



Duckietown Navigation Starter Pack

DT18-NAV-M



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2. General information

The Duckietown Navigation Starter Pack is a do-it-yourself (DIY) hardware kit for creating and assembling a modular model urban environment. It is available only in one variant (complete product).

Name	Variant	SKU
Duckietown Navigation Starter Pack	Complete Navigation Starter Pack	DT18-NAV-M

3. What's in the box

The Duckietown Navigation Pack Starter Pack includes the components necessary to create Duckietown tiles according to the Duckietown appearance specifications (see below). Additional tools such as scissors or cutters and a ruler will aid in the first construction and are not included in the box.

Subsystem	Name	Number
Structure	Double sided tape pads	30
City-road	Tile	15
City-road	White roll of duct tape	1
City-road	Yellow roll of duct tape	1
City-road	Red roll of duct tape	1
City-signal	Traffic sign stand	12
City-signal	Traffic signs with AprilTags	12
Swag	Duckies	25
Packaging	Outer box for shipping	1

4. Functionality overview

Duckiebots are designed to operate in a Duckietown urban environment. Up to date specifications on Duckietown urban environment can be found here:

https://docs.duckietown.org/daffy/opmanual_duckietown/out/dt_ops_preliminaries.html

From a functional perspective, Duckietown cities are an integral part of the robotic ecosystem we call Duckietown. They are designed to send information to the Duckiebots, so these can operate.

Duckietowns are *modular*. They are composed of fundamental building blocks that can be combined to create nearly arbitrary city landscapes.

At a high level, Duckietown is built with two layers, the *floor* and *signals* layers.

As long as the elements of the floor and signal layers are built according to the Duckietown appearance specifications, Duckiebots are able to operate autonomously.

There are no fixed maps. Floor elements assembled in compliant combinations will yield valid Duckietowns. The picture representation provided at the beginning of this document is just one example of a final result achievable through the items included in this box (and the recommended configuration for the "Self-driving cars with Duckietown" massive open online course 2021 edition).

Not all functionalities of the Duckiebots require all Duckietown city elements to work. We define Duckietown configurations of increasing complexity depending on what Duckiebot functionalities they support.

Only traffic signs (no city)

Without a Duckietown, it will not be possible for Duckiebots to showcase most of their behaviors. Nonetheless, traffic signs have AprilTags, which allow them to play with the AprilTag detection and relative pose estimation pipeline, and in turn with the camera calibration and system identification procedures.

City loops

The fundamental Duckiebot behaviors can be explored with a very simple Duckietown. We call these simple cities: *loops*.

City loops are closed road patterns, without intersections, that meet the appearance specifications. They can be made only of floor layer elements, with no signals.

City loops enable to play with the:

- *perception pipeline*: what happens when data is obtained in form of measurements (e.g., images), and how it is used to extract information, leading the Duckiebots to generate a belief of their position and orientation in the lanes.
- *lane control*: the process that Duckiebots apply to transform beliefs provided by the perception pipeline in decisions on how to steer in order to stay inside the lane.
- *traffic management*: the functionality for which Duckiebots stay at a safety distance from other Duckiebots driving in front of them.

When city loops are augmented with traffic signs, e.g., road names, it is then possible to explore the functionality of:

- *AprilTag detection and relative pose estimation*: how Duckiebots detect AprilTags, and determine their position and orientation relative to them. This information can be used to localize inside the map.

If you acquired a Duckietown Starter Pack, you have a city loop with traffic signs.

Navigable cities

More complex Duckiebot behaviors require intersections and other city elements such as traffic lights to work. We define cities that include intersections as *navigable* cities.

Navigable cities are city loops connected by intersections, meeting the appearance specification. Navigable cities require traffic signs.

Navigable cities enable testing of Duckiebot behaviors. A complete list (for one or more Duckiebots) of behaviors can be found in the demo section of the Duckiebot operation manual.

The Duckietown Navigation Starter Pack includes the components to build a navigable city.

5. Duckietown: Subsystems

Road layer

The floor layer is the substrate on which Duckiebots drive, i.e., the road.

Regardless of the geometry of the roads (straight, curve, intersections), roads are made of two lanes; one for each direction of driving. Lanes are obtained by applying lane markings to a black background. The lane markings need to adhere to the appearance specifications to be effective.

Signal layer

The signals layer contains all the signs and other functional objects (e.g., traffic lights) that sit on top of the mats. Objects are functional when they enable some behavior for the Duckiebots. For example, traffic signs are functional because they inform Duckiebots at intersections where they are and what they should look out for to know when to drive on.

Non-functional elements

The citizens of Duckietown like their cities to be colorful and fun, and encourage all efforts at adding non-functional components to the city. Non functional objects can still sit on the floor, e.g., decorative buildings, as long as they don't interfere with the floor and signal layers.

Moreover, although Duckiebot drivers all have their driving licenses and know to focus on the road, the *background*, i.e., whatever is in the room the Duckietown was assembled, plays a role in the resulting performance too.

6. Appearance Specifications

Specifications are a set of rules for which a functional system has been verified. This means that if these rules are followed while building a Duckietown, Duckiebots will (most probably!) work.

Any Duckietown not adhering to the rules described here cannot be considered a Duckietown, and may cause the Duckiebots operating within them to fail in unexpected ways.

Small perturbations to the appearance specifications might affect negatively the performance of Duckiebots, although most algorithms are robust to variations.

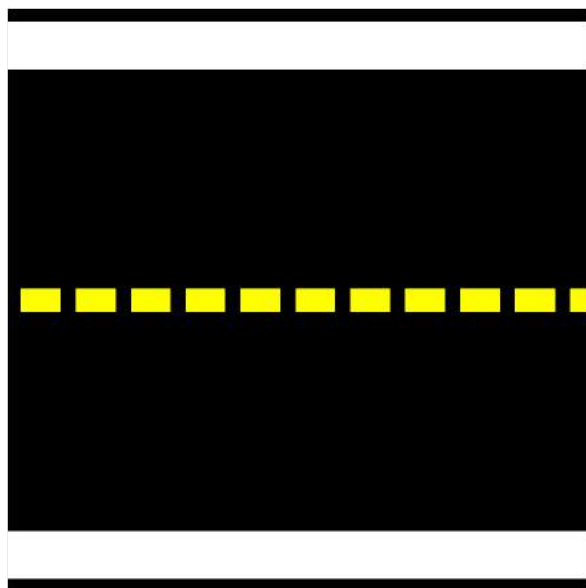
Layer 1 - The Floor Layer

The floor layer is made of interlocking black tiles. Each tile represents one road element:

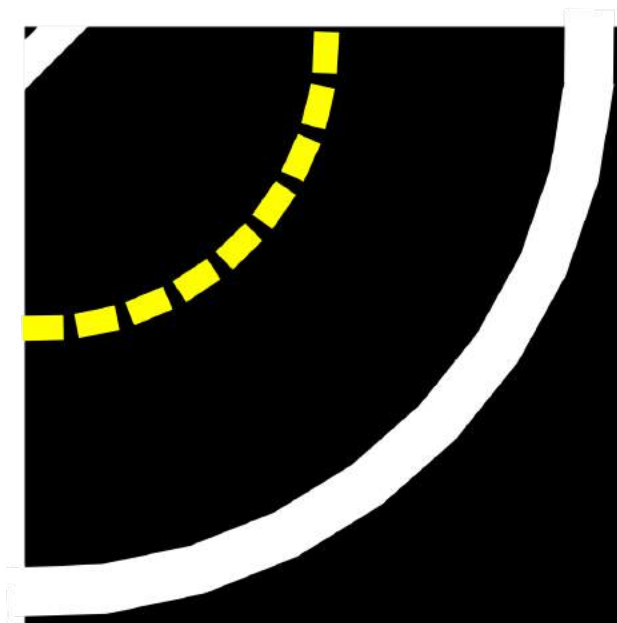
- straight,
- curve,
- 3-way intersection,
- 4-way intersection, and
- empty tile.

The road elements are positioned in specific orders to create compliant Duckietowns. The road elements are shown below. Note that the left turn and right turn tiles are symmetric: one is the 90 degree rotation of the other. The empty tiles can be of any color, although it is discouraged to use the same colors as the road markings (red, white and yellow). The green color represented below is just an example. Empty tiles are provided as black.

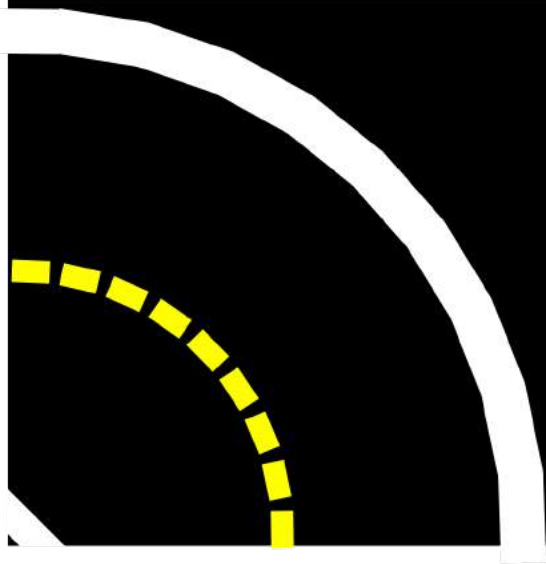
Each tile is square and measures 61 x 61 cm (2 ft x 2 ft) from the outer edges of the interlocking dents. The thickness of the tiles is not as important as the surface roughness. The objective is having good grip between the Duckiebots and the road in order to minimize slipping of the wheels.



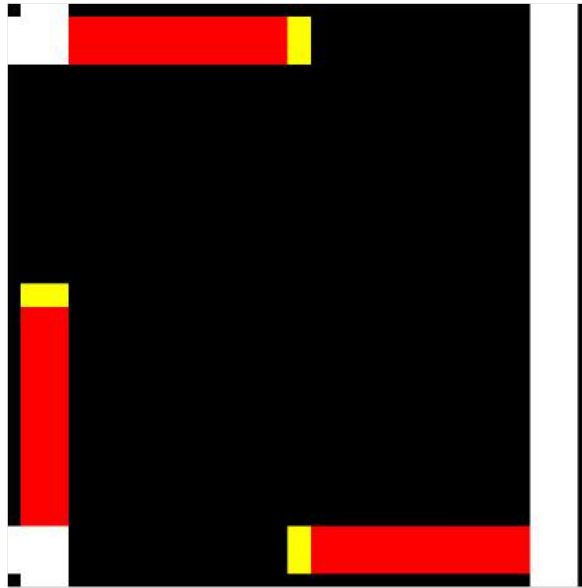
DT17_tile_straight



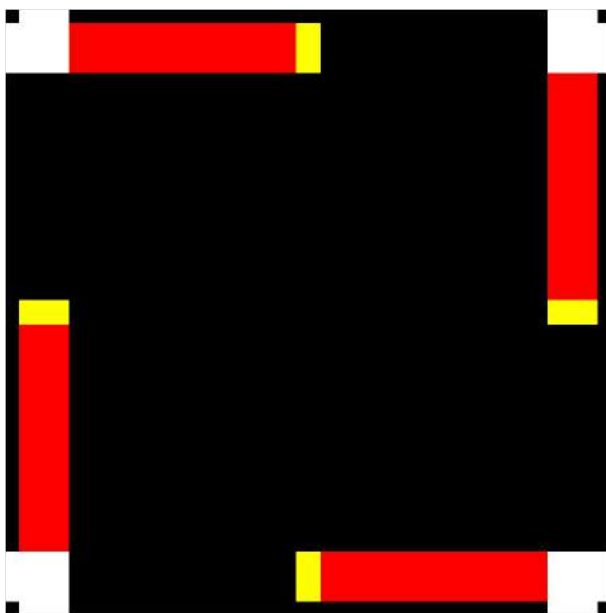
DT17_tile_curve_left



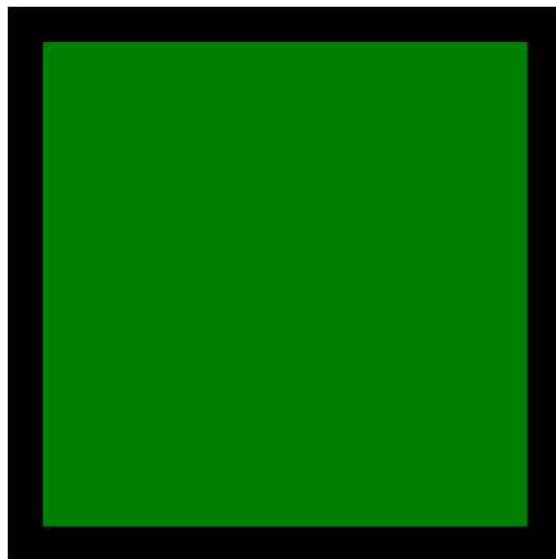
DT17_tile_curve_right



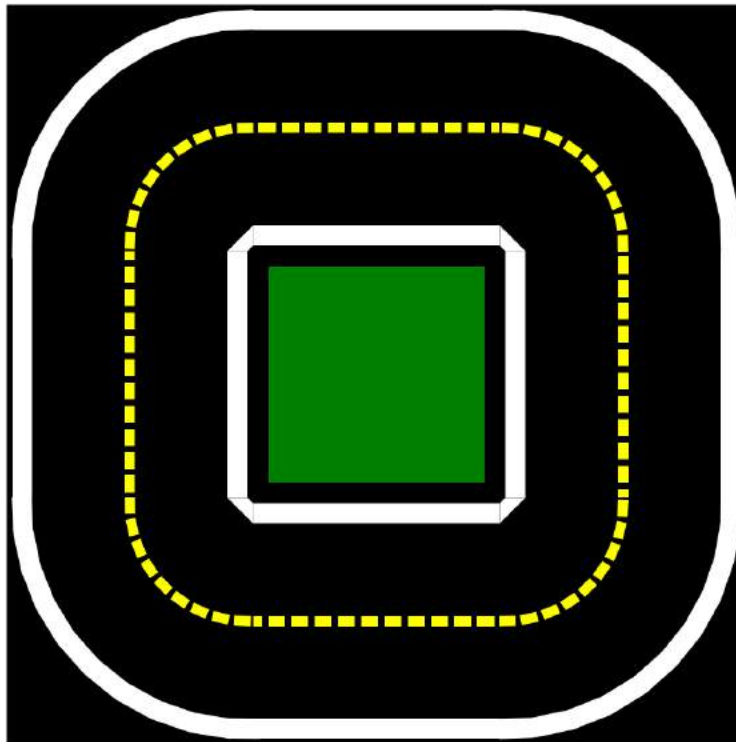
DT17_tile_three_way_center



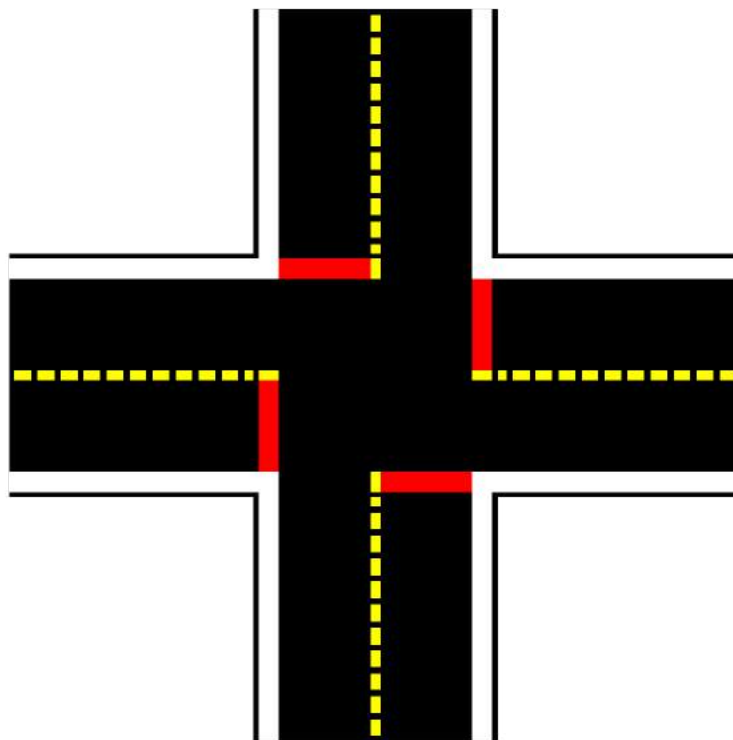
DT17_tile_four_way_center



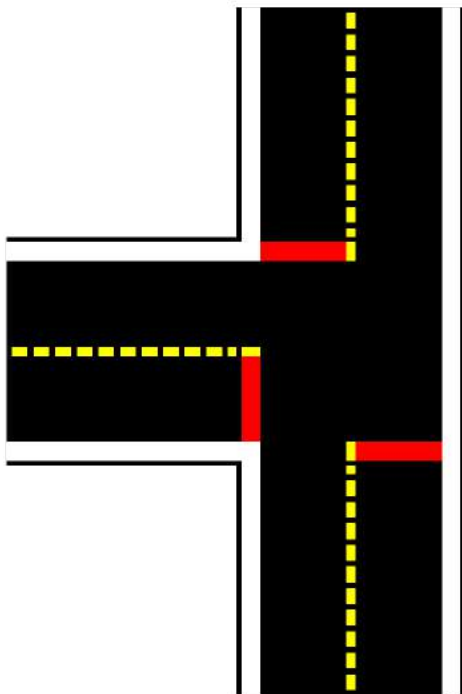
DT17_tile_empty



An example compliant 3 by 3 city loop (DT17_map_loop3)



Four way intersection usage



Three way intersection usage

For tiles to become road elements, we need to apply road markings. Road markings can be obtained through the application of tapes of different colors and sizes.

Tapes

There are 3 colors of tapes used in Duckietown: white, yellow, and red.

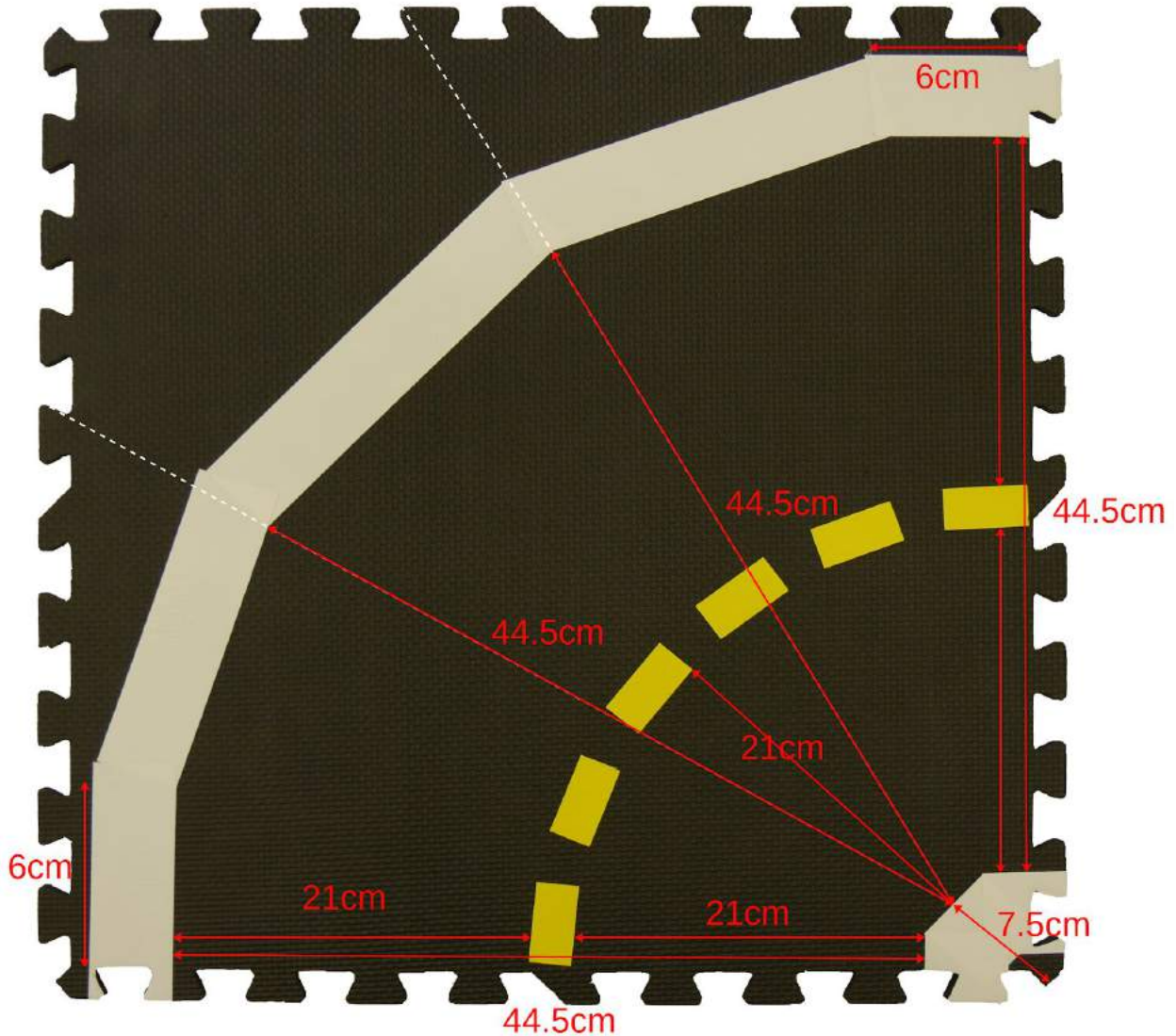
White tape

A Duckiebot on a road never collides with Duckiebots or other Duckietown elements if it never crosses or touches a white tape strip.

Here are some facts about the white tapes:

- White tapes must be solid (not dashed);
- The width of the white tape is roughly 4.8 cm (1.88 inches);
- The white tape is always placed on the right hand side of a lane. *We assume that the Duckiebots drive on the right hand side of the road.*
- For curved roads, the white lane marker is formed by five pieces of white tape, while the inner corner is formed by three pieces, placed according to the

specifications in the image below, where the edge pieces are matched to adjacent straight or curved tiles.



The specification for a curved road tile

Yellow tape

Here are some facts about the yellow tapes:

- Yellow tape must be dashed (not solid);
- Each piece should be 5 cm long and placed with a 2.5 cm gap between each piece;
- The width of the yellow tape is roughly 2.4 cm (0.94 inches);

- The yellow tape is always placed on the left hand side of a lane, i.e., in the center of the road. We assume that the Duckiebots drive on the right hand side of the road.

Yellow tapes on curves should be placed as shown in the figure above.

Yellow tape segments at the edges of the tiles should be placed in the center of the lane; the segment at the middle of the curve should be approximately 21 cm from the middle of the inner center white segment of tape, and an (approximated) circular arc should be built in between.

In general, the lane width (from edge to edge of tape) should always be 21 cm.

Red tape

Red tapes appear on intersection tiles.

The width of the red tape must be the same as the white tape (roughly 4.8cm or 1.88 inches) and it should cross the entire lane perpendicular to the road.

The placement of red tape should always be under yellow and white tape, as shown, e.g., in the figures above.

A Duckiebot navigates Duckietown by a sequence of:

- Navigating one or more straight tiles until a red tape appears,
- Waiting for the coordination signal,
- Executing an intersection traversal,
- Re-localizing in a straight tile.

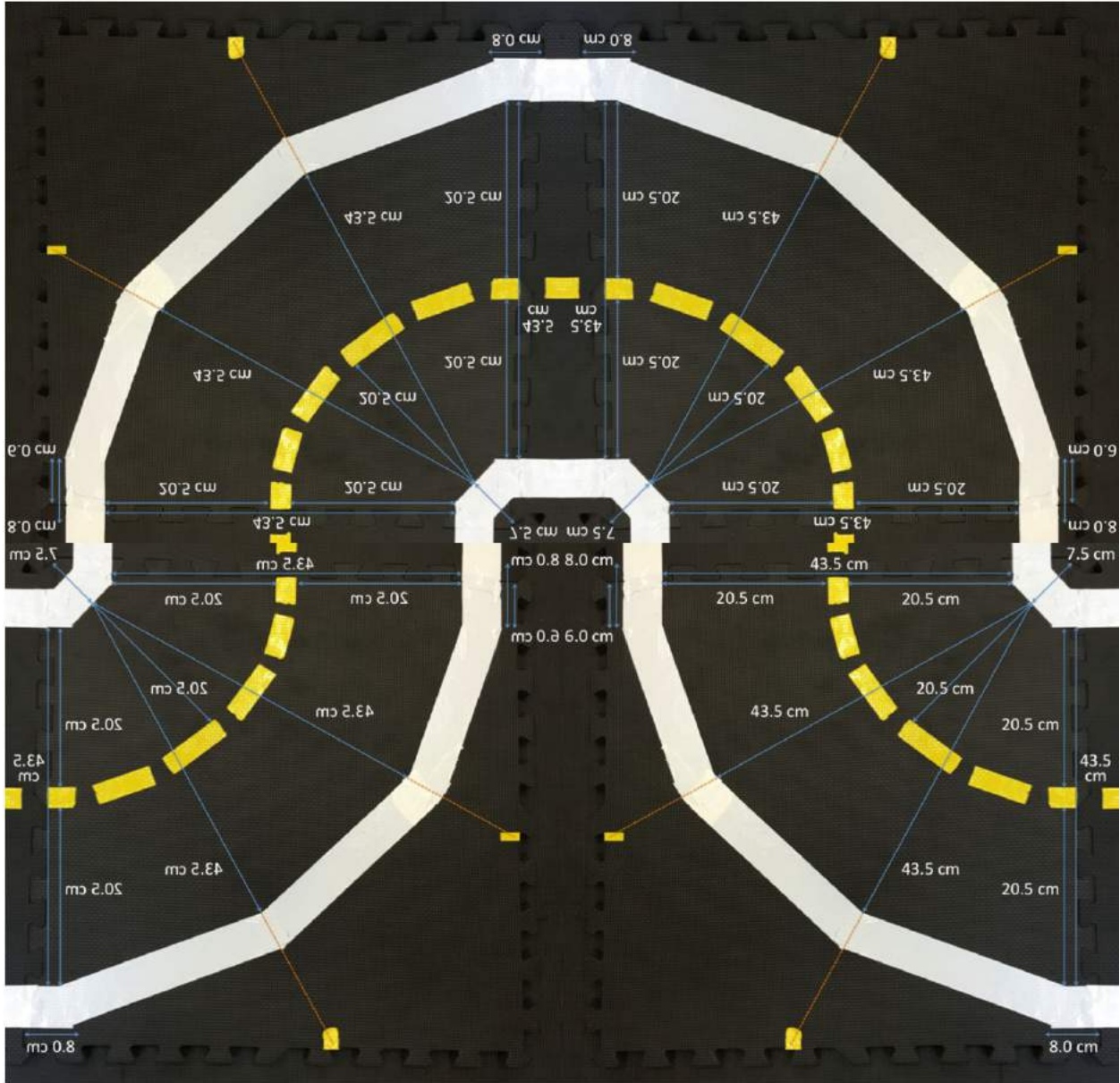
If the Duckiebot stops before or ON the red line (and the city is built respecting the specifications), a coordination signal will be obtained.

Topological Constraints During Map Construction

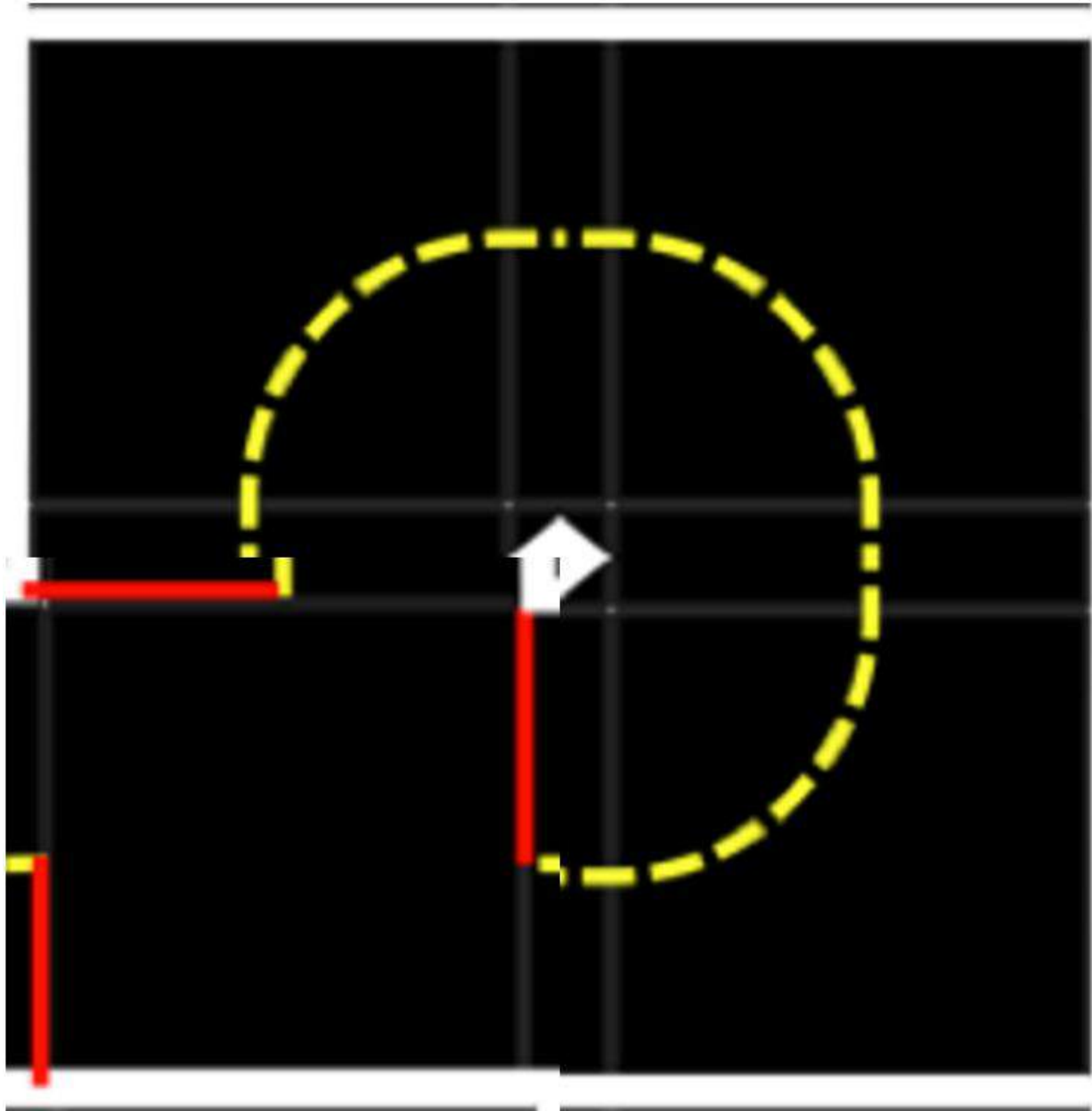
Here are some topological rule constraints that must be met:

1. An intersection can NOT be adjacent to a curved road tile or another intersection tile.
2. Any two adjacent non-empty tiles must have a feasible path from one to the other **of length two**: if they are adjacent, they must be connected.

Some examples of **non-conforming** topologies are shown below.



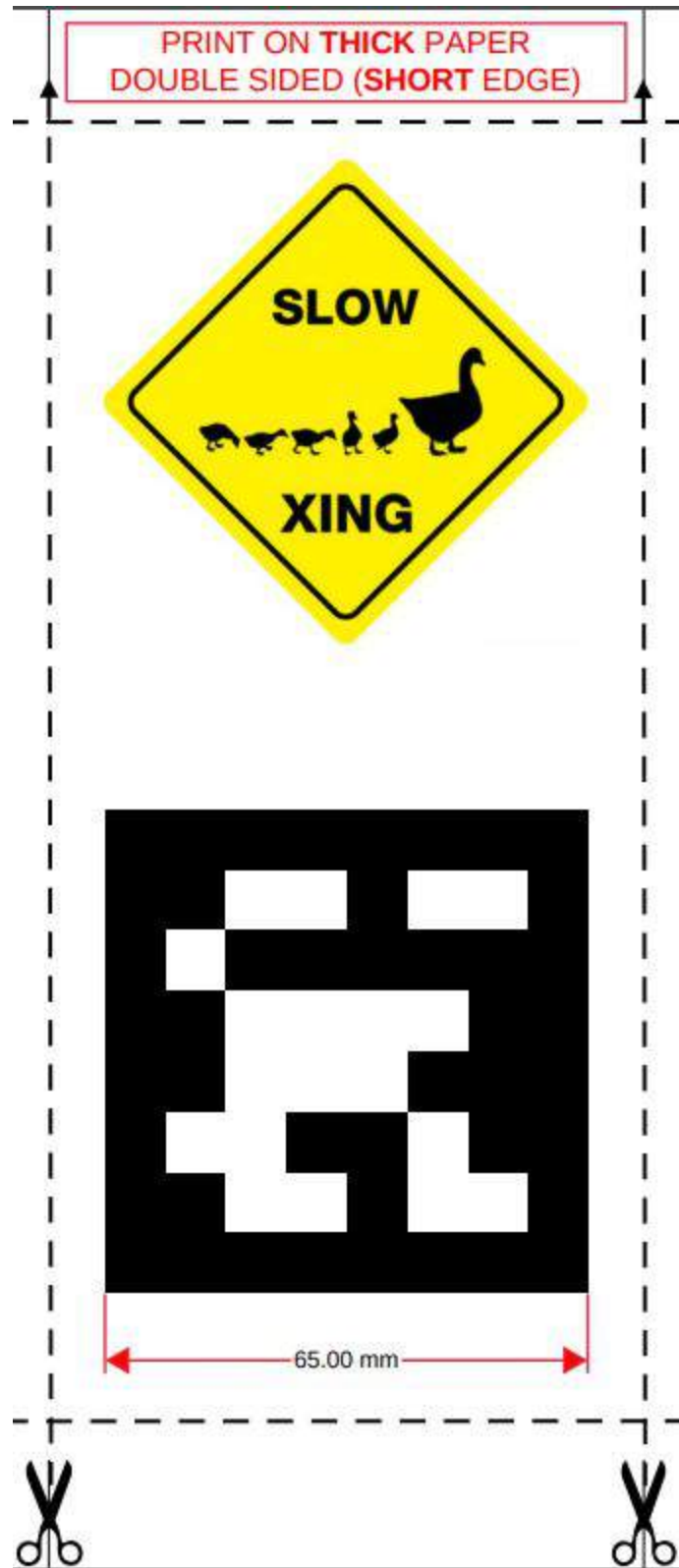
Topology violates rule 2 since the bottom two curved tiles are adjacent but not connected



Topology violates rule 1 since curved tiles are adjacent to intersection tiles

Traffic Signs

Traffic signage in Duckietown is obtained through the union of a traffic sign and an April Tag, as shown below. There exist many Duckietown compliant signs, each identified by a unique ID (on the back of the sign). All signs present in a city should have unique IDs (repeating signals with identical ID might interfere with global localization behaviors).



A traffic sign in Duckietown (do not print this one out!)

We call the symbol above *traffic sign*, while the code below is an AprilTag.

Specifications

For traffic signage to be compliant:

- The center of the traffic signs is 13 cm height from the floor layer;
- The AprilTag is 6.5 cm sq.;
- There is a white border of roughly 0.8 cm around them;
- The signage stands perpendicular to the ground, and the angle of the sign with the road is 90 degrees.
- The signal is flat (no deformation / folding) and without wrinkles. This can be obtained, e.g., by printing the signs on thick paper.

Types

The allowable traffic signs are as shown below.



stop



yield



no-right-turn



no-left-turn



do-not-enter



oneway-right



oneway-left



4-way-intersect



right-T-intersect



left-T-intersect



T-intersection



pedestrian



t-light-ahead



duck-crossing



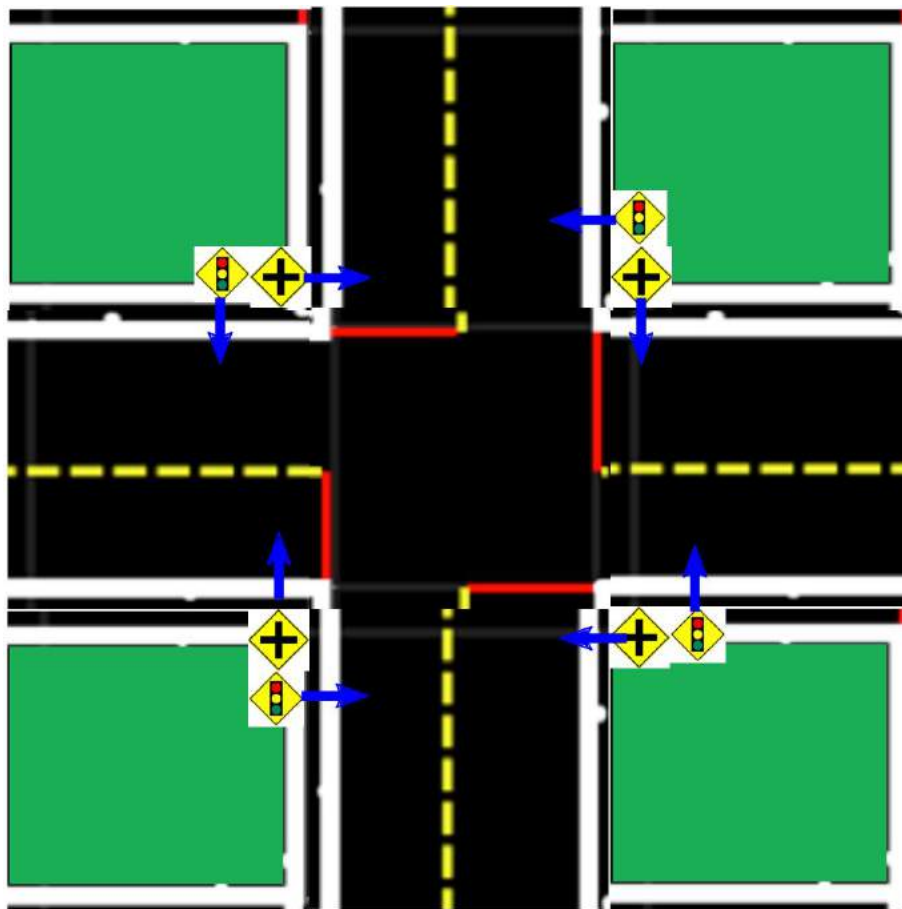
parking

Placement

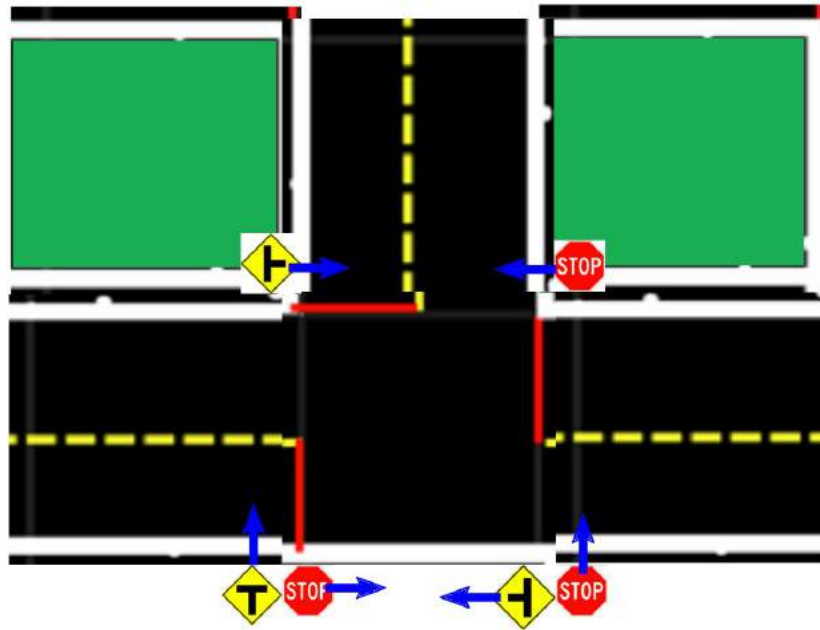
Signs may appear on the opposite side and at the corner of the adjacent tile from which they are viewed. In the absence of any signs, it is assumed that all network flows are allowed so a sign **MUST** be placed and visible whenever this is not the case.

Signs must only be placed on empty tiles, or next to one of the other tile types if on the border of a map. As mentioned, it is important to not overlap the base of the sign stand with any road marking.

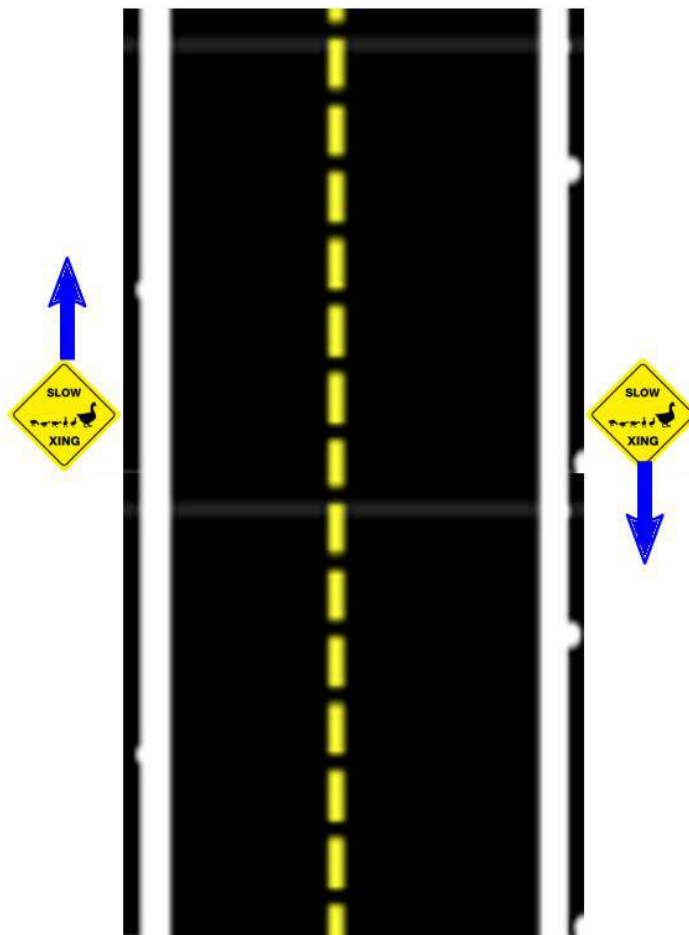
The sign placements for four different cases are shown in the figure below. At intersections, from each stop line 2 signs should be clearly visible: 1) the intersection type (traffic light or stop sign) and 2) the intersection topology (3-way with correct orientation, or 4-way).



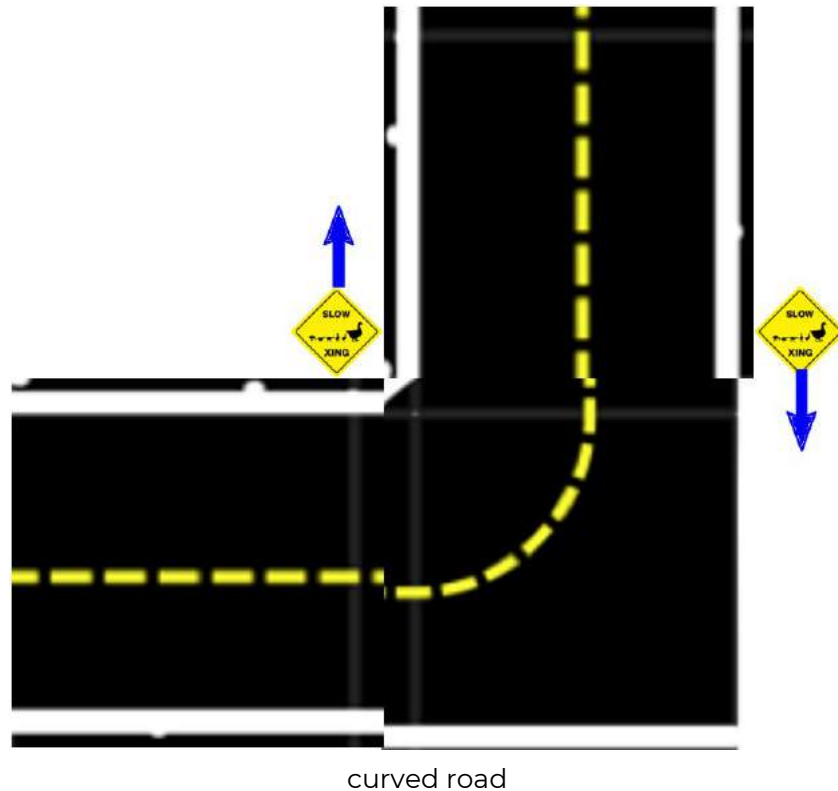
4-way intersection



3-way intersection



straight road



On straight and curved roads, additional signs can be added as desired. Their placement is indicated in the figures above. The signs should be placed at the border between two tiles and should face towards oncoming traffic as indicated.

In these figures the arrow is the direction of the sign.

7. Assembly

Before starting

To ensure that your streets will last long, make sure to follow these tips:

- clean the tiles with a cloth and some water and soap before attaching any tape;
- place the yellow tape on the tile and cut out pieces rather than pre-cutting them and attaching them to the tile as glue will be lost if you do not directly place them at the intended spot.

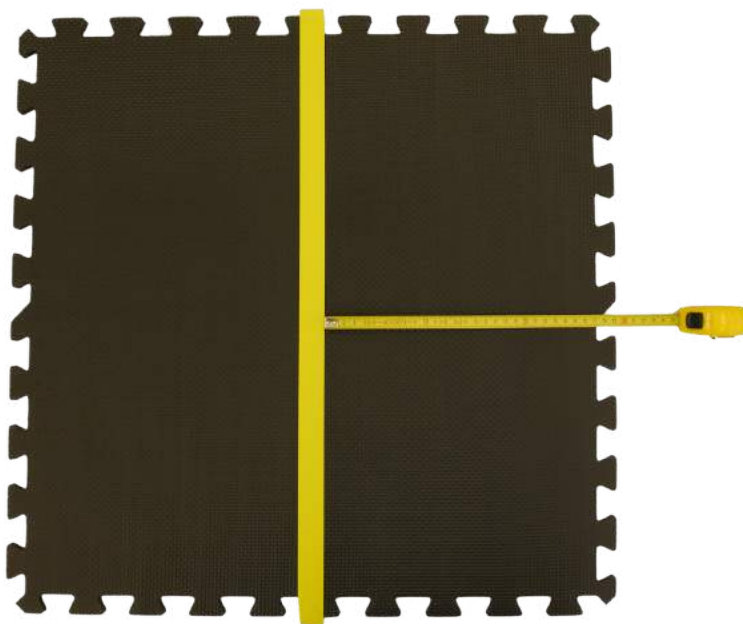
Straight roads

Each straight road segment has:

- Solid white markings on the outer sides of the lanes (right of direction of travel)
- Dashed yellow markings at the center
- Each lane is 21 cm wide (from end of white to beginning of yellow)

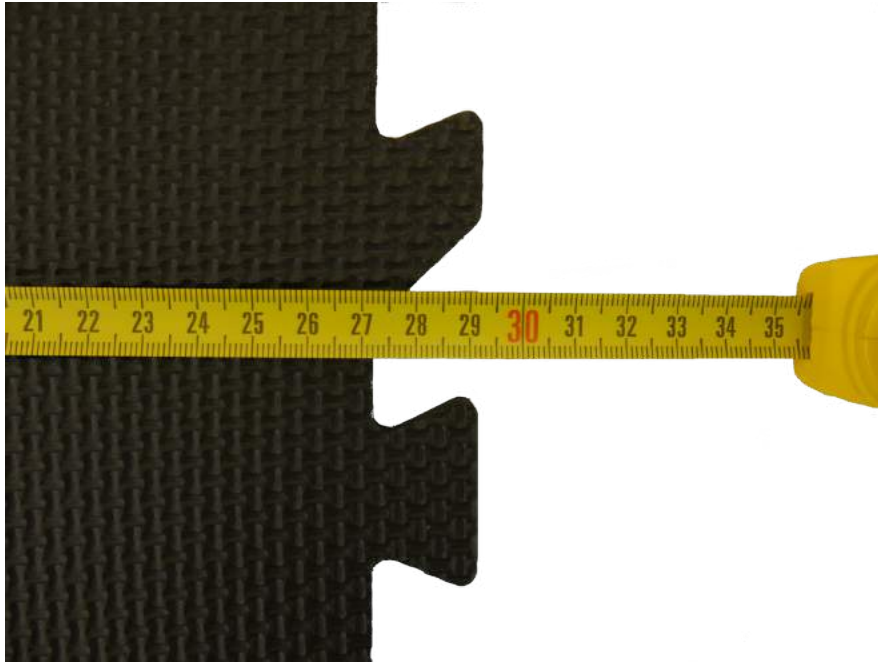
Assembly

Start by placing the yellow tape in the middle of the tile:



Placement of the yellow middle lane in the center of the tile.

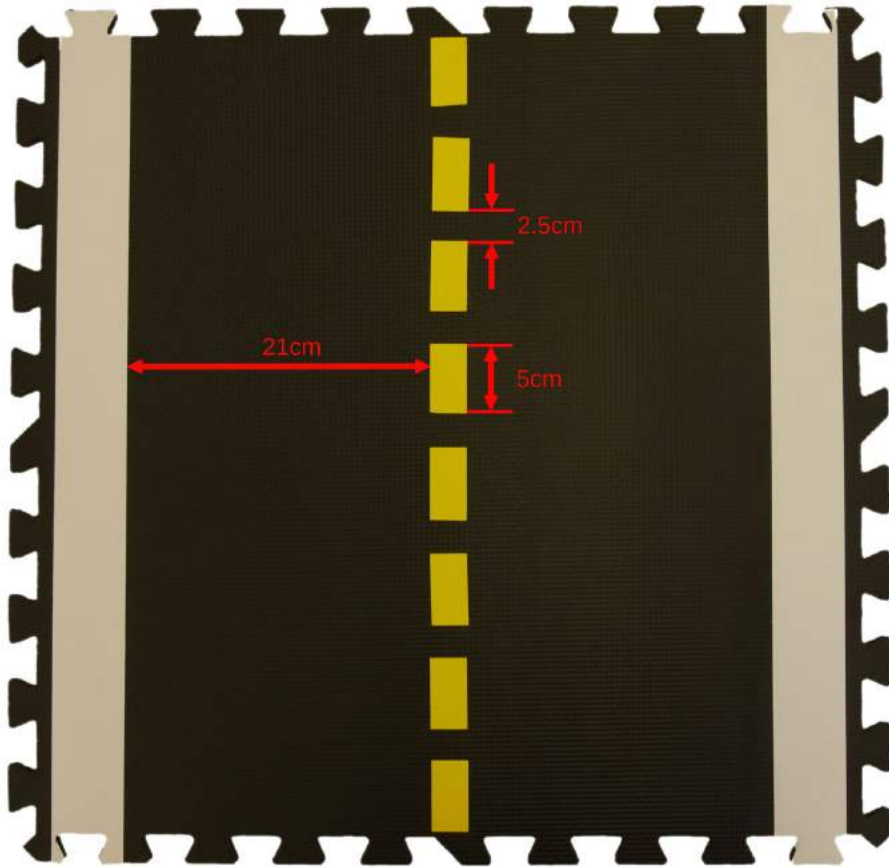
Make sure that the yellow tape is properly centered on the tile. The tile has a nominal width of 57cm without the interlocking teeth. This means from the end of the yellow tape to the end of the tile there should be a distance of 27.25cm:



Measurement from end of the yellow tape to the edge of the tile.

Once you have placed the yellow tape, cut out pieces of 2.5cm each, starting 5cm from the outer edge of the tile without the interlocking teeth.

Next, place the white lane markings at the outer part of the tile in a distance of 21cm to the end of the yellow tape. The Result can be seen in [Figure 1.3](#).



Finished straight road segment with measurements.

Curved roads

Each curved road segment has:

- Solid white markings on the outer sides of the lanes (right of direction of travel)
- Dashed yellow markings at the center
- Each lane is 21 cm wide (from end of white to beginning of yellow)

Assembly

Although not necessary, if you have a laser cutter available, you can use the provided file from [here](#) to laser cut the template shown below.

If you do not have access to a laser cutter, you have to create the middle line by hand. One way to do it is to take a string, place one end in the outer edge of the tile

(excluding the interlocking teeth) and make small markings in the form of a quarter circle in a distance of 27.25cm. This represents the inner border of where you have to put the yellow tape. The length of the single tape pieces is 5cm as for the straight road segment.

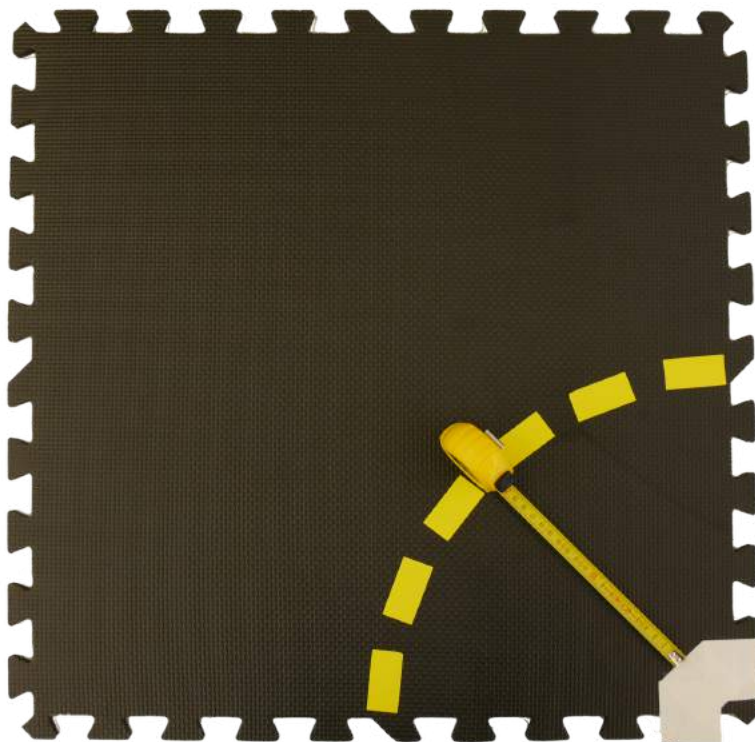


Placement of the yellow tape.



Measurement of lane width.

Once you have the middle of the lane in place, you are ready to add the inner white line of the road. Make sure that the lane width is 21cm.



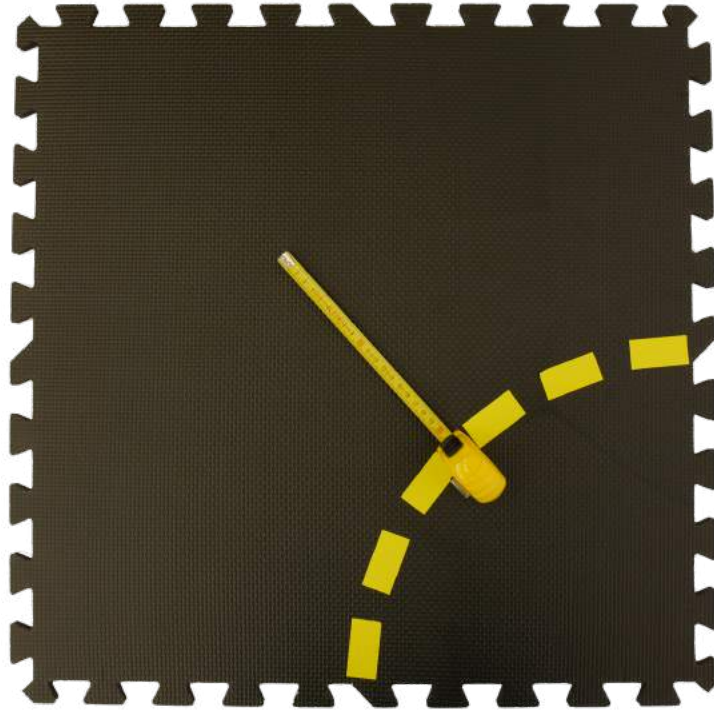
Measurement of lane width and white tape placement.

To add the outer white line you can either use another template from above or you will have to measure again. You can use the same technique as for the yellow middle line: place one end of a rope in the edge of the tile and draw a quarter circle with a radius of 50.75cm which will represent the inner boundary of the white tape. Alternatively, you can mark the lane width of 21cm at different locations and place the white tape accordingly.

Measurement of lane width

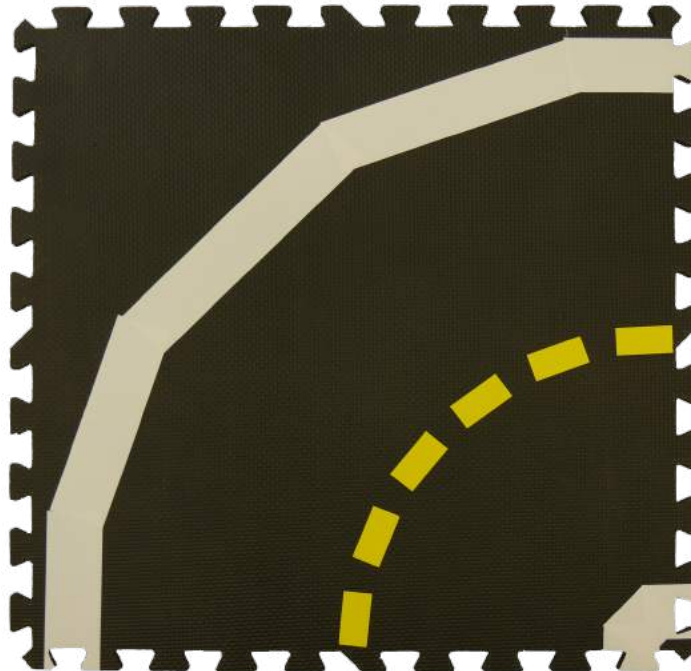


Measurement of lane width



Measurement of lane width.

The finished curved lane segment looks like this:



Finished curved road segment.

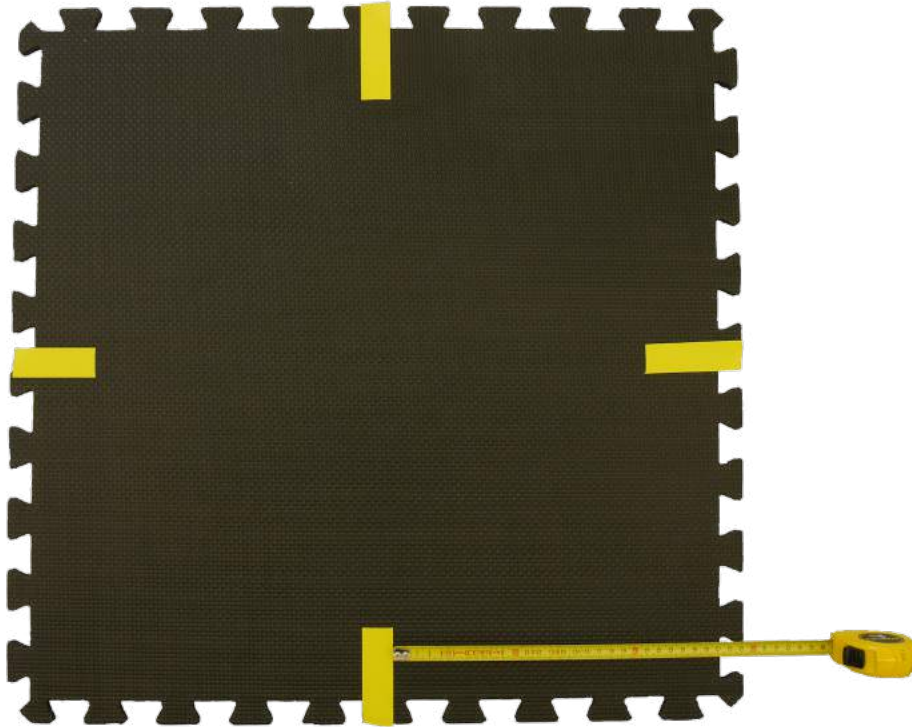
Intersections

Each intersection road segment (3- or 4- way) has:

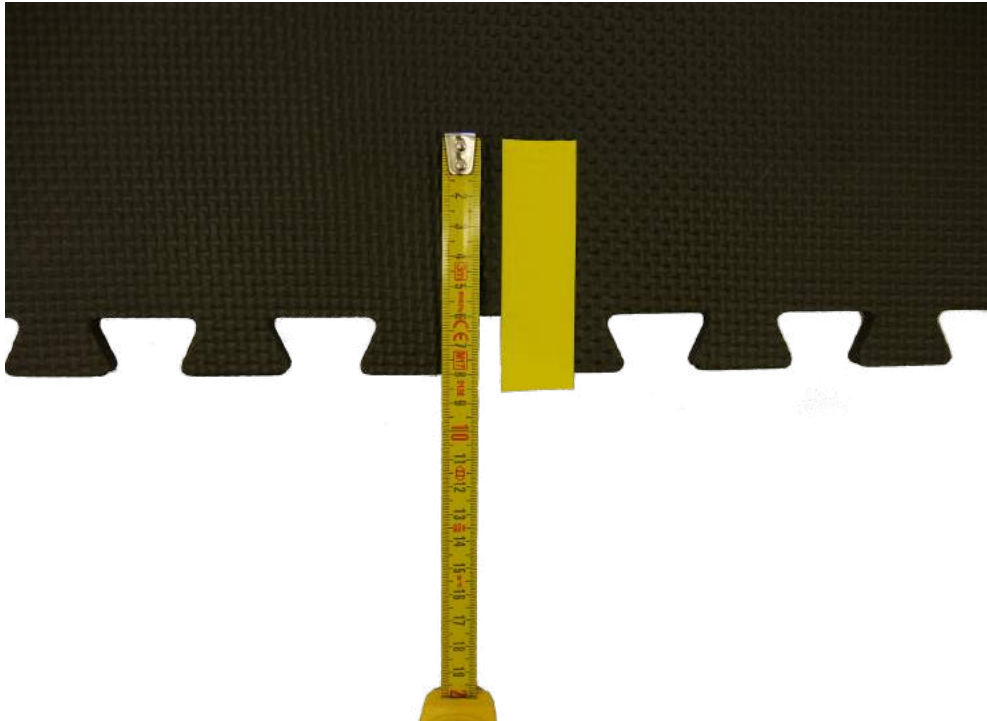
- Solid white markings on the outer sides of the lanes (right of direction of travel)
- Dashed yellow markings at the center
- Each lane is 21 cm wide (from end of white to beginning of yellow)
- Solid red markings as stop signs

Assembly of 4-way intersection

First, place four yellow tape strips as shown in the pictures below. Make sure that they are centered on the tile and that they reach in 6cm from the beginning of the tile without the interlocking teeth.

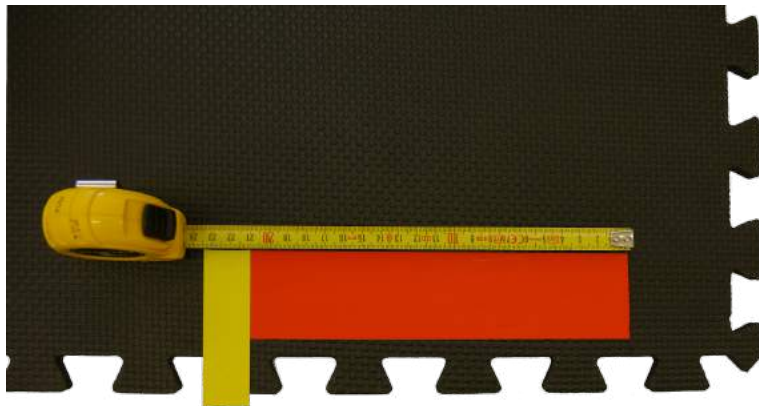


Placement of the yellow tape.



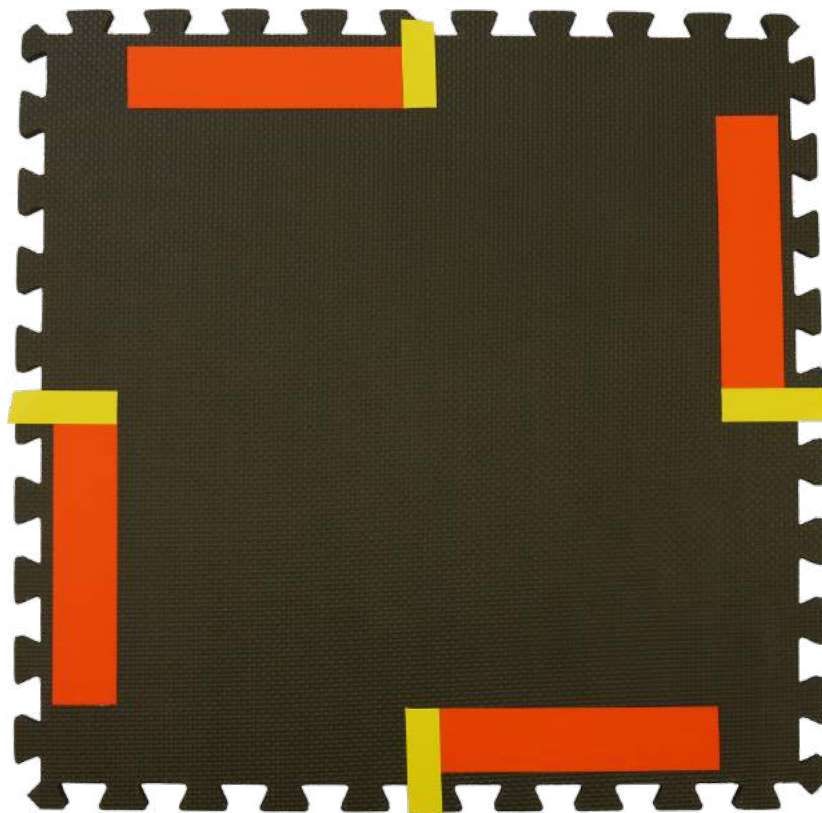
Placement of the yellow tape.

Now place the red tape aligned to the yellow tape. Ensure that the red tape is horizontally aligned with the edge of the tile and 21cm long.



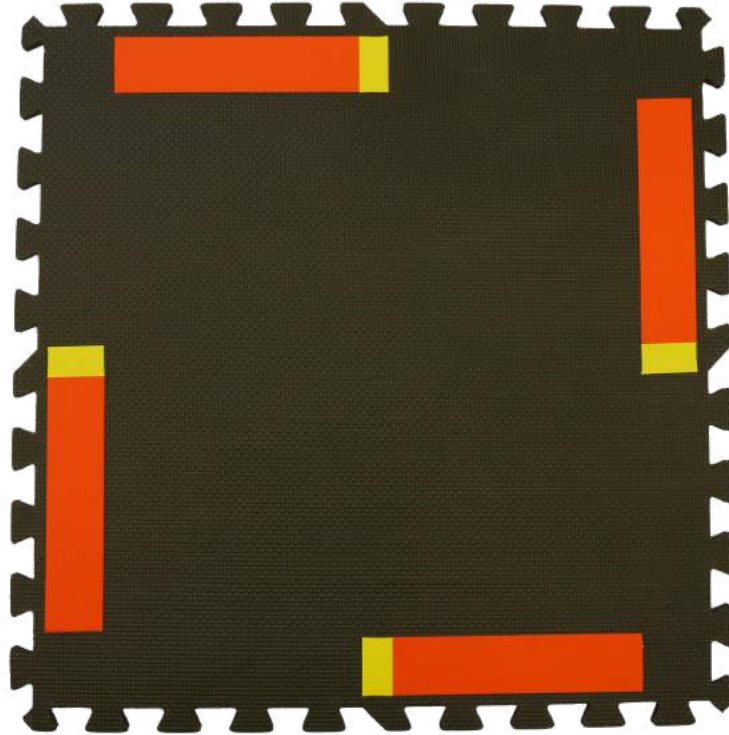
Placement of the red tape.

Repeat this for the other edges of the intersection.



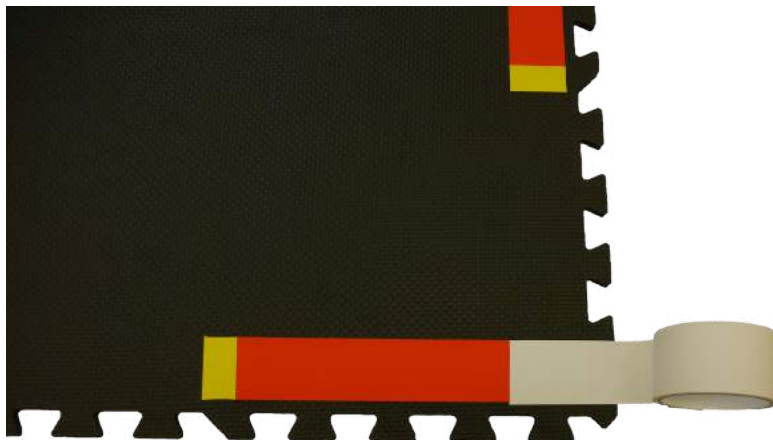
Placement of the red tape for the whole intersection.

Cut the yellow lane markings to a length of 5cm.



Yellow tape cut to 5cm length.

Finally, add the white tape on the sides. Do this for all the corners of the intersection.



Placement of the white tape.

The finished 4-way intersection lane segment looks like this:

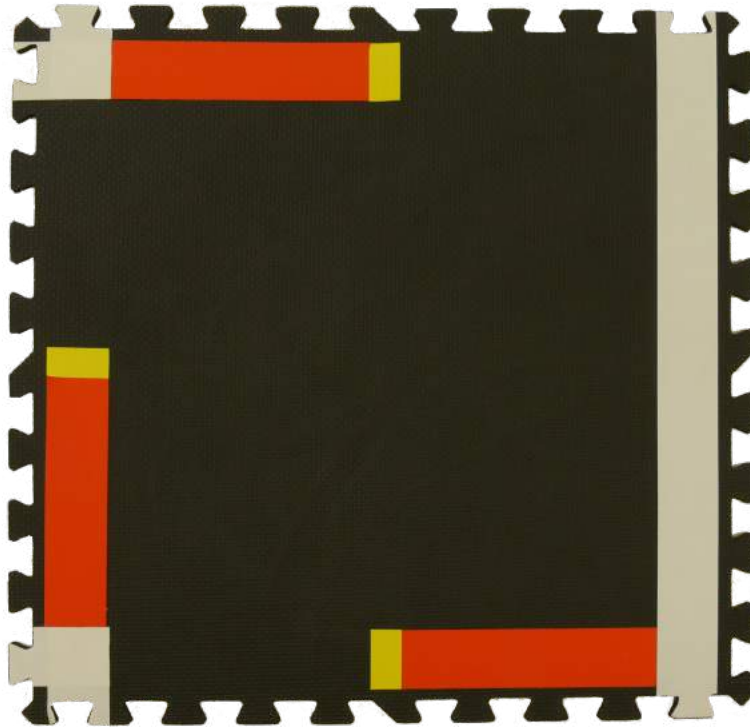


Finished 4-way intersection road segment.

Tip: You don't have to cut out the edges of the interlocking teeth from the white tape. Just use the overlapping tape to connect the road segment to the surrounding tiles nicely.

Assembly of 3-way intersection

3-way intersections are built the same way as 4-way intersections with the difference that on one edge white tape is placed instead of red and yellow. The resulting 3-way intersection can be seen below:



Finished 3-way intersection road segment.

8. Technical Support

For any questions related to the hardware, please contact hardware@duckietown.ch.

Alternatively, help can be obtained from the Duckietown community on the Duckietown Slack, in the #help-* channels. There are channels dedicated to various aspects of troubleshooting, e.g., robot assembly and operations.

9. Maintenance

It is recommended to:

- not step with shoes on the city - avoid dust marks as well as damaging the surface of the tiles or positioning of the road lanes
- periodically remove dust from the city

- avoid prolonged exposure to sunlight as it might cause discolorations or alter the mechanical properties of the glue
- do not spill liquids on the city
- keep away from active sources of fire (e.g., candles, fireplace, etc.)
- Do not bend, tear or otherwise deform the traffic signs or road lines

10. Conditions and methods of storage

The city tiles should be stored in a dry and cool place.

11. Warranty

For information on product guarantee contact hardware@duckieworks.ch.