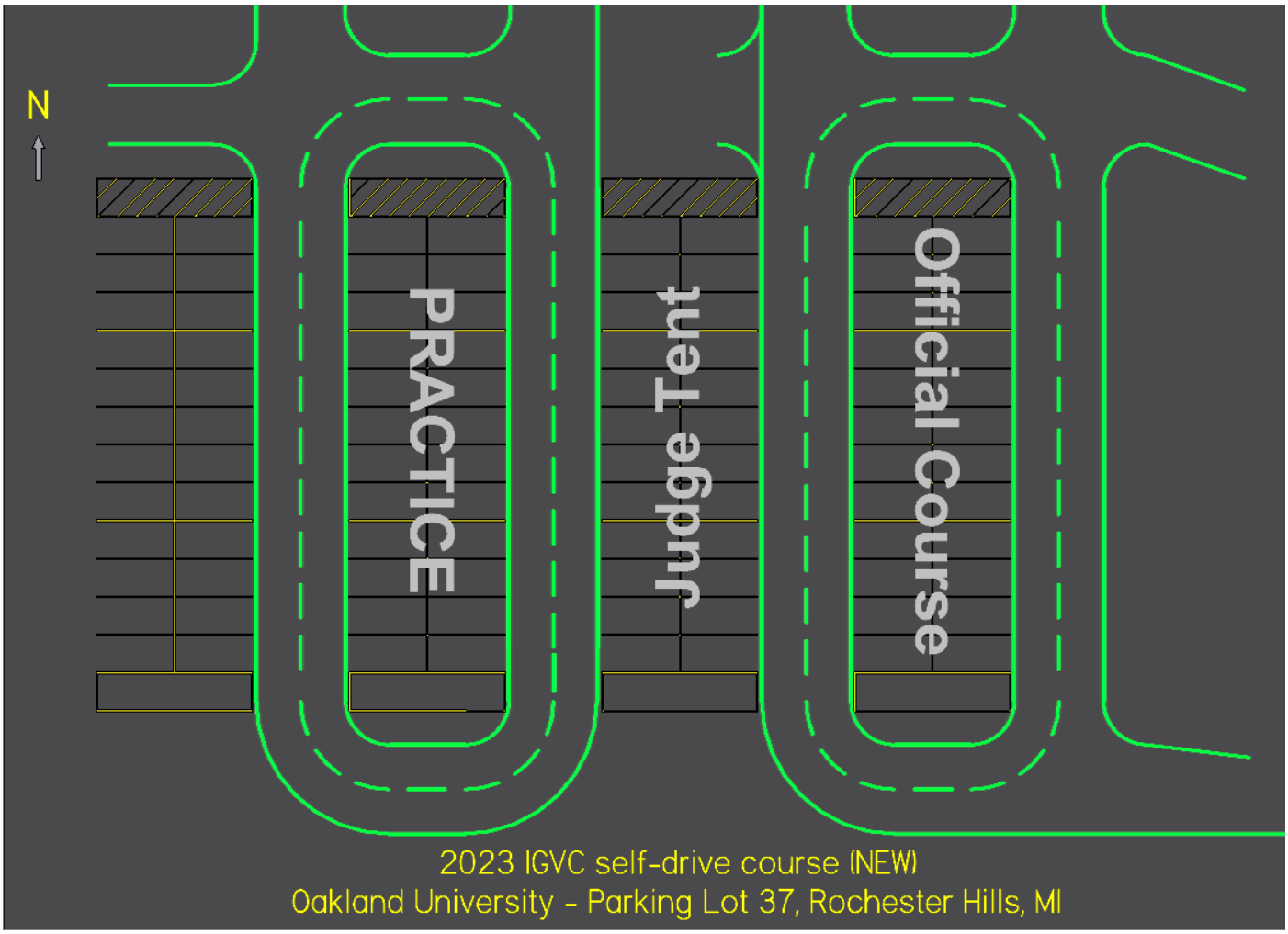

Figure 2: Self-Drive Course Parking Lot 37, Oakland University

V.B5 SELF-DRIVE COMPETITION RULES AND PROCEDURES

• All Self-Drive practice will be performed on a separate practice course, The official course is reserved for only

official scored runs.

• The competition will take place in the event of light rain or drizzle but not in heavy rain or lightning.

• Each qualified team will have up to two runs (time permitting) in each of three heats.

• Starting order will be based on order of qualification. Teams will setup on-deck in that order. Failure to be on-deck will place you at the end of the order for the run and may forfeit you final (second) run in a heat based on heat time completion.

• No team participant is allowed on the course before the team's first run, and only 3 student team members are ~~one student teammember is~~ allowed on the course during a run. This shall in no case be the faculty advisor. The faculty advisor is allowed to be on the course during the practice time.

• At the designated on-deck time, the competing team will be asked to prepare their vehicle for an attempt. On-deck teams start in the order they arrive in the starting area unless they give way to another team.

• A Starting Official will call teams to the starting line. The Starting Official's direction is final. The Starting Officials may alter the order to enhance the competition flow of entries; e.g. slower vehicles may be grouped together to allow successive running of two vehicles on the course simultaneously.

• A team will have one minute to prepare the vehicle at the starting line and point out to the Competition Judges the buttons to start and stop the vehicle.

• The Competition Judge will start the vehicle by a one touch motion; i.e. pushing a remote control button, hitting the enter key of a keyboard, a left mouse click, lifting the e-stop up, flipping a toggle switch, etc. The Competition Judge will also carry the wireless E-Stop.

• An attempt will be declared valid when the Competition Judge initiates the start signal at the designated competing time.

An attempt will continue until one of the following occurs:

- The vehicle finishes the course.
- The vehicle was E-Stopped by a judge's call.
- The team E-Stops the vehicle.

- Six minutes have passed after the vehicle run has started for the Self-Drive Course.
- The vehicle has not started after one minute after moving to the start line or at the judges' discretion.
- The full vehicle crossed over the lane.
- The barrel was displaced during the run.

• Time for each heat will be strictly observed.

• Tactile sensors will not be allowed.

• Based on the above allowable run times, if the vehicle has not completed the course in the 6 minute time period, the attempt will be ended by a judge's choice E-stop, with no additional penalty for that run.

• Each vehicle must navigate the course by remaining inside the course boundaries and navigating around course obstacles. Crossing internal lines is allowed with penalty of 25 points.

• For the following Traffic Violations, the appropriate ticket will be issued and deducted from the overall distance or time score. Refer to V.B6 Traffic Violation Laws.

• Hands should be visible and off the vehicle's steering wheel at all times during run time.

V.B6 TRAFFIC VIOLATION LAWS

	Traffic Violations	**Ticket Value Points**	**E-Stop**	**Measurement**
1	Hold-up Traffic	End of Run	Yes	>60 secs. to 88 ft
2	Lane Excursion	- 25	Yes	Yes
3	Crash/Obstacle Displacement	End of Run	Yes	Yes
4	Sideswipe/Obstacle Touch	- 25	No	No
5	Student's Choice E-Stop	- 10	Yes	Yes
6	Judge's Choice E-Stop	- 0	Yes	Yes
7	Blocking Traffic	- 5	Yes	Yes
8	Too slow, did not average 1 mph	Disqualified	No	No

Table 1: Traffic Violation Laws

• **Hold-up traffic**: An attempt to fix the issue on the spot, withholding an opportunity for other teams to run
• **Lane Excursion**: A portion of the vehicle crosses a lane. The penalty is applied only once per segment of the course. The number of excursions per segment is recorded.
• **Crash/Obstacle Displacement**: The barrel or another obstacle was fully displaced from its original position.
• **Sideswipe/Obstacle Touch:** The barrel was touched without being displaced.

• **Student E-Stop**: Student e-stop is used if the team feels that there may be damaged caused to their vehicle or they know that it is stuck and want to end their time.
• **Judge E-Stop**: The overall distance will be measured from the starting line to the front of the vehicle or where the final/furthest remaining part of vehicle if stopped, crossed the boundary outside edge.
• **Blocking Traffic**: Vehicles stopping on course for over one minute will be E-Stopped and measured.
• **Too Slow**: If the vehicle does not maintain 1 mph minimum average speed limit throughout the course this run is disqualified.

V.B7 HOW COMPETITION WILL BE JUDGED

• A team of judges and officials will determine compliance with all rules.
• Designated competition judges will determine the official times, distances and ticket deductions of each entry. At the end of the competition, those vehicles crossing the finish line will be scored on the time taken to complete the course minus any ticket deductions. Ticket values will be assessed in seconds (one foot = one second) if the vehicle completes the course within the run time.

• The team with the adjusted shortest time will be declared the winner.

• In the event that no vehicle completes the course, the score will be based on the distance traveled by the vehicle minus the ticket deductions. The team with the adjusted longest distance will be declared the winner.

• In the event that two or more teams had completed the course, the team with the better time score will be declared the winner.

• The scoring criteria is based on the weighted combination of Functions Testing (54 % weight) and completed Self-Drive course (46 % weight).Please see "Table 8: Self-Drive Cumulative Scoring System Example" for further details.

V.B8 GROUNDS FOR DISQUALIFICATION

• Judges will disqualify any vehicle which appears to be a safety hazard or violate the safety requirements during the competition.

• Intentional interference with another competitor's vehicle and/or data link will result in disqualification of the offending contestant's entry.

• Damaging the course or deliberate movement of the obstacles or running over the obstacles may result in disqualification.

• Actions designed to damage or destroy an opponent's vehicle are not in the spirit of the competition and will result in disqualification of the offending contestant's entry.

V.B9 SELF-DRIVE SCENARIOS

All tests shall be conducted on the paved test track with an open sky environment. The course will be two lanes wide and each lane will have a width of 10 ~~eight~~ ft. No other vehicles or unauthorized personal shall be present when the tests are active. The team's representative shall be seated at the driver seatand the test judge shall be seated as a passenger. The judge shall hold the remote e-stop in his/her hands.

After passing Qualification Testing (Appendix A), the team is ready for Self-Drive Functions Testing (Appendix B) and Main Course (Appendix C).

The following signs and obstacles may be present on the track during Functions Testing and Main Course.

Sign / Obstacle	Dimensions
"Road Closed"	24" H x 30" W minimum height from ground is 5 feet
"One Way"	12" H x 36" W minimum height from ground is 5 feet
"Stop"	24" H x 24" H minimum height from ground is 5 feet
“No Turns"	24" H x 24" H minimum height from ground is 5 feet
Mannequin	71.7" height, 18.1" width shoulder to shoulder, 37.4" chest, 29.9" waist, 37.8" hips
Barrel(s)	39.7"H x 23.5"W Weight: 8 lbs
Pothole	2' diameter solid white circle or plastic mirror

Table 2: Traffic Signs and Obstacles specifications

The evaluation will be completed with two judges who will track the vehicle through each test. Evaluation points and comments will be marked in the Self-Drive Evaluation Worksheet. After the test completion, the test score will be reviewed with a team representative. The Judge(s) and a team representative will initial the evaluation sheet upon finished discussion.

V.C1 Design OBJECTIVE See Sec III

Although the ability of the vehicles to negotiate the competition courses is the ultimate measure of product quality, the officials are also interested in the design strategy and process that engineering teams follow to produce their vehicles. Design judging will be by a panel of expert judges and will be conducted separate from and without regard to vehicle performance on the test course. Judging will be based on a written report, an oral presentation and examination of the vehicle.
Design innovation is a primary objective of this competition and will be given special attention by the judges. Innovation is considered to be a technology (hardware or software) that has not ever been used

by this or any other vehicle in this competition. The innovation needs to be documented, as an innovation, clearly in the written report and emphasized in the oral presentation.

V.D AWARDS AND RECOGNITION

All schools are only eligible to win award money once per Self-Drive; if more than one team from the same school places in the event, only the highest placing team will be placed in a standing and receive money for Self-Drive.

The scoring criteria is based on the weighted combination of Functions Testing (54 % weight) and completed Self-Drive course (46 % weight).
Please see the example below:

Results	Team 1	Team 2	Team 3	Team 4
Functions testing place	3	1	2	4
Function testing weighted (54%)	12.32	15.4	13.86	10.78
Self-drive course place	1	2	3	4
Self-drive course weighted (46%)	14.6	13.14	11.68	10.22
FINAL SCORE WEIGHTED =	26.92	28.54	25.54	21
FINAL PLACE	**3**	**1**	**2**	**4**

Table 8: Self-Drive Cumulative Scoring System Example

Awards See Section VII

{

V.E PUBLICATION AND RECOGNITION

Internal recognition of all participating teams through Self-Drive publications.
Videos of the competition event will be distributed to sponsors, media and the public. All design reports, articles, videos and pictures will be posted on the IGVC website www.igvc.org

Name	Editor(s)
Jerry Lane, Jane Tarakhovsky, Andrew Kosinski	2017-2022

Table 11: Self-Drive Rules Editors

All questions and concerns should be e-mailed to IGVCquestions@yahoo.com

V.F1 APPENDIX A. QUALIFICATION TESTING

Test Type	Test ID	Name	# of Runs	Time	Penalty Points	Comments
Qualification	Q.1	E-Stop Manual				
Qualification	Q.2	E-Stop Wireless				
Qualification	Q.3	Lane Keeping (Go Straight)				
Qualification	Q.4	Left Turn				
Qualification	Q.5	Right Turn				

Table 12: Qualification Test Data Sheet

Qualification Test Descriptions

Test Q.1 E-Stop Manual

1. Test Goal

This test is intended to evaluate safety features of Manual E-Stop.

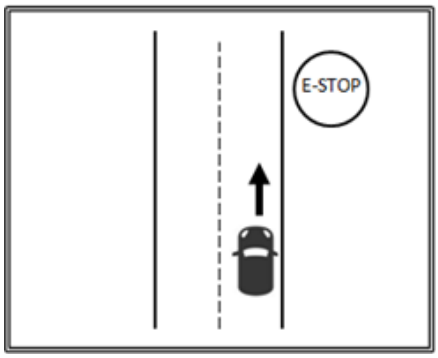

Figure 3: Qualification Testing, E-Stop Manual

2. Test Setup

The following items shall be placed on the road:

- **Flag 1** to indicate starting point at which vehicle is stationary
- **Flag 2** to indicate the position where E-Stop button is pressed
- **Flag 3** to indicate the maxim distance for the vehicle to come to the complete stop

3. Test Script

1. Begin test run
2. Judge pushes 'start' button
3. Vehicle takes off from full stop at **Flag 1**
4. Vehicle maintains the target speed
5. Judge manually pushes E-Stop at **Flag 2**
6. Vehicle comes to full stop before reaching **Flag 3**
7. End test run

4. Evaluation

Pass / Fail Criteria - vehicle is able to stop before reaching **Flag 3**

Test Q.2 E-Stop Wireless

1. Test Goal

This test is intended to evaluate safety features of Wireless E-Stop

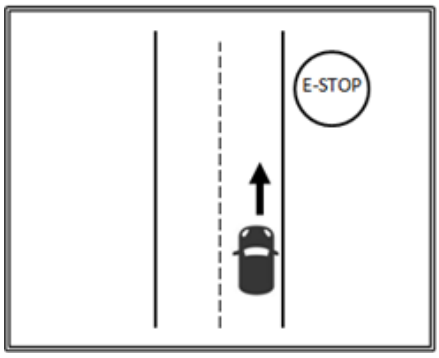

Figure 4: Qualification Testing, E-Stop Wireless

2. Test Setup

The following items shall be placed on the road:

- **Flag 1** to indicate starting point at which vehicle is stationary
- **Flag 2** to indicate the position where E-Stop button is pressed
- **Flag 3** to indicate the maxim distance for the vehicle to come to the complete stop

3. Test Script

1. Begin test run
2. Judge pushes 'start' button
3. Vehicle takes off from full stop at **Flag 1**
4. Vehicle maintains the target speed (between 4 – 5 mph)
5. Judge manually pushes E-Stop at **Flag 2**
6. Vehicle reaches full stop before reaching **Flag 3**
7. End test run

4. Evaluation

Pass / Fail Criteria - vehicle is able to stop before reaching **Flag 3**

Test Q.3 Lane Keeping (Go Straight)

1. Test Goal

This test is intended to evaluate if the vehicle is able to stay within lane boundaries, without wheels crossing the line or driving on the line.

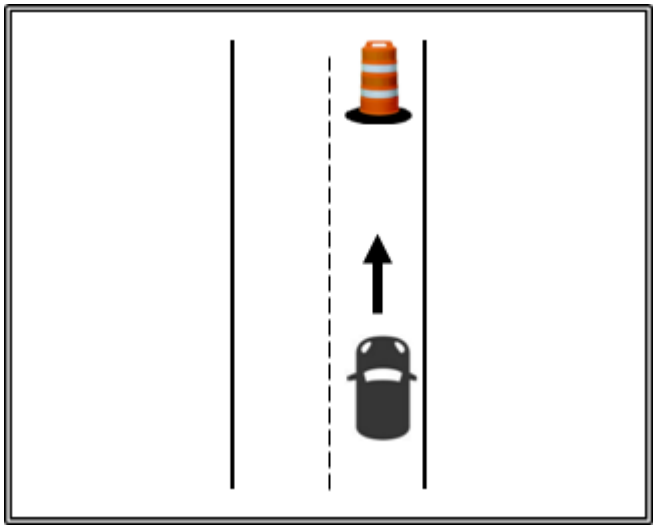

Figure 5: Qualification Testing. Lane Keeping. Go Straight

2. Test Setup

The following items shall be placed on the road:

- **Flag 1** to indicate starting point at which vehicle is stationary
- **Barrel** about 50 ft away to indicate ending point

3. Test Script

1. Begin test run
2. Judge pushes 'start' button
3. Vehicle takes off from full stop at **Flag 1**
4. Vehicle maintains the target speed (between 4 – 5 mph)
5. Vehicle reaches full stop within 3 ft from the obstacle (barrel)
6. End test run

4. Evaluation

Pass / Fail Criteria - vehicle stays within lane boundaries without wheels crossing the lines. Vehicle reaches full stop within 3 ft of barrel.

Test Q.4 Left Turn

1. Test Goal

This test is intended to evaluate if a vehicle is able to make a left turn across the traffic, merge into expected lane and drive within this lane until an obstacle is detected.

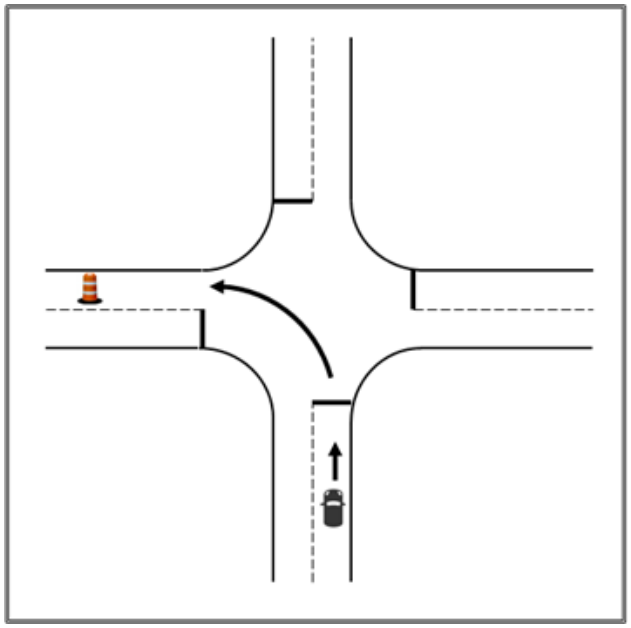

Figure 6: Qualification Testing. Left Turn

2. Test setup

The following items shall be placed on the road:

- **Flag 1** to indicate starting point at which vehicle is stationary. The flag could be placed near the stop bar or several feet away from the stop bar per judges' decision.
- **Barrel** to indicate ending point. The barrel is placed about 30 ft away from the stop bar in the right lane

3. Test Script

1. Begin test run
2. Judge pushes 'start' button
3. Vehicle takes off from full stop at **Flag 1**
4. Vehicle maintains the target speed (between 2 – 5 mph)
5. Vehicle turns left across the traffic and merges into correct lane
6. Vehicle maintains the target speed (between 2 – 5 mph)
7. Vehicle reaches full stop within 3 ft from the obstacle (barrel)
8. End test run

4. Evaluation

Pass / Fail Criteria - vehicle is able to turn left, merge into correct lane and stop without hitting the barrel or crossing boundaries

Test Q.5 Right Turn

1. Test Goal

This test is intended to evaluate if the vehicle is able to make a right turn, merge into the lane and drive within a lane until an obstacle is detected.

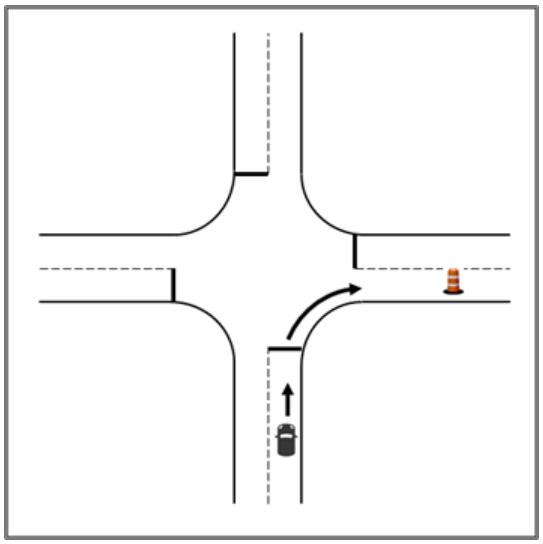

Figure 7: Qualification Testing, Right Turn

2. Test Setup

The following items shall be placed on the road:

- **Flag 1** to indicate starting point at which vehicle is stationary. The flag could be placed near the stop bar or several feet away from the stop bar per judges' decision.
- **Barrel** to indicate ending point. The barrel is placed about 30 ft away from the stop bar in the right lane

3. Test Script

1. Begin test run
2. Judge pushes 'start' button
3. Vehicle takes off from full stop at **Flag 1**
4. Vehicle maintains the target speed (between 4 – 5 mph)
5. Vehicle makes right turn and merges into correct lane
6. Vehicle maintains the target speed (between 4 – 5 mph)
7. Vehicle reaches full stop within 3 ft from the obstacle (barrel)
8. End test run

4. Evaluation

Pass / Fail Criteria - vehicle is able to turn right, merge into correct lane and stop without hitting the barrel or crossing boundaries

V.F2 APPENDIX B. FUNCTIONS TESTING

Functions Testing consists of the following independent tests:

Test Type	Test ID	Name	# of Runs	Time	Penalty Points	Comments
I. Traditional Machine Vision Tests						
Function	I.1	White Lines Detection				
Function	I.2	Pedestrian Detection				
Function	I.3	Tire Detection				
II. Traffic Sign Tests						
Function	II.1	Stop Sign Detection				
III. Intersection Tests						
Function	III.1	Lane Keeping				
Function	III.2	Left Turn				
Function	III.3	Right Turn				
IV. Parking Tests						
Function	IV.1	Parking. Pull Out				
Function	IV.2	Parking. Pull In				
Function	IV.3	Parking. Parallel				
V. VRU (Vulnerable Road User) Tests						
Function	V.1	Unobstructed STATIC Pedestrian Detection				
Function	V.2	Obstructed DYNAMIC Pedestrian Detection				
Function	V.3	STATIC Pedestrian Detection. Lane Changing				
Function	V.4	Obstacle Detection. Lane Changing				
VI. Curved Road Evaluation Tests						
Function	VI.1	Curved Road Evaluation. Lane Keeping				
Function	VI.2	Curved Road Evaluation. Lane Changing				
VII. Other Tests						
Function	VII.1	Pothole Detection				
Function	VII.2	Merging				

Table 13: Function Testing Scoring Sheet

Traditional machine vision and signs detection tests require GUI interface with displayed results during the test. The Stop Sign detection test shall display a relevant classification as “Stop Sign” or “Unknown”.

I. Traditional Machine Vision Tests

The goals of the traditional Machine Vision tests are to foster object detection primarily based on shape and color. Traditional machine vision and signs detection tests **require** GUI interface with displayed results during the test.

Test FI.1 White Lines Detection

1. Test Goal

This test is intended to evaluate detection of white lines using traditional Machine Vision algorithms. There are NO PENALTIES for crossing or moving over a line. A GUI interface with extracted white lines MUST be present during a run.

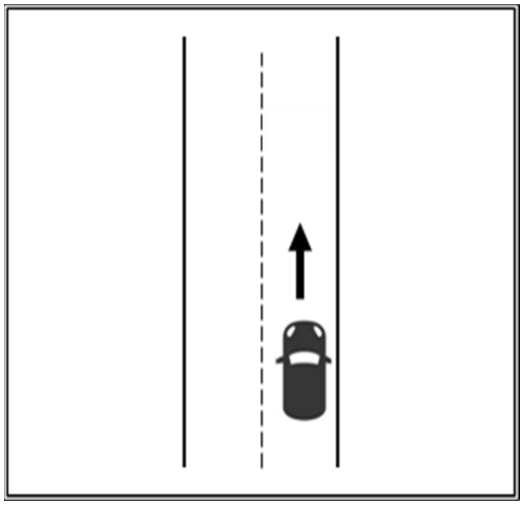

Figure 9: Machine Vision Tests, White Lines Detection

2. Test Setup

The following items shall be placed on the road:

- **Flag 1** to indicate starting point at which vehicle is stationary

3. Test Script

1. Begin test run
2. Judge pushes 'start' button
3. Vehicle takes off from full stop at **Flag 1**
4. Vehicle maintains the target speed (between 2 – 5 mph)
5. Judge pushes ‘start’ button
6. End test run

Test FI.2 Static Pedestrian Detection

1. Test Goal

This test is intended to evaluate detection of a mannequin using traditional Machine Vision algorithms. A mannequin wears ORANGE construction vest. A GUI interface with extracted orange blob MUST be present during a run. There are NO PENALTIES for crossing or moving over a line.

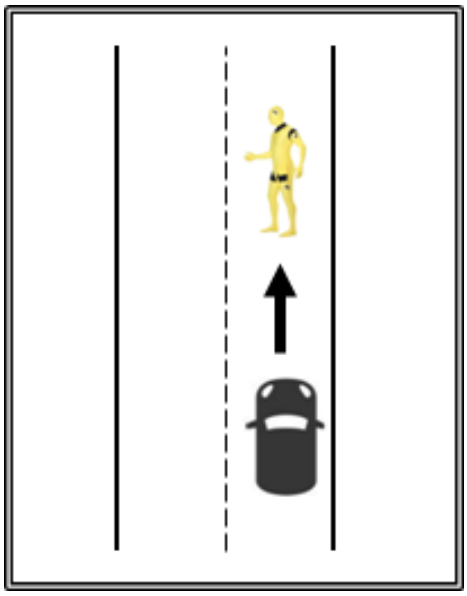

Figure 10: Machine Vision Tests. Static Pedestrian Detection

2. Test Setup

The following items shall be placed on the road:

- **Flag 1** to indicate starting point at which vehicle is stationary

3.Test Script

1. Begin test run
2. Judge pushes 'start' button
3. Vehicle takes off from full stop at **Flag 1**
4. Vehicle maintains the target speed (between 2 – 5 mph)
5. Judge pushes ‘start’ button
6. End test ru

Test FI.3 Tire Detection

1. Test Goal

This test is intended to evaluate detection of a small item present in a current lane using traditional Machine Vision algorithms. A GUI interface with extracted shape of a tire MUST be present during a run. There are NO PENALTIES for crossing or moving over a line.

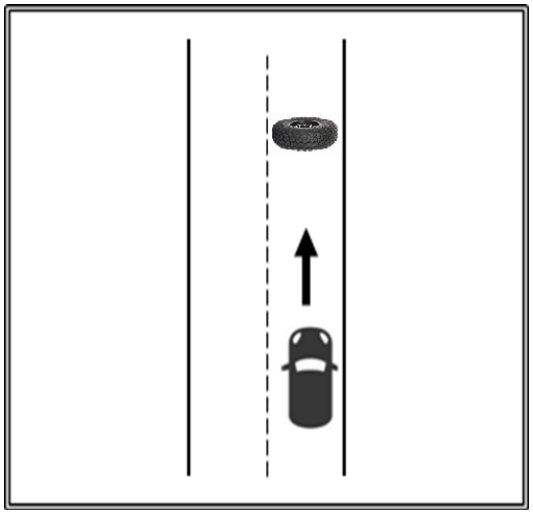

Figure 11: Machine Vision Tests, Tire Detection

2. Test Setup

The following items shall be placed on the road:

- **Flag 1** to indicate starting point at which vehicle is stationary

3.Test Script

1. Begin test run
2. Judge pushes 'start' button
3. Vehicle takes off from full stop at **Flag 1**
4. Vehicle maintains the target speed (between 2 – 5 mph)
5. Judge pushes ‘start’ button
6. End test run

II. Traffic Sign Tests

Test FII.1 Stop Sign Detection

1. Test Goal

This test is intended to evaluate Stop Sign classification detection and accuracy. Before test, a RANDOM picture might be put on top of a STOP sign. A forgery sign could be red in color with different letters, be a different color with same letters or be a different picture. A GUI interface shell display a relevant classification as “Stop Sign” or “Unknown”. There are NO PENALTIES for crossing or moving over a lane.

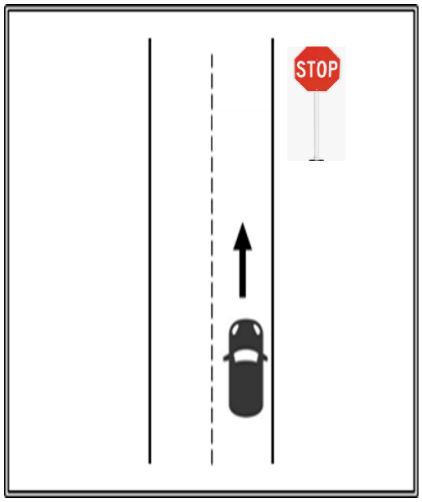

Figure 12: Functions Testing. Stop Sign Detection

2. Test Setup

a. **Flag 1** to indicate starting point at which vehicle is stationary

3. Test Script

1. Begin test run
2. Judge pushes 'start' button
3. Vehicle takes off from full stop at **Flag 1**
4. Vehicle maintains the target speed (between 2 – 5 mph)
5. Vehicle reaches full stop within 2 ft from the "Stop" sign
6. End test run

III. Intersection Tests

The goals of the Intersection tests are to evaluate vehicle's ability to maneuver at a road intersection.

Test FIII.1. Lane Keeping

1. Test Goal

This test is intended to evaluate if the vehicle is able maneuver within lane boundaries, without wheels crossing the line or driving on the line while driving XX road drive.

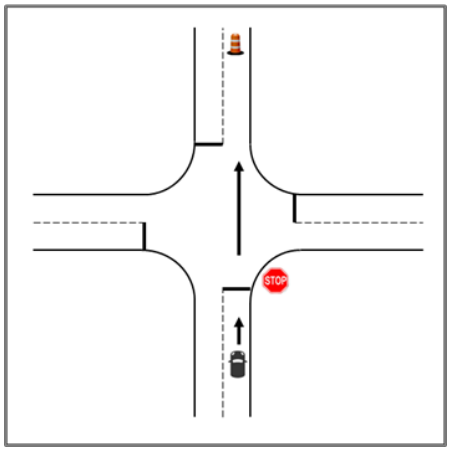

Figure 13: Intersection Tests, Lane Keeping

2. Test Setup

The following items shall be placed on the road:

2. **Flag 1** to indicate starting point at which vehicle is stationary
3. **'Stop'** sign
4. **Barrel** to indicate ending point

3.Test Script

1. Begin test run
2. Judge pushes 'start' button
3. Vehicle takes off from full stop at **Flag 1**
4. Vehicle maintains the target speed (between 4 – 5 mph)
5. Vehicle reaches full stop within 30 cm from perpendicular white line next to the "Stop" sign
6. Vehicle takes off from full stop
7. Vehicle maintains the target speed (between 4 – 5 mph)
8. Vehicle reaches full stop within 3 ft the obstacle (barrel)
9. End test run

Test FIII.2. Intersection Testing. Left Turn

1. Test Goal

This test is intended to evaluate if a vehicle is able to stop at the 'Stop' traffic sign, make a left turn across the traffic, merge into expected lane and drive within this lane until an obstacle is detected.

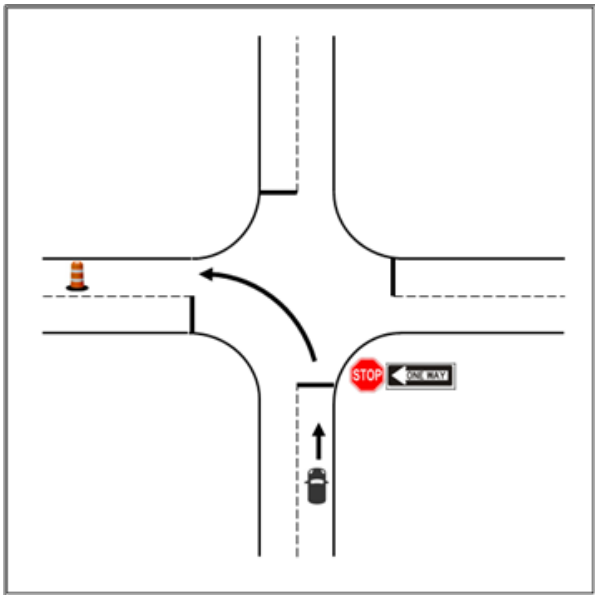

Figure 14: Intersection Testing. Left Turn

2. Test Setup

The following items shall be placed on the road:

- **Flag 1** to indicate starting point at which vehicle is stationary
- '**Stop**' sign
- **'One Way'** sign
- **Barrel** to indicate ending point

3. Test Script

1. Begin test run
2. Judge pushes 'start' button
3. Vehicle takes off from full stop at **Flag 1**
4. Vehicle maintains the target speed (between 4-5 mph)
5. Vehicle reaches full stop within 30 cm from perpendicular white line next to the "**Stop**" sign
6. Vehicle takes off from full stop
7. Vehicle turns left across the traffic and merges into correct lane
8. Vehicle maintains the target speed (between 4 – 5 mph)
9. Vehicle reaches full stop within 3 ft from the obstacle (**Barrel**)
10. End test run

Test FIII.3. Intersection Testing. Right Turn

1. Test Goal

This test is intended to evaluate if a vehicle is able to stop at the 'Stop' traffic sign, make a right turn, merge into the lane and drive within a lane until an obstacle is detected.

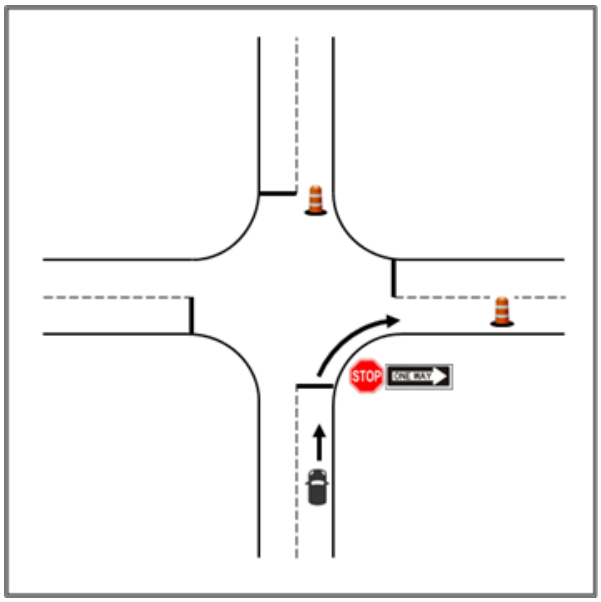

Figure 15: Intersection Testing. Right Turn

2. Test Setup

The following items shall be placed on the road:

- **Flag 1** to indicate starting point at which vehicle is stationary
- '**Stop'** sign
- **'One Way'** sign
- **Barrel** to indicate blocked road
- **Barrel** to indicate ending point

3. Test Script

1. Begin test run
2. Judge pushes 'start' button
3. Vehicle takes off from full stop at **Flag 1**
4. Vehicle maintains the target speed (between 4 – 5 mph)
5. Vehicle reaches full stop within 30 cm perpendicular white line next to the "**Stop**" sign
6. Vehicle takes off from full stop
7. Vehicle turns right and merges into correct lane
8. Vehicle maintains the target speed (between 4 – 5 mph)
9. Vehicle reaches full stop within 3 ft from the obstacle (**Barrel**)
10. End test run

IV. Parking Tests

Test FIV.1 Parking. Pull Out

1. Test Goal

This test is intended to evaluate if a vehicle is able to reverse out (or pull out) of the representative parking space.

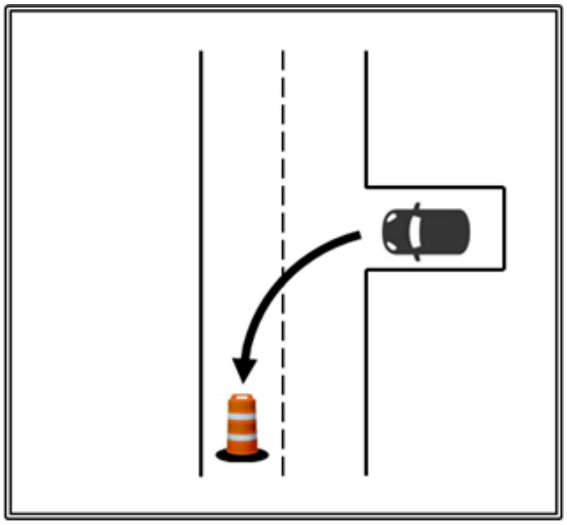

Figure 16: Parking. Pull Out

2. Test Setup

The following items shall be placed on the road:

- **Flag 1** to indicate starting point at which vehicle is stationary
- **Barrel** to indicate ending point

3. Test Script

1. Begin test run
2. Judge pushes 'start' button
3. Vehicle takes off from full stop at **Flag 1**
4. Vehicle slowly pulls out from the parking spot
5. Vehicle reaches full stop within 3 ft from the obstacle (**Barrel**)
6. End test run

Test FIV.2. Parking. Pull In

1. Test Goal

This test is intended to evaluate if a vehicle is able to pull into a representative parking space.

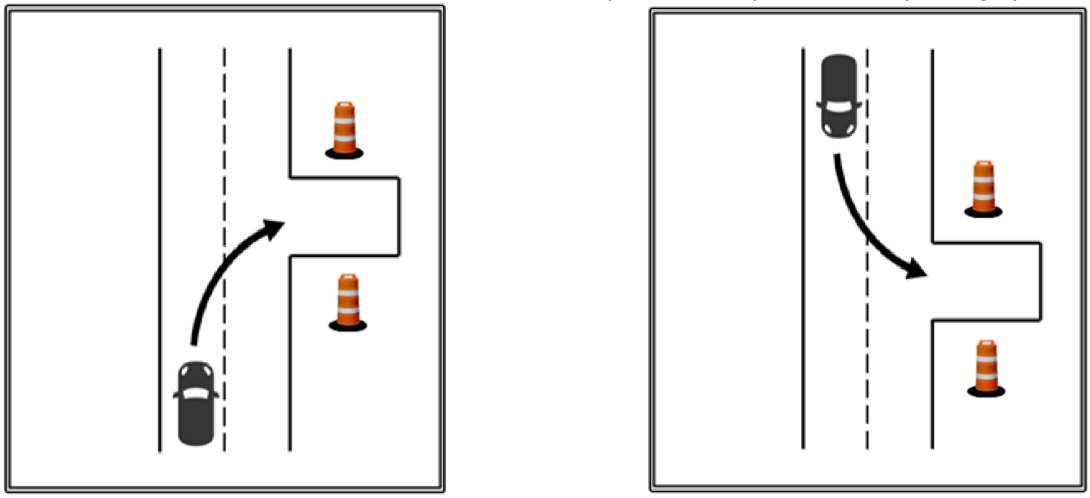

Figure 17(a,b): Functions Testing, Parking, Pull In

2. Test Setup

The following items shall be placed on the road:

- **Flag 1** to indicate starting point at which vehicle is stationary
- **Flag2** to indicate ending point

3. Test Script

1. Begin test run
2. Judge pushes 'start' button
3. Vehicle takes off from full stop at **Flag 1**
4. Vehicle slowly pulls into the parking spot
5. Vehicle reaches full stop. It should be fully in the box without crossing any lines.
6. End test run

Test FIV.3. Parking. Parallel

1. Test Goal

This test is intended to evaluate if a vehicle is able to parallel park into the representative parking space.

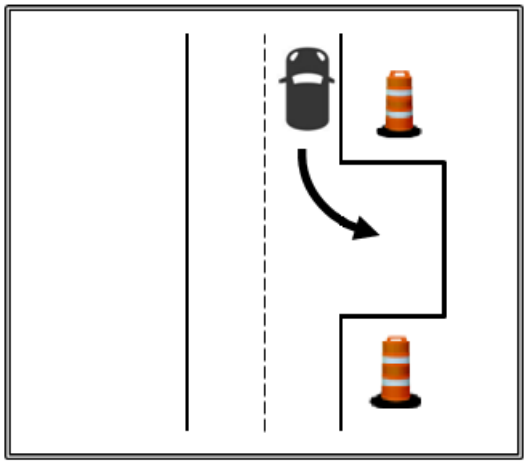

Figure 17: Functions Testing, Parking, Parallel

2. Test Setup

The following items shall be placed on the road:

- **Flag 1** to indicate starting point at which vehicle is stationary
- **Barrel 1** to indicate 1st obstacle in front of the parking spot
- **Barrel 2** to indicate 2nd obstacle behind the parking spot

3. Test Script

1. Begin test run
2. Judge pushes 'start' button
3. Vehicle backs off from full stop at **Flag 1**
4. Vehicle slowly pulls into the parking spot
5. Vehicle reaches full stop. It should be fully in the box without crossing any lines.
6. End test run

V. VRU (Vulnerable Road User) and Obstacle Tests

Test FV.1 Unobstructed STATIC pedestrian detection

This test evaluates ability of Ego vehicle to stop if a pedestrian is detected within boundaries of a current lane.

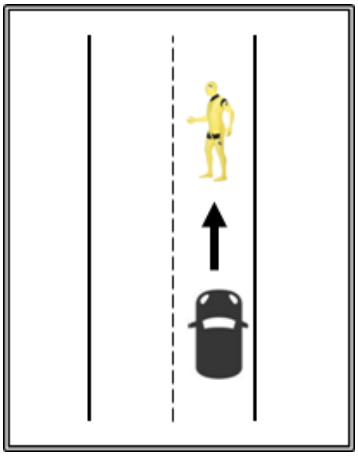

Figure 19: Functions Testing. Unobstructed Static Pedestrian Detection

2. Test Setup

The following items shall be placed on the road:

- **Flag 1** to indicate starting point at which vehicle is stationary
- **Barrel** to indicate ending point
- **Mannequin**

3. Test Script

1. Begin test run
2. Judge pushes 'start' button
3. Vehicle takes off from full stop at **Flag 1**
4. Vehicle maintains the target speed (between 4 – 5 mph)
5. Vehicle reaches full stop within 5 ft from the obstacle (**Mannequin**)
6. End test run

Test FV.2 Obstructed DYNAMIC pedestrian detection

1. Test Goal

This test evaluates ability of Ego vehicle to stop if an obstructed by barrel pedestrian (mannequin) suddenly starts crossing an Ego's vehicle lane.

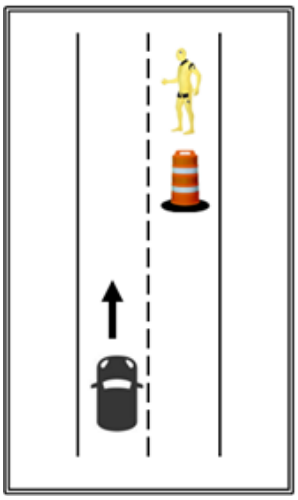

Figure 20: Functions Testing. Obstructed Dynamic Pedestrian Detection

- **Flag 1** to indicate starting point at which vehicle is stationary
- **Barrel** to indicate ending point
- **Mannequin**

3. Test Script

1. Begin test run
2. Judge pushes 'start' button
3. Vehicle takes off from full stop at **Flag 1**
4. Vehicle maintains the target speed (between 3 – 5 mph)
5. Vehicle reaches full stop within 5 ft from the obstacle (**Mannequin**)
6. End test run

Test FV.3 STATIC Pedestrian Detection. Lane Changing

1. Test Goal

This test imitates a situation of a broken vehicle in a current lane with STATIC pedestrian standing BEHIND a barrel and in FRONT of Ego's vehicle. Ego vehicle must slow down and safely change into an adjacent lane.

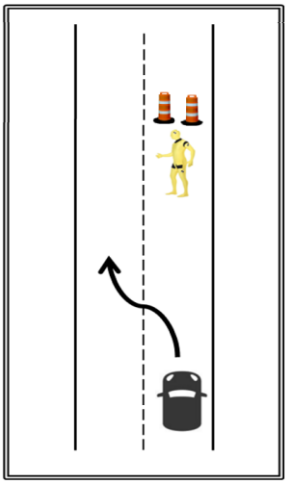

Figure 21: Functions Testing. Pedestrian Detection. Lane Changing

2. Test Setup

There will be a distance of approximately 85 ft between the mannequin/barrel when mannequin will start crossing the road.
The following items shall be placed on the road:

- **Flag 1** to indicate starting point at which vehicle is stationary
- **Mannequin** to indicate obstacle
- **Barrels 1 and 2 to indicate broken vehicle in a current lane**
- **Barrel 3** to indicate end of a run

3. Test Script

1. Begin test run
2. Judge pushes 'start' button
3. Vehicle takes off from full stop at **Flag 1**
4. Vehicle maintains the target speed (between 3 -5 mph)
5. Vehicle detects **Mannequin**
6. Vehicle performs safe transition into the next lane 10 ft away from the Mannequin
7. Vehicle maintains the target speed in the new lane (between 3-5 mph)
8. Vehicle reaches full stop within 3 ft from the obstacle (**Barrel 3**)
9. End test run

Test FV4. Obstacle detection. Lane Changing

1. Test Goal

This test evaluates Ego vehicle's ability to safely change lane if a stationary object is present within a current lane.

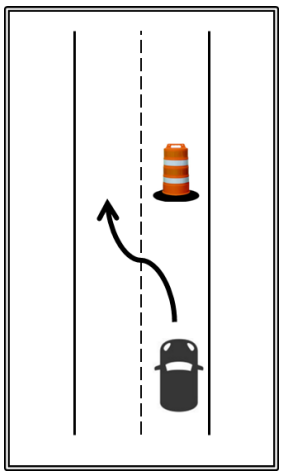

Figure 22: Functions Testing. Obstacle Detection. Lane Changing

1. Test Setup

There will be a distance of approximately 85 ft between the barrel and the vehicle.
The following items shall be placed on the road:

- **Flag 1** to indicate starting point at which vehicle is stationary
- **Barrel 1** to indicate obstacle
- **Barrel 2** to indicate ending point

2. Test Script

1. Begin test run
2. Judge pushes 'start' button
3. Vehicle takes off from full stop at **Flag 1**
4. Vehicle maintains the target speed (between 3 – 5 mph)
5. Vehicle detects obstacle (**Barrel 1)** and safely moves into the next lane
6. Vehicle maintains the target speed in the new lane (between 3 – 5 mph)
7. Vehicle reaches full stop within 3 ft from the obstacle (**Barrel 2**)
8. End test run

VI. Curved road Evaluation Tests

The minimum inside curve radius is 10 meters (32.8084 feet).

Test FVI.1 Curved Road Evaluation. Lane Keeping

1. Test Goal

This test is intended to evaluate Ego vehicle's ability to stay in the lane on a curved road and be able to stop at the obstacle within a current lane. This test consists of 4 possible case scenarios: driving in right lane on the left curve, driving in left lane on the left curve, driving in right lane on the right curve and driving in left lane on the right curve. Any of above scenarios could be chosen as this year's test.

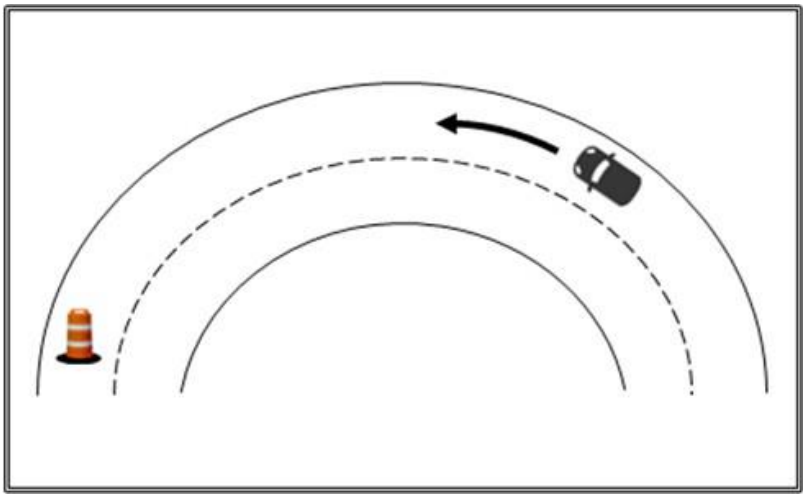

Figure 23: Functions Testing. Curved Road Evaluation. Lane Keeping

2. Test Setup

The following items shall be placed on the road:

- **Flag 1** to indicate starting point at which vehicle is stationary
- **Barrel** to indicate ending point

3. Test Script

1. Begin test run
2. Judge pushes 'start' button
3. Vehicle takes off from full stop at **Flag 1**
4. Vehicle maintains the target speed (between 3 – 5 mph)
5. Vehicle reaches full stop within 3 ft from the obstacle (barrel)
6. End test run

Test FVI.2 Curved Road Evaluation. Lane Changing

1. Test Goal

This test is intended to evaluate if a vehicle is able to perform a lane change on the curved road if obstacles are detected. This test consists of 4 possible case scenarios: changing right lane on the left curve, changing left lane on the left curve, changing right lane on the right curve and changing left lane on the right curve. Any of above scenarios could be chosen as this year's test.

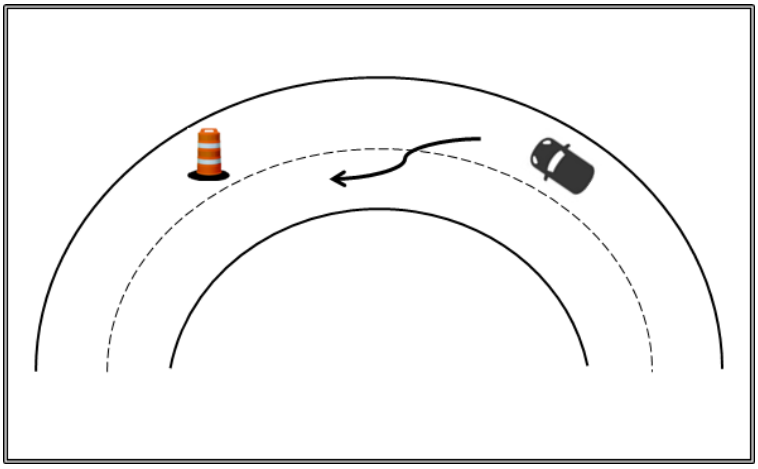

Figure 24: Functions Testing. Curved Road Evaluation. Lane Changing

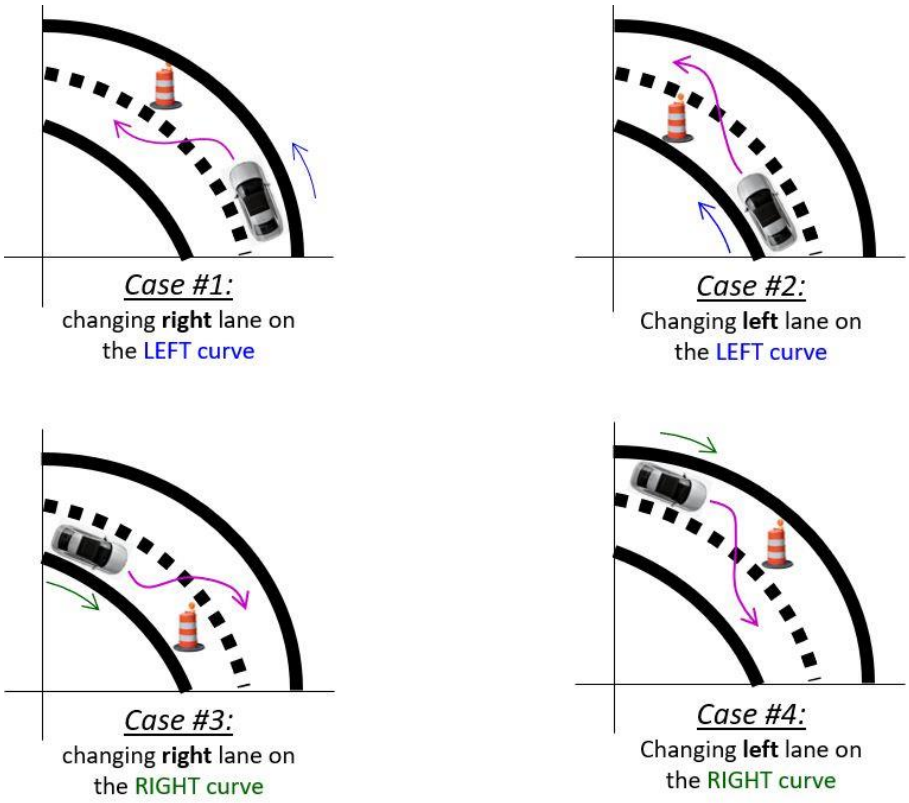

Figure 25: Types of Curved Road Evaluation scenarios

2. Test Setup

The following items shall be placed on the road:

- **Flag 1** to indicate starting point at which vehicle is stationary
- **Barrel 1** to indicate 1st obstacle
- **Barrel 2** to indicate 2nd obstacle
- **Barrel 3** to indicate ending point

3. Test Script

1. Begin test run
2. Judge pushes 'start' button
3. Vehicle takes off from full stop at **Flag 1**
4. Vehicle maintains the target speed (between 3 – 5 mph)
5. Vehicle detects obstacle (**Barrel 1)** and safely moves into the next lane
6. Vehicle maintains the target speed in the new lane (between 3 – 5 mph)
7. Vehicle detects obstacle (**Barrel 2)** and safely moves into the next lane
8. Vehicle maintains the target speed in the new lane (between 3 – 5 mph)
9. Vehicle reaches full stop within 3 ft from the obstacle (**Barrel 3**)
10. End test run

VII. Other Tests

Test FVII.1 Pothole Detection

1. Test Goal

This test is intended to evaluate Ego vehicle's ability to detect a pothole and safely change lane.

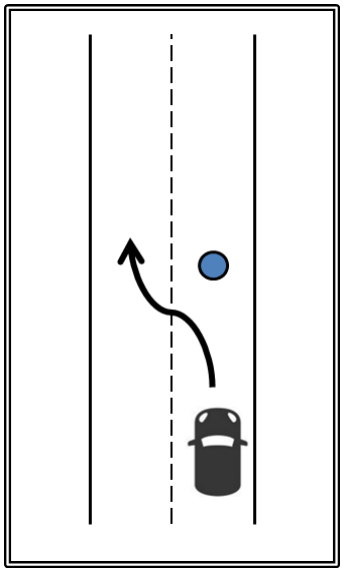

Figure 26: Functions Testing, Pothole Detection

2. Test Setup

The following items shall be placed on the road:

- **Flag 1** to indicate starting point at which vehicle is stationary
- **Pothole** (2 feet diameter solid white circle or plastic mirror)
- **Barrel** to indicate ending point

3. Test Script

1. Begin test run
2. Judge pushes 'start' button
3. Vehicle takes off from full stop at **Flag 1**
4. Vehicle maintains the target speed (between 4 – 5 mph)
5. Vehicle detects pothole and safely moves into the next lane
6. Vehicle maintains the target speed in the new lane (between 4 – 5 mph)
7. End test run

Test FVII.2 Merging

1. Test Goal

This test is intended to evaluate if a vehicle is able to perform a merge onto a representative highway.

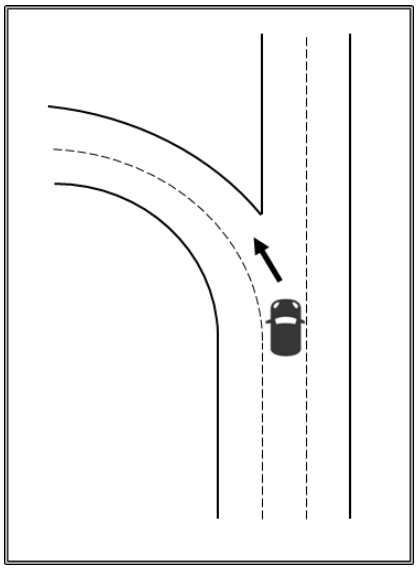

Figure 27: Functions Testing, Merging without Waypoints

2. Test Setup

The following items shall be placed on the road:

- **Flag 1** to indicate starting point at which vehicle is stationary
- **Barrel** to indicate ending point

3. Test Script

1. Begin test run
2. Judge pushes 'start' button
3. Vehicle takes off from full stop at **Flag 1**
4. Vehicle maintains the target speed (between 3 – 5 mph)
5. Vehicle merges into the next lane
6. Vehicle maintains the target speed (between 3 – 5 mph)
7. Vehicle reaches full stop within 3 ft from the obstacle (**Barrel**)
8. End test run

V.F3 APPENDIX C. MAIN COURSE TESTING

Main Test Description

1. Test Goal

This test is intended to evaluate if a vehicle is able to follow lane, change lane, detect and avoidobstacles, detect signs, merge into loop and park at the specified locations.

~~At least two waypoints will be present on the course.~~

[TBD]

Figure 23: Main Course Testing Location, Oakland University

2. Test Setup

The following items shall be placed on the road:

- **Flag 1** to indicate starting point at which vehicle is stationary
- **Barrels**
- **Mannequin**
- **Signs**

3. Test Script

TBD

4. Evaluation

Name:					
Item	**Functions**		**Attempted**	**Passed**	**Penalty Points**
1	**Speed within limits**				
2	**Lane Keeping**	wheels completely within marked boundaries of travel lane			
3	**Lane Changing**	moves completely to next lane			
		keeps safe distance from obstacle during the change			
4	**Pedestrian Detection**	static pedestrian			
		unobstructed pedestrian			
		obstructed pedestrian			
5	**Obstacle/Vehicle Detection**	stationary vehicle			
		moving ahead vehicle			
		crossing vehicle			
6	**Merging**	5-10 seconds delay before merging			
		passed 2 or more GPS waypoints			
7	**Left Turn**	10 sec delay			
8	**Right Turn**				
9	**Intersection detection/logic**				
10	**Stop sign/ cross lines detection**				
11	**Pothole detection**				

Table 14: Overall Test Performance Scoring Sheet

V.G REFERENCES

[1]. "Automated Driving Systems 2.0: A vision for safety". U.S. Department of Transportation, NHTSA, September 2017

https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/13069a-ads2.0_090617_v9a_tag.pdf

VI. CYBER CHALLENGE

VI.1 OBJECTIVE

The overall goal of the IGVC Cyber Challenge is to promote knowledge of vehicle security best practices in an educational context. Understanding of the NIST RMF process is a primary objective of this competition and will be given special attention by the judges. Understanding of the NIST RMF process will be demonstrated by a written report describing the process in general, followed by a specific case study using either a provided or novel threat concept applied to a specific vehicle. An oral presentation will be delivered during the IGVC competition and will demonstrate team understanding of the NIST RMF process as well as how it was applied to the choice, design, and implementation of cyber controls for team robots specific to chosen threat scenario. Cyber controls as outlined in the report and implemented on the team vehicle will be audited by judges after oral presentation. The audit will rely on the professional experience of the judges and will rely on teams describing ahead of time how they intend to prove efficacy of implemented controls ahead of the competition in the written report.

VI.2 WRITTEN REPORT

The IGVC Cyber Challenge report shall follow a modified version of the American Astronautical Society (AAS) paper format that is used by the Association for Unmanned Vehicle Systems International (AUVSI). The report must follow the outlined format provided in section III.6 **(DESIGN REPORT FORMAT – MANDATORY)** located at the end of this Written Report section. Each vehicle must have a complete report in defined format below of its own (a report cannot cover more than one vehicle). All reports, both for new vehicles and for earlier vehicles with design changes, must include a statement signed by the faculty advisor certifying that the design and engineering of the vehicle (original or changes) by the current student team has been significant and equivalent to what might be awarded credit in a senior design course.

Participants are required to submit an electronic copy in PDF format along with a scanned copy of the statement in PDF format by **May 15, 2023.** Report and statement must be e-mailed along with any questions to IGVCquestions@yahoo.com. Reports arriving after that date will lose 10 points in scoring for each day late, statements arriving after that date will lose 5 points in scoring for each day late. Teams are encouraged to submit reports even several weeks early to avoid the last minute rush of preparing vehicles for the competition. The electronic copy of the report will be posted on the competition's web site in PDF format after the completion of the competition.

VI.3 ORAL PRESENTATION

The technical presentation should relate the highlights of the written report described above and include any updates of the design since the written report. Audio or video presentations of the text are not allowed, but graphic aids may be presented by video, slide projection, computer projection, overhead transparencies, or easel charts. The presentation must be made by one or more student members of the team to the judges and other interested members of the audience and should last not more than 10 minutes. A penalty of 5 points will be assessed for each minute or fraction thereof over 11 minutes. After the presentation, judges only may ask questions for up to 5 minutes. The audience should be considered as a senior management group of generally knowledgeable engineers upon whom the project is dependent for funding and the team is dependent for their employment.

Effective use of graphic aids includes not blocking the view of the screen by the presenter and simple enough graphics that are large enough to read (block diagrams rather than detailed circuit diagrams). Articulation refers to the clarity and loudness of speaking. Eye contact refers to speaking to the audience and judges (not reading notes or screen or looking above audience heads). Response to questions means short answers that address only the question. Salesmanship refers to the enthusiasm and pride exhibited (why this vehicle is the best).

Participants are responsible for providing their own visual aids and related equipment (the vehicle itself may be displayed). A computer-connected projector will be made available. Projectors may also be supplied by the participants.

During the oral presentation, the following question period and the examination of the vehicle, team members sitting the audience may participate by assisting the oral presenters, but at no time is the faculty advisor to participate in this part of the design competition.

VI.4 Cyber Controls Audit

The vehicle must be present and will be examined by the judges immediately after the oral presentation and will last no more than 40 minutes. The burden of proof for the efficacy of the implemented controls lies with the student groups and should be fully explained in the written report and oral presentation. Proof of working controls should not rely solely complex software tools which would themselves require independent audit.

Demonstrations of controls should favor those which rely on common sense interpretation per below. Any controls which require engineering interpretation will be judged effective at the sole discretion of the auditing official(s).

Examples of Controls Requiring Common Sense Auditor Interpretation

Team implements access control to program/alter robot software. Access control has login screen which will accept correct password (as given to official to enter), but forbids access when incorrect code is entered.

Example of Control Requiring Partial Engineering Interpretation

Team implements wireless access encryption which they claim adheres to some industry standard. Demonstrated by means of remote laptop with correct access credentials which both works and doesn't with correct and incorrect credentials.

Whether claimed encryption adheres to the standard the student team claims would require extensive independent testing and thus in terms of the scope of the competition will rely solely on the subjective judgement of the auditing official.

In this example the remote login demonstrated would constitute a common sense demonstration, but the claim of encryption graded xyz is not easily verified. Because the common sense portion constitutes a fully implemented control independent of the encryption, full points would be awarded.

Example of Control Requiring Only Engineering Interpretation

Team implements complex intrusion avoidance algorithm which is claimed to ignore unauthorized robotic actuation commands.

While a very impressive feat indeed, because extensive third-party penetration testing would be required to verify the claim, this control would likely not receive any points toward the audit.

Efficacy being at the sole discretion of the auditing official, it's possible that such a case could result in full points if and only if the means of demonstration were as novel as the control, leaving no doubt as to the controls efficacy.

VI.5 DESIGN REPORT FORMAT - MANDATORY

First Section: Team Intro and Overview

Title Page

- University/College Name
- Vehicle/Team Name
- Vehicle Photo/Sketch/Symbol
- Date Submitted
- Team Captain's Name and E-Mail
- Team Members Names and E-Mails
- Faculty Advisors Name and Statement of Integrity

Conduct of design process, team identification and team organization

- Introduction
- Organization

Second Section: Demonstrate Understanding of NIST RMF Process

Overview of NIST RMF process

- Categorize
- Select
- Implement
- Assess
- Authorize
- Monitor

Identified threat concept

- Pick from provided list

Thorough threat modelling

a. Security category vs security impact level
b. Info needed to categorize an information system
c. Information system boundaries
d. Types of information process by information systems

Identification and mapping of cyber controls to counter identified threats

e. Defense-in-depth
f. Technology based controls
g. Management and operational controls
h. Security policies
i. Holistic approach to information security

Third Section: NIST RMF Process Applied to Competition Robot

Description of implemented cyber controls

- Relation of Chosen Controls to Mitigated Risk
- Design and Implementation Details of Controls
- Description of Appropriate but Unimplemented Controls

Description of cyber controls demonstration strategy

- Describe in detail how controls will be demonstrated
- Demonstration/control must be provable by simple audit (no special tools that would require further audit)

VI.6 EXAMPLE THREAT CONCEPTS

Scenario 1: Military Robotic Patrol

Your robot is part of a mission to protect a forward operating base (FOB) in Southwest Asia. It is a hot, empty desert environment surround by various sized sand dunes. The FOB is considered to be basic and temporary, and therefore consists of an arrangement of tents that serve various functions (including a hospital, a machine shop, and sleeping quarters) and a large open space to park ground vehicles and other similar systems. The FOB is under constant threat of attack by enemy forces, and is therefore protected by a ring of barbed wire with a fortified entry control point, and sentries (mounted and dismounted) in key tactical locations. Your robot is part of a team of robots

tasked with autonomously patrolling the FOB perimeter to detect intrusions. Your robots are not weaponized and only serve to provide early warning to the sentries of an imminent attack. Your robots may also patrol areas around the perimeter that are out of the sentry line-of-sight, during daytime and nighttime, and be out of communication range for brief periods of time.

Scenario 2: Robotic Warehouse Inventory Management

Your robot is part of a large wholesale distribution company that manages a very large inventory of items. The inventory is housed among multiple warehouse buildings in a distribution center the size of square mile. Your robot is tasked with transporting listed items between the various warehouse buildings and the mailing center, and therefore will operate in both indoor and outdoor environments. The robots also communicate and synchronize their jobs via a local campus-wide wireless network. The distribution center campus is shared among approximately 2000 other company employees or contractors, and new deliveries (via trucks) are arriving every 15 minutes around the clock.

Scenario 3: Make-Up-Your-Own

Create a scenario for your robot to operate in and consider the various cyber threats that it can be exposed to. Get as creative as you like! Consider ideas like: robotic assisted living, planetary exploration, subterranean or mining applications, autonomous pizza delivery, amusement park entertainment, etc. Make it hard, make it real, make it secure!

VI.7 Cyber Controls

- Data ports turned off (could be on a sliding scale for judging. For example not even powered for full compliance, partial compliance if powered but doesn't appear in OS device manager when attached, minimal compliance if doesn't auto-load/mount devices and appears as unrecognized device)
- Something like a token that is required for operation which expires, a keypad to enable robotic operation, a wireless tether with a render useless capability, geo-fencing.
- Wireless encryption/login

Examples from NIST include (https://nvd.nist.gov/800-53/Rev4/impact/moderate):

AC-1 Access Control Policy and Procedures
AC-2 Account Management
AC-3 Access Enforcement
AC-4 Information Flow Enforcement
AC-8 System Use Notification
AC-14 Permitted Actions without Identification and Authentication
AC-17 Remote Access
AC-18 Wireless Access
AC-19 Access Control for Mobile Devices
AC-20 Use of External Information Systems
AU-2 Audit Events
AU-5 Response to Audit Processing Failures
CA-1 Security Assessment and Authorization Policy and Procedures
CA-2 Security Assessments
CA-3 System Interconnections
CA-7 Continuous Monitoring
CA-9 Internal System Connections
CM-2 Baseline Configuration
CM-4 Security Impact Analysis
CM-6 Configuration Settings
CM-8 Information System Component Inventory
CM-11 User Installed Software

IA-3 Device Identification and Authentication
IA-5 Authenticator Management
IR-4 Incident Handling
MA-1 System Maintenance Policy and Procedures
PE-5 Access Control for Output Devices
PL-2 System Security Plan
PL-8 Information Security Architecture
RA-3 Risk Assessment
RA-4 Vulnerability Scanning
SA-5 Information System Documentation
SA-8 Security Engineering Principles
SA-9 External Information System Services
SA-11 Developer Security Testing and Evaluation
SC-2 Application Partitioning
SC-7 Boundary Protection
SC-13 Cryptographic Protection (If Applicable)
SC-15 Collaborative Computing Devices
SC-18 Mobile Code
SC-39 Process Isolation
SI-3 Malicious Code Protection
SI-4 Information System Monitoring
SI-7 Software, Firmware, and Information Integrity

VI.8 CYBER CHALLENGE SCORING

Written Report

Judges will score the oral presentations as follows:	**Maximum Points**
1. Quality of Documentation (English, grammar, completeness, and style)	50
2. Overview of NIST RMF Process	50
3. Identified threat concept	50
4. Thorough threat modelling	50
5. Identification and mapping of cyber controls	50
6. Description of implemented cyber controls	100
7. Description of cyber controls demonstration strategy	100
Total	450

Oral Presentation

Judges will score the oral presentations as follows:	**Maximum Points**
1. Clear, well planned and understandable explanation of NIST RMF Process	100
2. Logical organization and subject knowledge of the talk	50
3. Effective use of graphic aids	50
4. Articulation and eye contact during presentation	50
5. Response to questions	50
Total	300

Cyber Audit

Judges will score the vehicle examinations as follows:	**Maximum Points**
1. Cyber controls are appropriate for identified threats	150

2. Cyber controls are able to be demonstrated	150
3. Cyber controls implemented operate successfully	100
4. Cyber controls are effective in mitigating related threat	50
Total	450

Aggregate Score

Judges will score the vehicle examinations as follows:	**Maximum Points**
1. Written Report	450
2. Oral Presentation	150
3. Cyber Audit	600
Total	1200

VII. AWARDS AND RECOGNITION

All schools are only eligible to win award money once per event (Auto-Nav Challenge, Design Competition and IOP Challenge); if more than one team from the same school places in the same event, only the highest placing team will be placed in a standing and receive money for that event.

VII.1 AUTO-NAV & SELF DRIVE CHALLENGE COMPETITION

Award Money

(Vehicle must complete AutoNav course autonomously and Self Drive vehicle must perform all functions and full course autonomous) AutoNav

1ST Place	$ 3,000
2ND Place	$ 2,000
3RD Place	$ 1,500
4TH Place	$ 1,000
5TH Place	$ 750
6TH Place	$ 500

Nominal Award Money

(AutoNav must attain one ramp waypoint in No Man;s Land & Self drive Vehicle must qualify and successfully complete Function Tests 1-4)

1ST Place	$ 1,000
2ND Place	$ 800

3RD Place	$	600
4TH Place	$	500
5TH Place	$	400
6TH Place	$	300

SELF DRIVE CHALLENGE COMPETITION

Award Money

(Vehicle must complete All functions and entire Self Drive course autonomously

autonomous)

1ST Place	$ 2,000
2ND Place	$ 1,500
3RD Place	$ 1,000

Nominal Award Money

Self drive Vehicle must qualify and successfully complete Function Tests 1-4)

1ST Place	$ 1,000
2ND Place	$ 800
3RD Place	$ 600

VII.1 VEHICLE DESIGN COMPETITION

Design Competition Standard Awards

Dr. William G. Agnew Awards

	Auto Nav	Self Drive
1ST Place	$ 2,000	1000
2ND Place	$ 1,500	750
3RD Place	$ 1,000	500
4TH Place	$ 750	-------
5TH Place	$ 500	-------
6TH Place	$ 250	-------

Nominal Award Money

(Vehicle did not pass Qualification)

	Auto Nav	Self Drive
1ST Place	$ 600	600
2ND Place	$ 500	500
3RD Place	$ 400	400
4TH Place	$ 300	-----
5TH Place	$ 200	-----
6TH Place	$ 100	-----

VII.2 IOP CHALLENGE on-hold for 2023

VII.3 CYBER CHALLENGE AWARDS for AutoNav or Self Drive

VIII	1st ----------$1,500
IX	2nd----------$1,100
X	3rd----------$900
XI	4th----------$700
XII	5th----------$500

XII.1 ROOKIE-OF-THE-YEAR AWARD

The Rookie-of-the-Year Award will be given out to a team from a new school competing for the first time ever or a school that has not participated in the last five competitions (for this year the team would be eligible if they haven't competed since the 2012 IGVC). To win the Rookie-of-the-Year Award the team must be the best of the eligible teams competing and perform to the minimum standards of the following events. In the Design Competition you must pass Qualification, in the AutoNav Challenge you must pass the Rookie Barrel and in the IOP Challenge you must be compliant. The winner of the Rookie-of-the-Year Award will receive $1,000 in award money; in the case the minimum requirements are not met the best of the eligible teams competing will receive $500.

XII.2 GRAND AWARD

The Grand Award trophies will be, presented to the top three teams that perform the best overall in either AutoNav and Self Drive (combined scores per below), in three challenges. For each Challenge, points will be awarded to each team, below is a breakdown of the points:

Standard Grand Award Points*

Challenge AN or SD	First	Second	Third	Fourth	Fifth	Sixth
AutoNav-Self Dr	24	20	16	12	8	4
Design	12	10	8	6	4	2

Nominal Grand Award Points**

Challenge	First	Second	Third	Fourth	Fifth	Sixth
AutoNav-Self Dr	12	10	8	6	4	2
Design	6	5	4	3	2	1

* For Standard Grand Award Points, the team must complete the Auto-Nav & Self Drive courses and qualify in Auto Nav or Self Drive for the Design Competition points

** For Nominal Grand Award Points in each Challenge, the team must qualify to be eligible in the Auto-Nav or Self Drive Challenges and have their vehicle present for the Design

Competition.

VIII PUBLICATION AND RECOGNITION

International recognition of all participating teams through AUVSI publications.

Videos of the competition event will be distributed to sponsors, media and the public. All design reports, articles, videos and pictures will be post on the IGVC website www.igvc.org.

Name	Years as Editor
Jerry Lane, Jane Tarakhovsky & Andrew Kosinski	2018-2022
Jerry Lane & Andrew Kosinski	2014-2018
Bernard Theisen	2013-2014
Jerry Lane	2011-2013
Bernard Theisen	2006-2010
Greg Gill	2005-2006
Bernard Theisen	2004-2005
Dan Maslach	2003-2004
Bernard Theisen	2001-2003
Stephen W. Roberts	2000-2001
Scot Wheelock	1999-2000
Geoff Clark	1998-1999
G. Edzko Smid	1997-1998
Candy McLellan and G. Edzko Smid	1996-1997
Jerry Lane, Paul Lescoe and Ka C. Cheok	1992-1996

IGVC Rules Editors

All questions and concerns should be e-mailed to IGVCquestions@yahoo.com.

IX "IGVC In Memory Of"

Paul Lescoe	TARDEC Robotics Engineer	IGVC Co-Founder & Co-Chair
Dr.James Overholt	TARDEC Chief Roboticist	IGVC Judge & Official
Dr. Nattu Natajaran	UMD Professor	IGVC Faculty
Wayne Wheelock	Former TARDEC Director	IGVC Design Judge
Dr William G. Agnew	Former GM Research Lab Director	IGVC Design Challenge, Navigation Challenge, and Follow the Leader Challenge Founder
Hank Lewandowski	IGVC supporter	Printed IGVC T and official shirts 1992-2001

28 September 2022 version