# Autonomous Driving Challenge 2018 Rule Book

10/09/2018

# 1. Objective

The Autonomous Driving Challenge is a contest of scale autonomous cars for university students of engineering, computer science or related fields. The participants will develop software architecture and will program the specific autonomous driving functionalities (perception, planning and control) to control the car in a scale circuit.

The competition consists of three different challenges with an increasing level of difficulty to demonstrate the car abilities to overcome different everyday situations:

1. Drive in a road without obstacles or other vehicles, without taking into account normal traffic signals (see section 9 for more details).
2. Drive in a road without obstacles or other vehicles, but taking into account normal traffic signals (see section 10 for more details).
3. Drive in a road with other static and dynamic obstacles, taking into account the traffic signals and also performing a parking maneuver (see section 11 for more details).

# 2. Important dates

The important dates for this tournament are shown in Table 1. The exact dates for each milestone may change and will be communicated to the participating teams at the start of each edition.

| **Milestone** | **Date** |
|---|---|
| Workshop | May |
| First deliverable | End of July |
| Second deliverable | ~~End of September~~ October 22nd |
| Tournament | November |

Table 1. Milestones

## 2.1. Workshop

The workshop will be done in Barcelona in May (exact dates may change for each edition) and will last for two days. At the start of the workshop the model cars will be handed out to the participating teams with all the necessary material.

The main objective of the workshop is to provide a first practical contact with the model car with the help of experienced personal, which include but it is not limited to:

- The operation of the model car itself.
- The operation of the sensors.
- The calibration procedures (camera, IMU and steering)

The documentation of the workshop is publicly available here.

After the workshop, all the support to the participating teams will be through the Slack application. All participants are encouraged to create and account and communicate with the organization committee through this application.

## 2.2. First deliverable: simulation

The first deliverable will be due before the end of July. For this deliverable, each team must send to the organization a video showing the following features of the model car in simulation:

- Follow a road made of straight and curve segments.
- Perform a parking maneuver (either in parallel or in line or both)
- Detect traffic signals (semaphores and other traffic signals)

This deliverable is not optional and failing to provide it before the end of July may incur in some kind of penalty.

## 2.3. Second deliverable: real model car

The second deliverable will be due before the end of September. For this deliverable, each team must send to the organization a video showing the following features of the real model car:

- Follow a road made of straight and curve segments.
- Perform a parking maneuver (either in parallel or in line or both)
- Detect traffic signals (semaphores and other traffic signals)

This deliverable is not optional and failing to provide it before the end of September may incur in some kind of penalty.

## 2.4. Tournament

The tournament will take place in November coinciding with an event in Barcelona or Madrid. The tournament will last for three days:

- **First day**:
  The track will be available to all teams to perform the necessary setups and calibrations. There will be two time slots (15 minutes each approximately) assigned to each team with exclusive access to the track. In the remaining time, all teams will have access to the track.

During the first day, each team will also be required to do a presentation of their approach to solve the three challenges (5 minute approximately). This presentation and the proposed methods will be evaluated by a group of experts and will contribute to the teams final score.

- **Second day:**
  The two first challenges will be performed during the second day: the first one in the morning and the second one in the afternoon. The track will be available to all teams during the time before and after each challenge.

- **Third day:**
  The last challenge will be performed in the morning of the third day, and the price ceremony in the afternoon. The track will be available to all teams during the time before and after the challenge.

# 3. Track

At one side of the track, either inside or outside of the track perimeter depending on the space available and the road shape, there will be the jury area consisting in:

- The main jury, to keep track of the vehicle performance and to control the challenge execution.
- The current team representative, so he/she can easily communicate with the main jury.
- Two members of the next team, to prepare the vehicle and do last minute checks before starting the challenge.

The other sides may be open to the general public to watch the competition or blocked by walls.

All around the track there will be solid fence (20 cm high approximately) to avoid problems with noisy detections with the lidar sensor, and also to prevent people from stepping on the track.

The track will also have some decorative elements. These elements will have a solid base (20 cm high approximately) that will be easily detected by the lidar sensor of the model car, to avoid collisions and/or for mapping purposes. The number, size and position of this elements is no predefined.

Above the track, a set of visual markers will be placed to help in localizing the vehicle inside the track. See the visual GPS description in section 3.5 for more details. Also above the track, a wide angle camera will be placed to record all the tournament. The videos may be used by the jury to help in clarifying any doubts regarding the final score when requested by a team.

Diffuse light will be used all over the track to avoid as much as possible any problems of reflections and shadows. However, take into account that the tournament will take place inside

an event compound with other stands all around the track, which may introduce uncontrolled color and light sources. Also, only photography without flash will be allowed.

No one, neither team members or committee members, may enter the track area with shoes to avoid damaging or degrading the track.

## 3.1. Road

The road that will be used in the three challenges of the Autonomous Driving Challenge may include one or more of the following items:

- A roundabout with a curvature radius of no less than ~~1 meter~~ 80cm. See Fig. 2.
- Straight segments with no length limitations. See Fig 1.
- Curve segments with a radius of no less than ~~1 meter~~ 80cm. See Fig. 1.
- T intersections at 90 degrees. See left image of Fig. 4.
- Cross intersections at 90 degrees. See right image of Fig. 4.
- In line parking area. See left image of Fig. 3.
- Side by side parking area. See right image of Fig. 3.
- A start position placed on a straight segment of the road.

The final shape of the road will be presented at the first day of the tournament, and will depend on the space available.

The straight and curve segments of the road have two adjacent lanes with opposite traffic directions. There is no predefined circulation direction for each challenge. The committee members will decide, for each challenge, the starting direction (either clockwise or counterclockwise). This decision will be made before each challenge starts and it will be the same for all the teams.

The road is delimited by two continuous lines at each side with a width of 2 cm. The two lanes are separated by a discontinuous line, also 2 cm wide, made of 25 cm long segments separated 25 cm each. Each lane is 40 cm wide.

The road itself will be black matt, and all the lines will be white. The left side of Fig. 1 shows all the relevant dimensions of the straight segments, and the right side shows the dimensions of the circular segments.

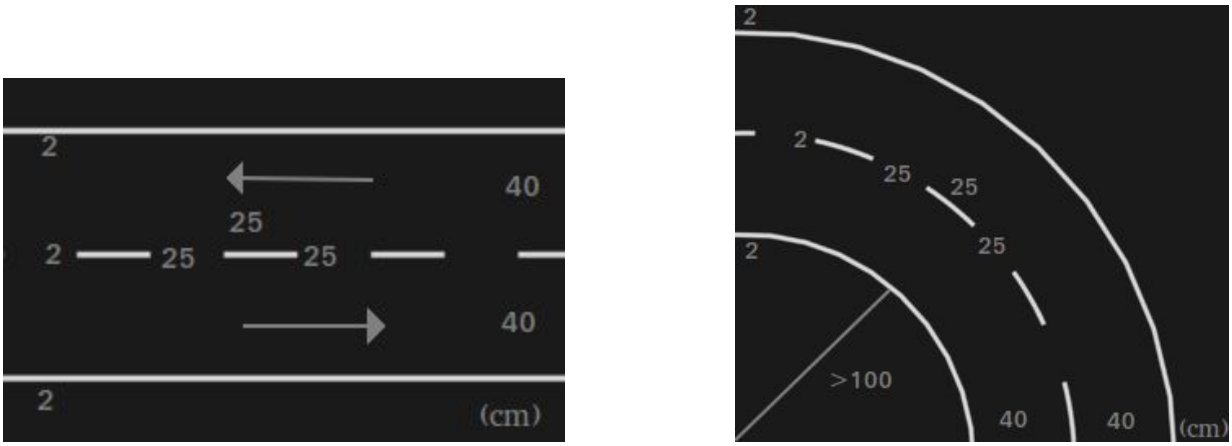


Fig. 1: Relevant dimensions for the straight segments (left) and the curve segments (right)

The only exception to this rule is the roundabout, which will have a single lane ~~80~~ 60 cm wide (without any discontinuous line) with a fixed counterclockwise circulation direction. The roundabout will have at least three different access points, but there is no upper limit. Fig. 2 shows the general layout of a roundabout.

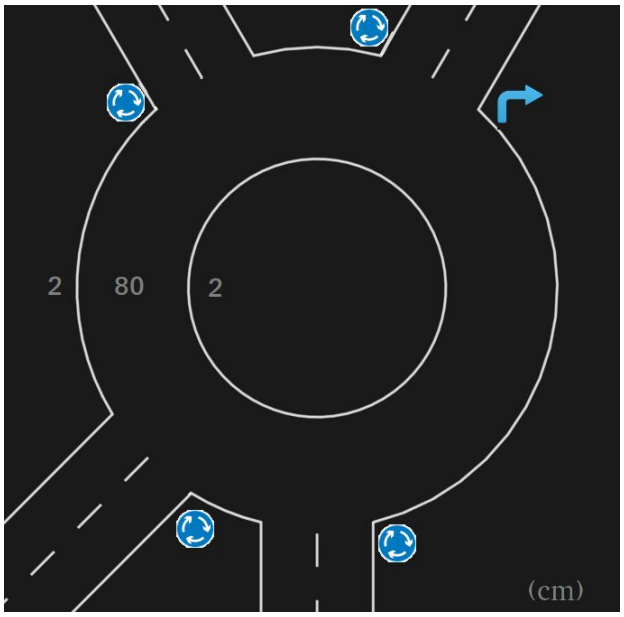


Fig. 2 General layout of a roundabout

The parking slots in both parking areas will be 25 cm wide by 50 cm long, and separated from the road by 2 cm, as shown in Fig. 3. At least ~~4~~ 3 adjacent parking slots will be available for each parking area, and the presence or not and the number of other parked cars is not known a priori, but will be the same for all teams.


Fig 3: In line (left) and side by side (right) parking areas

Both T and cross intersections will be at an angle of 90 degrees. The middle area in the intersection will have no discontinuous lines separating both lanes. Fig. 4 shows the general layout of both types of intersection.

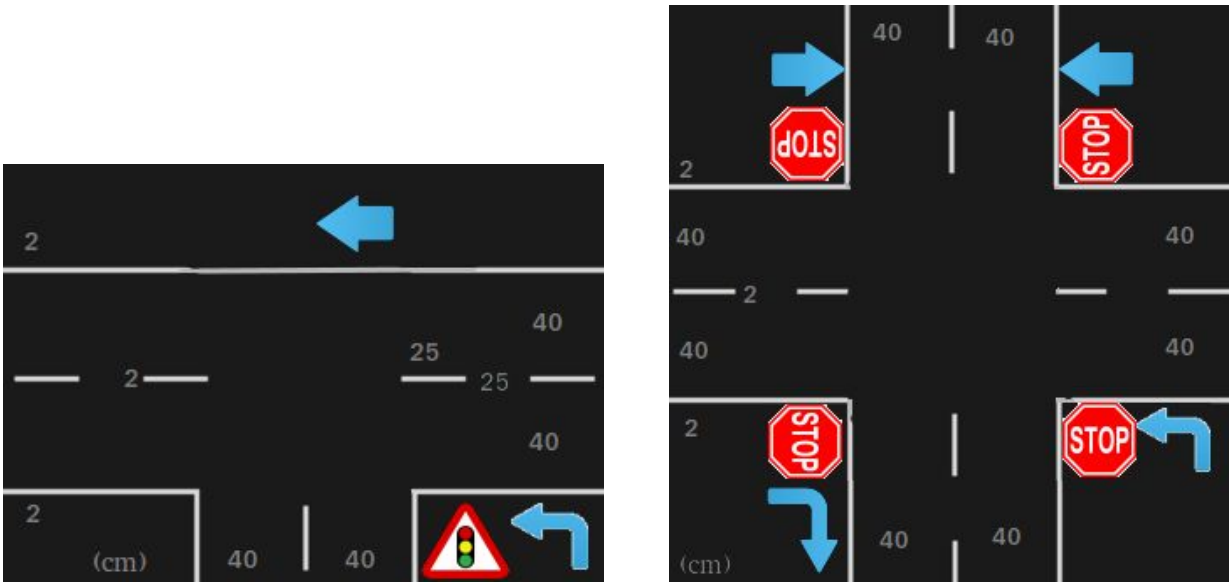


Fig. 4: General layout of a T intersection (left) and a cross intersection (right)

The minimum clearance of the road, at both sides, is ~~40~~ 30 cm. In this space, only traffic signals will be placed, but no decorative elements or obstacles will be present.

## 3.2. Starting point

The start point of all challenges is the same, and will be announced the first day of the tournament. The start point will be placed in a straight segment of the road.

Each challenge may have its own starting procedure that will be explained in more detail in the corresponding section: section 9.3 for the first challenge, section 10.3 for the second and section 11.3 for the third one.

## 3.3. Traffic signals

Some semaphores or traffic signals, used to signal several different conditions, will be placed on the track. All traffic signals will have a similar physical structure and will be identified by a unique AR Tag symbol. In the case of semaphores, the AR Tag will identify the traffic signal as a semaphore, but its actual state must be detected by the teams.

All traffic signals will have a color other than white to avoid confusion with the road lines.

The different traffic signals that may be present on the track are:

- **Green/red light semaphores**: As a regular semaphore, the green light indicates the car can continue moving, while the red light indicates the car must stop until the light turns green.
  The state of these semaphores will be directly controlled by the jury. This kind of semaphore will be placed in road crossings to handle the traffic flow, and also, for the second and third challenges, they can be used to signal the start condition. See the left image of Fig. 4 for the approximate location of the semaphores with respect to the road.

- **Blue light semaphores:** These semaphores will indicate, when active, that the car must find an empty parking slot in the corresponding parking area, and perform the parking maneuver.
  This type of semaphore will be placed at the beginning of each parking areas, at the same side where the parking areas are located, and in the direction of the traffic. They will be controlled by the jury. See Fig. 3 for the approximate location of the semaphores with respect to the parking areas.

- **Turn left/right and go forward arrow signals:** These signals will be placed at each intersection to signal the cars which is the desired direction, and also at the roundabout to indicate the desired exit. See Fig. 2 and Fig. 4 for the approximate location of these signals with respect to the road.

- **Roundabout signals:** These signals will be placed at each entrance of the roundabout to signal the cars of its presence. See Fig. 2 for the approximate location of this signal with respect to the roundabout.

- **Stop signals:** This signals can be used instead of green/red light semaphores in intersections. In this case, the model cars must always stop, check for other traffic in the other directions, and cross when it is safe to do so.
  See the right image of Fig. 4 for the approximate location of the stop signals with respect to the road.

Fig. 5 shows the basic structure of light semaphore.

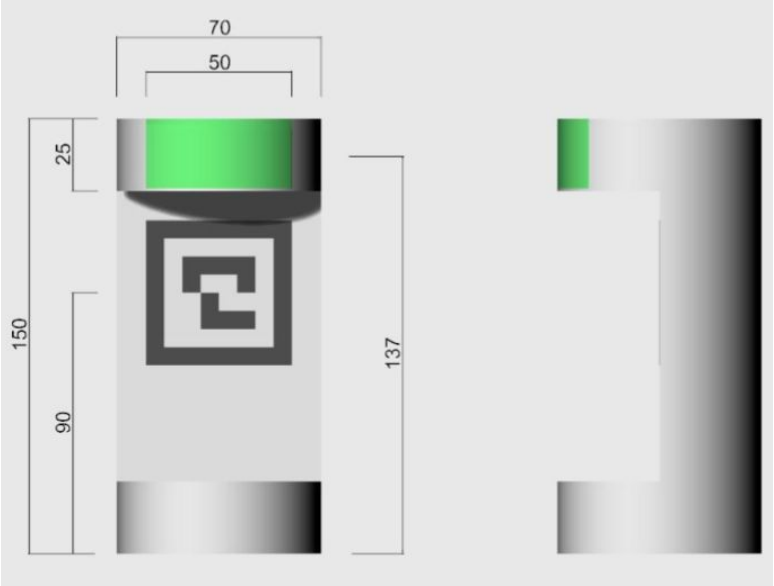


Fig 5: Traffic signal detail (mm)

Table 2 shows the exact AR Tag ID associated to each of the traffic signals. You can find the marker images here: [ar_track_alvar/markers0to8.png]

| **Signal type** | **AR tag ID** |
|---|---|
| Green/red semaphore | 0 |
| Parking semaphore | 1 |
| Turn right | 2 |
| Turn left | 3 |
| Go forward | 4 |

| | |
|---|---|
| Roundabout | 5 |
| Stop | 6 |

Table 2. Traffic signals AR Tags

The road itself will not have any ground traffic signals (i.e. pedestrian crossing, etc.) that the car should detect while driving.

A ROS node to detect these AR Tags, as well as the used patterns can be found in:

> http://wiki.ros.org/ar_track_alvar
> `sudo apt-get install ros-kinetic-ar-track-alvar`

## 3.4. Road obstacles

The static obstacles will simulate road works, stopped cars or other slow moving vehicles such as bikes. The static obstacles will have the dimensions shown in Fig. 6, and their color will be such that it is easy to detect, but it does not interfere with the line detection.

The exact color of the static obstacles will be communicated to the teams before the competition starts. Their position will always be the same for all the teams.

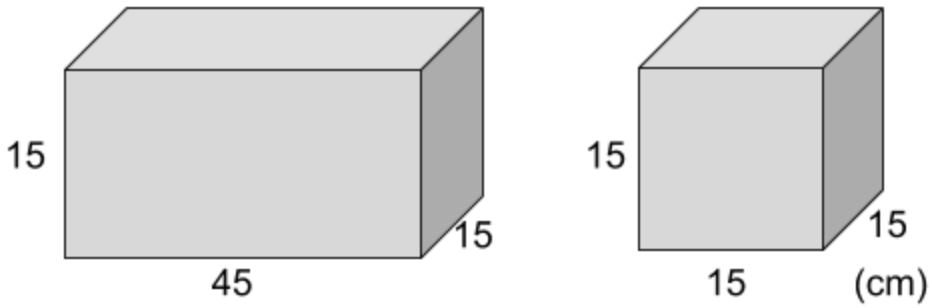


Fig. 6: Static and dynamic obstacles.

The dynamic obstacles will simulate other moving cars in the same lane of the participating car and will be implemented with one of the model cars of the organization.

The dynamic obstacles will have the same behavior for all teams. The dynamic obstacle will start stopped at a given position (not known a priori but the same for all teams) and only when the participating car passes through a given section of the track, the dynamic obstacle will start moving at a low speed. The dynamic obstacle will follow the road for a certain distance and then stop again.

The number of obstacles may vary, but at least one dynamic and one static obstacles will be present on the road.

## 3.5. Visual GPS

Since there will be no reliable GPS coverage in any indoor environment, an alternative is provided. A total of four 60 by 60 cm square panels with active color light will be placed at the top of the track at a certain height (around 4m approximately).

The position of these panels will be known a priori and can be used to triangulate the approximate position of the car inside the track using the top wide angle camera. At least three panels should be detected to generate a good estimation, but it will be better to detect the four of them to get the best estimation.

However, full visual GPS coverage is not guaranteed, that is, it may be some areas of the road where it is not possible to detect at least three of the panels. Furthermore, the resolution of the pose estimation will probably not be enough to use it exclusively for the car navigation.

The colors of the four panels will be red, green, blue and yellow. Each panel will source coloured light, so that the exposure time of the top camera can be lowered, therefore cancelling out most of the possible passive color interferences that may be present.

The teams are encouraged to develop their own visual GPS software to obtain the model car position. However, as an example a set of ROS nodes that implement a simple version is provided here:

https://gitlab.iri.upc.edu/seat_adc/iri_blob_detector
https://gitlab.iri.upc.edu/seat_adc/iri_visual_gps

Also, a simple tool to get the necessary information for the blob detector is provided here:

https://gitlab.iri.upc.edu/seat_adc/iri_color_calibration

# 4. Vehicles

All the university teams will have the same scale autonomous car, with the same hardware and software architecture, that will be provided at the workshop (see section 2.1 for more details). The hardware can not be modified by the teams, which can only provide new software to complete the tasks.

The manual of the vehicle car is located in:

https://github.com/AutoModelCar/AutoModelCarWiki/wiki

Also, a ROS-Gazebo simulator of the car and the track can be downloaded from:

https://gitlab.iri.upc.edu/seat_adc/seat_car_simulator.git

The car must be able to complete each of the challenges with a single battery. The teams will not be able to change the battery at the middle of the challenge. If the car runs out of battery, only the points achieved to that moment will be taken into account.

The use of the car lights is mandatory in any of the challenges. See the detailed description of each challenge for a complete list of all the necessary light signals.

# 5. Teams

The teams must be composed between 3 and 5 students that are active in the bachelor, master or PhD degrees. One person can not belong to more than one team.

Each team must choose a representative to communicate with the competition committee regarding ruling, punctuation or other issues. Also the committee will only communicate any pertinent new information to the team's representative.

The minimum skills required of the participating students are programming under Linux OS (C/C++, Python, etc.) and the ROS middleware. Other skills such as image processing, path planning, etc. will also be required to complete most of the challenges.

# 6. Procedures

## 6.1. Startup procedure

For each challenge the competition committee will randomly select the order in which the teams will participate. This process will take place before each challenge and it will be public.

All the cars must be placed at the jury area before the challenge starts. Only then, the members of the jury will set up the track for each of the challenges (traffic signals, obstacles, etc.). This is intended to avoid modifying the behaviour of the car depending on a particular set up in order to improve its performance.

The following steps must be followed to start each challenge:

1. While the car of the previous team is completing the challenge, the next team must move to the preparation area and do the last minute checks on the vehicle.
2. While in the preparation area, one of the members of the jury will remove the WiFi antenna, and replace it with a bluetooth module. From this moment it will be only possible to communicate with the car using the Ethernet connection.
   This bluetooth module will allow the committee members to send certain information to the car, using a joypad, in several cases:
   a. To signal the start of the first challenge (see section 9.3 for more details)
   b. To signal each new attempt.
   c. To reposition the car inside the track (see section 6.3 for more details).
   This will be achieved through a ROS node that all cars must launch as part of the setup procedure. You can check the ROS node documentation and downloaded it from here.
   At this moment, the member of the jury will make sure that the car is receiving the commands from the joypad.
3. When the current participating team finishes, and the main jury allows it, the next team will have a period (5 minutes approximately) to place the car at the starting point ready to begin. Only two members of the team are allowed inside the track.
   For the first team to participate, the jury will also allow that period to ready the vehicle before actually starting the challenge.
4. After placing the car at the starting position, no further communication with it will be allowed by any means. If the teams want to save some logs, it should be done onboard the car.
5. The car must keep its position at the starting point until the main jury signals the start condition, which may be different for each challenge. At this moment the time starts counting and the vehicle should start moving.
6. During the challenge only the members of the committee may access the track area. The members of the team should remain on the current team area.

## 6.2. Challenge procedure

Each team will have a maximum time (8 minutes approximately) for each challenge. During this time, the current team can make as many attempts as they can, and the final score will be the median of the score of all attempts (thus discarding the best and worst attempts).

If the model car does not start moving 10 seconds after the start signal has been given, this will be considered as an attempt with 0 total points.

In case of a hardware malfunction, the teams can ask for a timeout (defined to 2 minutes, for example) to try and solve the problem. If the problem is not solved during this time, the team will not be allowed to make any more attempts. Each team can only ask for one timeout period for each challenge. During the timeout period, no software modifications of any kind will be allowed.

During the execution of the challenge, only the committee members are allowed inside the track. During this time:

1. The track committee will take note of all the penalties in order to notify them to the main jury when the challenges finishes.
2. The team representative can challenge to the main jury any of the track committee members decisions in case of disagreement. If in doubt, the images recorded by the zenital camera could be used to make the final decision. The main jury decision will be final.
3. The team representative can only communicate with the main jury in the committee area. Under no circumstance, he/she will be able to communicate with the track committee members.
4. If the car gets completely out of the road, collides with an static or dynamic obstacle or has to be placed at the start position after successfully completing an attempt, the procedure in section 6.3 will be executed.

## 6.3. Car repositioning procedure

When the car gets outside of the road, fails to follow the defined challenge path, collides with an static or dynamic obstacle or has to be placed at the start position again after finishing an attempt, the closest track committee member will:

1. Use a joypad or similar pad to send a signal to the car. When the car receives this signal it must stop completely and start blinking the four intermittent lights.
2. The track jury will then move the car to the appropriate position:
    - If the car has collided with an obstacle, it will be placed at a predefined position, always before the collision point. In this case, if the car fails to overtake the obstacle for three times, the track jury may place the car after the obstacle with an additional penalty.
    - If the car has gone out of the track, it will be placed at the closest predefined position, always before the exit point.
    - If the car has successfully completed the challenge and the team wants to try again, the car will be placed at the start position. In this case the start procedure described in section 6.1 will be executed from point 4.

    While the car is being placed at the appropriate position, the four intermittent lights must blink.

    The predefined points depend on the final shape of the track, but they will be notified to the teams during the setup day, and they will also be clearly marked on the track.
3. After the car has been placed at the predefined position, the track jury will send another signal to the car. At this point, the car must stop blinking the intermittent lights, wait for 2 seconds and continue.

## 6.4. End procedure

The challenge may end by one of the following reasons, unless otherwise noted in each of the challenges:

1. The maximum allowed time expires. In this case the main jury will notify one of the track committee members to remove the car and hand it to the team members.
2. The team members decide the robot is not operating properly and want to finish the challenge. In this case the team representative must notify that to the main jury, who will notify one of the track committee members to remove the car and hand it to the team members.
3. The car exhibits some unsafe behavior and one of the track committee members decides it is not safe to continue. In this case any track committee member will notify the main jury, pick up the car and hand it to the team members.

When a teams finishes a challenge (for any reason), the final score will be computed as the median of all the attempts. See section 7 for details on the scoring system.

# 7. Scoring system

All three challenges will count together to form the total number of points (100). Given the rising difficulty of the challenges, they will be rated on different levels. The maximum number of points for each challenge are:

- 20 for the first challenge.
- 35 for the second challenge.
- 45 for the final challenge.

Additional points can be obtained as follows:

- 5 points for providing the deliverables on time (2.5 points each)
- Maximum of 5 points for the technical presentation of the team approach to solve the challenges

Of the total points of each challenge, 40% will be awarded by time and the other 60% by the actual execution. If some of the teams do not reach a minimum score at one of the challenges (defined beforehand by the committee), they may be disqualified to continue on the next challenge.

Regarding the execution points, when all the teams have completed a challenge, the maximum penalty score will be used as a lower bound, being the upper bound the perfect execution without any penalties. Then each team will get a score proportional to the performance of all teams.

Furthermore, the resulting score will be weighted by the total distance travelled. That is, the execution score will be multiplied by the % of the circuit completed by the car. See the following equation for more details:

$$Score_{execution} = execScore_{max} \cdot \left(1 - \frac{team_{penalties}}{max_{penalties}}\right) \cdot dist(\%)$$

where $execScore_{max}$ is the maximum execution score for each challenge, $team_{penalties}$ is the penalty score of a given team, $max_{penalties}$ is the highest penalty score of all teams and $dist(\%)$ is the % of the circuit completed by the team. The final execution score will be rounded to the closest integer value.

As an example, Table 3 shows a possible scoring for five teams for the last challenge $(execScore_{max} = 27)$.

| Team | Penalty score | Distance traveled (%) | Execution score |
|---|---|---|---|
| 1 | 5 | 30% | 6 |
| 2 | 10 | 75% | 12 |
| 3 | 25 | 80% | 0 |
| 4 | 1 | 100% | 26 |
| 5 | 10 | 100% | 16 |

Table 3: An example of an execution score for 5 teams.

The third team gets 0 points because they have the most penalties, no matter how far they get. The fourth team gets almost all the points because they have complete the track with only 1 penalty.

For the first and second teams, although the first one has the lower penalty score, proportionally to the distance traveled, it has a lower performance than the second team, and therefore they get a lower execution score.

The last team has the same penalties as the second one, but they have completed the whole track, so they get more executions points.

Regarding the time points, the time of the fastest car will be used as the upper bound, being the maximum time of the challenge the lower bound. Then each team will get a score proportional to the performance of all teams.

$$score_{time} = timeScore_{max} \cdot \left(1 - \frac{team_{time} - best_{teamTime}}{max_{time} - best_{teamTime}}\right)$$

where $timeScore_{max}$ is the maximum time score for each challenge, $team_{time}$ is the time of a given team, $best_{teamTime}$ is the time of the fastest team, and $max_{time}$ is the maximum allowed time for the challenge. The final time score will be rounded to the closest integer value.

As an example, Table 4 show a possible scoring for five teams for the last challenge $(timeScore_{max} = 18)$, with a maximum time of 8 minutes $(max_{time} = 480s)$

| Team | Team time | Time score |
|---|---|---|
| 1 | 480 | 0 |
| 2 | 480 | 0 |
| 3 | 480 | 0 |
| 4 | 360 | 7 |
| 5 | 183 | 18 |

Table 4: An example of a time score for 5 teams.

The first 3 teams didn't complete the challenge, so they have 0 time points. The 5th team is the fastest and earns the maximum challenge time points.

Continuing with the example, Table 5 shows the final score for that challenge, with the execution score shown in Table 3 and the time score shown in table 4.

| Team | Challenge score |
|---|---|
| 1 | 6 |
| 2 | 12 |
| 3 | 0 |
| 4 | 33 |
| 5 | 34 |

Table 5: Final score for all 5 teams.

## 7.1. Penalties

Each challenge may have its own penalties that will be explained in more detail in the corresponding section. However, there exist some general penalties that will apply to all challenges:

- Stepping on the continuous line is allowed only if most of the car stays on the road. Otherwise, it will be penalized by 1 point each time, up to a maximum of 5 points. The same applies for the discontinuous line.
- Stepping repeatedly on the continuous line (according to the jury criteria) will have a penalty of 2 points. The same applies for the discontinuous line.
- Getting completely out of the road will have a penalty of 3 points. In this case the jury will place the robot at the closest road point to continue the challenge.
- Completely crossing the discontinuous line, except for and overcome maneuver, will also be penalized with 3 points.
- Colliding with an obstacle (static or dynamic), a decorative element or the external wall will have a penalty of 3 points. In this case the jury will reposition the car on the track following the procedure introduced in section 6.3.
- Failing to signal an action or event with the car lights will have a penalty of 1 points each time, with a maximum of 5 points.

# 8. Competition Committee

The competition committee team will be composed of at least three persons. At least one chair jury seated on the competition committee area besides the track controlling the semaphores, the time and any penalizations the other committee members may report.

At least two other committee members will stay inside the track at all time to monitor the progress of the car, report any penalties and handle it, if necessary. These two members will stay away enough from the robot to avoid interfering with its normal operation.

All committee members will be properly identified. The team representative can only communicate with the main jury.

The penalties reported by the track committee members can be challenged by the team representative to the main jury. This exceptions will be noted and analyzed after the current challenge has ended. However, once the main jury arrives at a decision, it will be final.

The committee members reserve the right to modify the rules before the competition. Once started, in case of ambiguity or conflict, the rules can be modified or exceptions added.

# 9. Challenge 1: simple navigation challenge

## 9.1. Objective

The car needs to complete a single lap to the track fully autonomously, without any other obstacles (static or dynamic) on the road and without taking into account any traffic signals. The car must stay inside its lane and navigate straight lines and curves.

This first challenge will not include any roundabouts. All the intersections that may appear on the model car path should be ignored, and it must continue forward. The parking areas can not be removed and must be ignored if detected.

There will be a single possible circuit, that may be executed in either direction. The actual direction will be decided before the challenge starts and will be the same for all the teams.

## 9.2. Traffic signals

In this challenge no traffic signals will be used, and they will not be even placed on the track to avoid any kind or interference.

## 9.3. Starting the challenge

Since no traffic signals are used in this first challenge, the jury will use the joypad to signal the start of the challenge as explained in section 6.1.

## 9.4. Car lights

In this challenge, the model car should signal all the following actions or events with the corresponding light signals shown in Table 6

| **Action or event** | **Light signal** |
|---|---|
| Start of the challenge | Blink the front lights twice |

Table 6: Light signals for the first challenge

## 9.5. Additional penalties

There are no additional penalties in this challenge. See section 7.1 for a detailed description of all general penalties.

## 9.6. Ending the challenge

The challenge will end when the car drives through the starting point. If there is still time remaining, the team leader may choose to reposition the car at the starting point and make another attempt.

# 10. Challenge 2: navigation with traffic signals

## 10.1. Objective

In this challenge, the car must also complete a single lap to the track fully autonomously, without any other obstacles (static or dynamic) on the road, but taking into account any traffic signals present (see section 3.3 for a complete description of all possible traffic signals).

The car must stay inside its lane and navigate straight lines, curves, roundabouts and intersections.

**Roundabouts**
Each entrance point of the roundabouts will be marked by the appropriate signal, and the desired exit will be marked by a turn right traffic signal. See Fig. 2 for an example placement of the roundabout traffic signals.

**T intersections**
If the car is driving with the main traffic flow, it will find only one of the turn left, turn right or go forward traffic signals, which will indicate the expected behaviour of the model car. If the car is driving on the access road, it will find two different traffic signals:

- A green/red light semaphore or a stop signal to handle the flow of traffic. If there is a semaphore, the car must stop while the light is red, and continue when it turn green. In case of a stop signal, the car must always stop, check it is save to cross the intersection and execute the maneuver.
- A turn left or turn right signal which indicate which will indicate the expected behaviour of the model car.

In this second case, both traffic signals will be placed one besides the other on the right hand side of the road in the travel direction. The semaphore or stop signal will be the closest to the road.
See the left image of Fig. 4 for an example placement of the traffic signals on a T intersection. In this figure a semaphore is shown, but a stop signal could also be used instead.

**X intersections**
In this case, since there is no main traffic flow, the model car will always find two traffic signals:

- A green/red light semaphore or a stop signal to handle the flow of traffic. If there is a semaphore, the car must stop while the light is red, and continue when it turn green. In case of a stop signal, the car must always stop, check it is save to cross the intersection and execute the maneuver.
- A turn left, turn right or go forward signal which indicate which will indicate the expected behaviour of the model car.

See the right image of Fig. 4 for an example placement of the traffic signals on a X intersection. In this figure a stop signal is shown, but a semaphore could also be used instead.

## 10.2. Traffic signals

In this challenge all the traffic signals presented in section 3.3 may be present, except for the parking semaphores.

## 10.3. Starting the challenge

In this challenge, a green/red light semaphore will be used to signal the start of the challenge. The starting semaphore will be placed at the right hand side of the road in the travel direction.

The cars will be placed at the necessary distance from the semaphore to be able to detect it. The semaphores will be controlled by the main jury, who will switch from red to green to indicate the start of the challenge.

The challenge time will start counting from the time the semaphore turns green.

## 10.4. Car lights

In this challenge, in addition to the light signals introduced in Table 6, the model car should signal all the following actions or events with the corresponding light signals shown in Table 7.

| **Action or event** | **Light signal** |
|---|---|
| Waiting on a stop signal or semaphore | Turn on the two tail red lights |
| Turn left at any intersection | Blink the left intermittent light during the maneuver |
| Turn right at any intersection or roundabout | Blink the right intermittent light during the maneuver |
| Go forward at any intersection | Blink both intermittent lights for 2 seconds |

Table 7: Additional light signals for the second challenge.

## 10.5. Additional penalties

In this challenge, the following additional penalties are taken into account:

- Ignoring a semaphore will have a penalty of 2 points. Additionally, if the semaphore is ignored, the team will get a time penalty equal to twice the time the semaphore is in the red state. In this case the car can continue without any committee member intervention.
- Misuse of the car lights will have a penalty of 1 points each time, with a maximum of 5.

## 10.6. Ending the challenge

The challenge will end when the car drives through the starting point. If there is still time remaining, the team leader may choose to reposition the car at the starting point and make another attempt.

# 11. Challenge 3: navigation with traffic signals, obstacle avoidance and parking maneuver.

## 11.1. Objective

In this challenge, the car must also complete a single lap to the track fully autonomously taking into account any traffic signals present (see section 3.3 for a complete description of all possible traffic signals), overtaking any static or dynamic obstacle present in the road, and also performing a parking maneuver.

The car must stay inside its lane and navigate straight lines, curves, roundabouts and intersections.

The possible obstacles the car may find in the road are described in section 3.4. When an obstacle is detected (either static or dynamic), the model car must start the overtaking maneuver without colliding with the obstacle. During the overtake maneuver is the only moment that the car can cross to the other lane without being penalized.

There may be some static obstacles at the opposite direction lane that should be ignored, but never close to the part of the road where the car has to perform an overtake maneuver.

The circuit the cars must follow may be different from the second challenge, and the traffic signals will be placed accordingly.

When the car detects an active parking semaphore, it should find the closest empty parking slot, detect which kind of parking it is (parallel or perpendicular) and execute the necessary maneuver.

In the parking area, there will be other static obstacles, but at least one empty slot will always be available. The committee will decide which of the parking semaphore is turned on during the challenge, but it will be the same for all the teams.

## 11.2. Traffic signals

In this challenge all the traffic signals presented in section 3.3 may be present.

## 11.3. Starting the challenge

The starting procedure for this challenge will be the same as the second one (see section 10.3 for more details).

## 11.4. Car lights

In this challenge, in addition to the light signals introduced in Table 6 and Table 7, the car should signal all the following actions or events with the corresponding light signals shown in Table 8.

| **Action or event** | **Light signal** |
|---|---|
| First half of the overtake maneuver | Blink the left intermittent light |
| Second half of the overtake maneuver | Blink the right intermittent light |
| Parking area detection | Blink the intermittent light in the same side as the parking area. |
| Completing the parking maneuver | Blink both intermittent lights for a few seconds. |

Table 8: Additional light signals for the third challenge.

## 11.5. Additional penalties

In addition to the penalties presented in section 10.5, the specific penalties for this challenge have to do with the advance maneuver of both static and dynamic obstacles:

- If the participating car does not complete the overtake maneuver of the dynamic obstacle before it stops, it will have a penalty of 3 points.

- If the car is placed after an obstacle by the jury, after colliding with it 3 times, there will be an additional penalty of 10 points.
- Crossing an intersection when a car is nearby will have a penalty of 2 points. In this case the car can continue without any jury intervention, except if the two cars collide, in which case an additional penalty of 3 points will be given, and one of the track jury members will reposition the car on the road.
- Not completing the parking sequence in the allowed time will have a penalty of 3 points. However, if the team can show the car is capable to successfully perform a parking sequence afterwards, only half the penalty will be applied. A parking sequence consists in detecting a parking semaphore, locating an empty slot and performing a parking maneuver.

## 11.6. Ending the challenge

The challenge will end when the car completes the parking maneuver (signaled by blinking both intermittent lights for a few seconds). If there is still time remaining, the team leader may choose to reposition the car at the starting point and make another attempt.