HANDBOOK OF TEST METHODS FOR VIRTUAL OFFSIDE LINE ASSESSMENT

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1. Introduction

Virtual Offside Lines have been used for several years to graphically analyse a (potential) situation of offside in the game of football. Not least with Video Assistant Refereeing having been introduced into the Laws of the Game in 2018, has there been a quest to determine their accuracy in order to make confident decisions off the back of these lines. Research carried out by FIFA between 2016 and 2019 has shown that the most frequent sources of error for such virtual lines are the topography of the field (particularly the field camber), camera angle distortion, player occlusion and the issue of tracking individual body parts. This leads to no two broadcast images ever representing the same scenario and therefore introduces unknown and unsystematic error to the visualization of the line. In order to counteract these major influencing factors, this test protocol was developed to ensure any system that obtains certification can cope with the above-mentioned challenges.

The assessment of Virtual Offside Line systems to be used for VAR, shall be assessed with two distinct test blocks aiming at determining the accuracy and the repeatability of each provider. The first test block is based on 2-dimensional markers and a zoomed-out perspective thus verifying that the system is capable of correctly placing an offside line across the entire field thus accounting for the topography and different camera angles. The second test block, using a marker suspended in space and with tighter camera angles assesses the systems calibration and capability of pinpointing an exact location across several cameras in a more match-like scenario thus addressing issue of individual body parts or player occlusion.

How the Lines are Created and Measured

The offside lines shall be tested in a football stadium with a minimum broadcast setup of 4 cameras (Main camera, 16M right, 16M left and a tactical high-behind camera) recording in broadcast quality to an OB van or equivalent. Tests cover the entire field in order to ensure full pitch calibration and all providers must be able to draw correct offside lines on three of the main cameras (and possibly the tactical camera when one of the others is not available). The still images are then used to evaluate position vis-à-vis the ground truth. Providers must either pass all scenarios, or meet the scoring requirements stated to obtain approval.

Understanding Limitations of Measurements

The research that went into the development of this manual has pointed out some of the limitations that today's technologies and realistically available site equipment have with regards to measuring virtual offside lines. Overlaying images and detecting exact points, even in high-resolution images, can have a degree of uncertainty depending on which pixel is selected. As with all measurements, there is a (known) degree of error which has been considered when selecting the requirements.

The updated test method which follows aims at reducing the degree of error in the testing by minimising the human error in the analysis stage. The latest method uses qualitative analysis to determine whether the Virtual Offside Line falls within a predefined set of tolerances. This therefore reduces the source of human error previously present, particularly with pixel selection during quantitative analysis.

2. Test Protocol for Virtual Offside Lines

2.1. Test Setup

2.1.1. Broadcast Setup & Image Capturing

- A minimum of 4 broadcast cameras (including main camera, 16m left, 16m right and a tactical high behind) shall be provided to the providers in sufficient broadcast quality (SDI HD or similar). The broadcaster will provide the offside line providers with the respective feeds at the determined location in the stadium where the test is taking place (room or cabin in broadcast compound as applicable).

- Once set up, the offside line providers shall be given some time to complete their individual calibrations, along with the ability to request sweeps from the broadcast cameras if necessary;

- Upon completed calibration, the test is carried out by placing lines on dedicated markers in accordance with the below test sections. The output is an image in the highest possible resolution displaying the line (min. 1080x1920 pixels);

- For each test location, there shall be a time limit by which images must be obtained by (approx. 60 seconds);

2.1.2. Line Width and Measurement Points

A specific issue that has arisen in the past is around line width and placement of the line. The centre of the line should never be used as the reference point but rather the leading or trailing edge. In case only the last defender is being tracked (as is the case for these tests), the leading edge is the most suited for determining the exact position i.e. the edge closest to the goal in each respective half. Should the trailing edge be chosen by any given provider, this must be made clear to the test institute prior to the testing. The method selected must be consistent throughout testing.

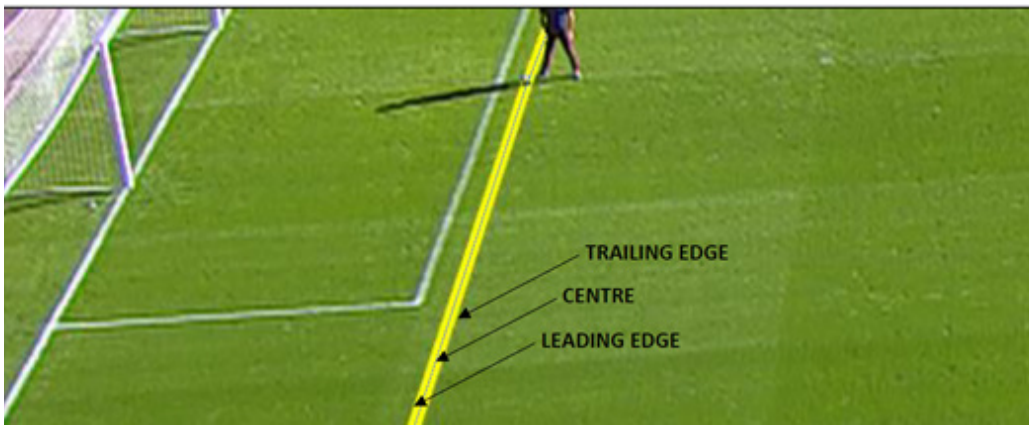

Image 1 – Defining the leading edge of the offside line

2.1.3. Testing Framework

A robotic total station should be set-up within the stadium, with a clear view of the entire field of play, including both goals. Two points on each goal line should be identified and surveyed using the total station, in order to provide the reference plane for all subsequent measurements in the respective halves. Both halves shall be treated independently from the other during the testing. A string line on the goal plane and a laser level should be used to accurately identify the two points on the goal line to be surveyed, approximately 100mm in from each post.

2.1.4. Apparatus

The following equipment should be used for the assessment of the ground truth on the field:

Survey equipment (i.e. robotic total station) with a measurement accuracy of <10mm
- e.g. Trimble SPS620 Robotic Total Station
- e.g. Trimble TSC3 Handheld Controller

Laser Level
- e.g. Leica Lino L2P5

200mm diameter surface markers
- e.g. Sondico Space Markers

Football boot
- Miscellaneous

Tripod with extendable boom arm
- Miscellaneous

2.2. Test Methods

Testing shall consist of two sections:
- 2-dimensional full width analysis (sixty metres scenario width)
- 3-dimensional zoomed analysis (twenty metres scenario width)

Both test sets will analyse the accuracy of the virtual offside placement, as well as the accuracy of the line in comparison to the goal plane. The accuracy of the VOL placement will be more focused in the 3-dimensional zoomed testing, with a tighter tolerance zone at the location of the 'second last defender'.

2.2.1. Test Section 1: 2-Dimensional Full-Width Line Assessment

Principle

Section 1 aims to verify that a system can accurately place an offside line in a zoomed-out scenario over the full width of the field, based on a 2-dimensional point.

Procedure

Five markers will be measured out using a total station and placed on the surface on each half of the field prior to the test. These markers will be placed according to pre-set coordinates and will be numbered one through ten for reporting purposes – each scenario number will be communicated to the providers prior to each scenario. Four additional perimeter markers will be placed on the surface at each scenario. Broadcast cameras should be zoomed out accordingly, so that all four markers are visible on the screen before the test begins, ensuring full coverage of each scenario.

A random marker will be selected in the chosen starting half. The test engineer will proceed to stand at the chosen marker, and request the providers to place a virtual offside line on the offside plane; the tester thus acting as the second last defender – the providers should place the VOL on the player's toe which marks the correct location. A through ball will be kicked to determine the exact moment the offside line should be placed. The providers must place the leading edge of their offside line on the correct offside plane. The providers should obtain and save a full-screen screenshot at minimum 1080x1920 pixel resolution, within a specified time limit, showing the virtual offside line spanning the full width of the field. This should be completed for two camera angles at each location. Both cameras should remain in the same position for the time following this shot.

A further ten markers will be measured out and placed on the surface, surrounding the reference marker with adjusted Easting and Northing values according to the below table (Table 2). Another screenshot should be obtained and saved at minimum 1080x1920 pixel resolution, with no virtual offside line on display, and only the surface markers visible. This must be from the same camera angle as the previous image with the virtual offside line for analysis purposes, and the same resolution as the first image. Both the image showing the VOL and the image showing the marker at each location must overlay perfectly for analysis purposes.

Marker	Easting	Northing
1	-30m	-0.25m
2	-30m	+0.25m
3	-15m	-0.25m
4	-15m	+0.25m
5	0m	-0.25m
6	0m	+0.25m
7	+15m	-0.25m
8	+15m	+0.25m
9	+30m	-0.25m
10	+30m	+0.25m

Table 2 - Coordinates of additional markers in relation to reference marker.

The above process should be repeated for each of the five locations on both halves of the field in a random order. A total of ten scenarios will be analysed, covering two camera angles at each.

2.2.2. Test Section 2: 3-Dimensional Match Scenario

Principle

This section aims to verify that a system can accurately locate an offside position from a 3-dimensional marker suspended in space, assessing the accuracy by which the virtual offside line can be translated and placed on the surface. Although full-width scenarios are sometimes required in matches, this section will mimic more match-like scenarios than Test Section 1.

Procedure

Five locations shall be measured out using a total station on each half of the field prior to the test. These locations will be according to pre-set coordinates and will be numbered one through ten – each scenario number will be communicated to the providers prior to each scenario. No visible markers will be placed on the surface at this stage for the providers to view.

The first location will be chosen at random by the test engineer. A football boot suspended on a tripod with boom arm will be placed at this location, using a laser level to accurately place the toe of the boot (i.e. nearest point to the goal) to the location measured on the surface. The suspended football boot will act as the second last defender in this scenario. As in section 1, four perimeter markers will be placed around each location. Once placed, the camera may be zoomed appropriately to convey a more match-like scenario, whilst ensuring the markers are clearly visible.

Once the appropriate angle has been identified, the providers should place their virtual offside line on the surface of the pitch, corresponding to the suspended marker's position. A through ball will be kicked to determine the moment the offside line should be placed. The providers must place the leading edge of the offside line on the correct offside plane, as demonstrated in Figure 1. The providers should obtain and save a full-screen screenshot at minimum 1080x1920 pixel resolution, within a specified time limit, showing the virtual offside line spanning the width of the scenario. The camera should remain in the same position for the time following this shot. This should be completed for the two specified camera angles at each location.

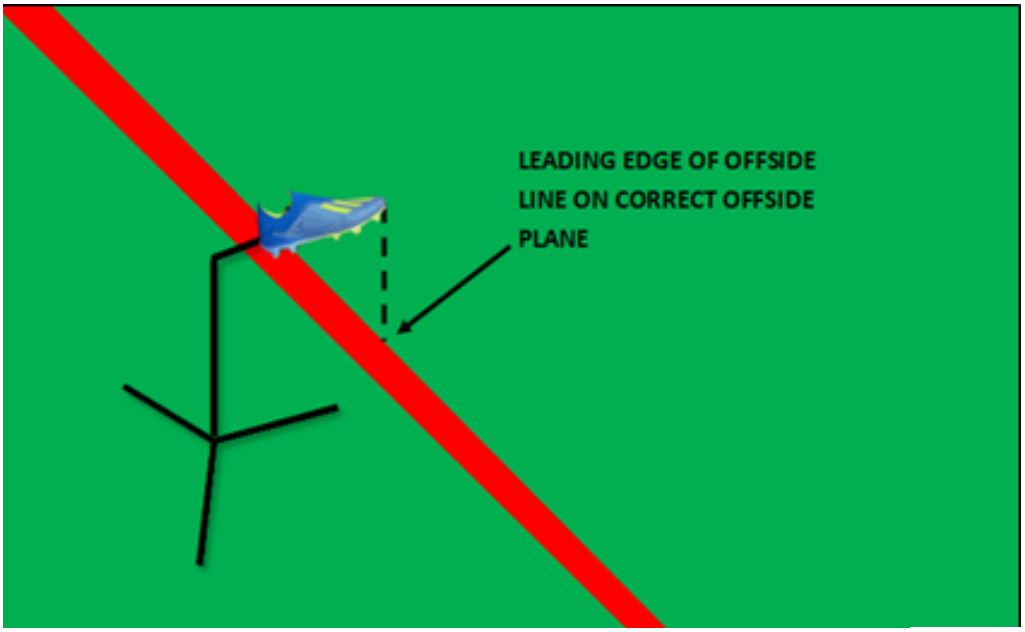

Figure 1 - Image showing leading edge of the offside line correctly placed on the true offside plane at the toe of the boot.

A further six markers will be measured out and placed on the surface, surrounding the reference marker with adjusted Easting and Northing values according to Table 3.

Marker	Easting	Northing
1	-10m	-0.25m
2	-10m	+0.25m
3	0m	-0.20m
4	0m	+0.20m
5	+10m	-0.25m
6	+10m	+0.25m

Table 3 - Coordinates of additional markers in relation to reference marker.

Another screenshot should be obtained at minimum 1080x1920 pixel resolution, with no virtual offside line shown, and only the surface markers visible. This must be from the same camera angle as the previous image with the virtual offside line for analysis purposes, and the same resolution as the first image.

The above process should be repeated for each of the five locations on both halves of the field. A total of ten scenarios will be analysed.

2.2.3. Analysis & Results

Analysis of each scenario will be assessed visually, evaluating whether the virtual offside line is within the predefined tolerances across the width of each scenario measured – sixty metre full width and twenty metre zoomed in.

The field survey prior to the testing ensures all markers placed on the surface of the field on the same Northing value will be parallel to the goal plane, and thus parallel to the true offside plane. The visual references (markers) placed on the field surface automatically means therefore that ground truth is accounted for at all locations and camera angles, demonstrated in Figure 2.

Figure 2 - Image from a previous testing set, showing a dynamic yellow line between the centre of the markers laid on the pitch showing that Ground Truth is accounted for at each zone, compared to a perfectly straight black line drawn between the widest markers.

Analysing the full width and the zoomed in scenarios requires both images obtained from each camera for each scenario to be utilised. The two images are overlaid on top of each other in order to view both the virtual offside line on the same image as the external markers placed on the surface during the test. The two screenshots should be the same resolution and overlay perfectly on top of each other.

Should for any reason the camera moves between obtaining the screenshot with the offside line and obtaining the screenshot showing only the markers, the scenario will be discounted from analysis. If the images do not match up due to provider error (i.e. different resolution/aspect ratios), the scenario will be considered failed.

Full Width

Each full width scenario is assessed to ensure the leading edge of the offside line falls within the tolerance at each of the zones spanning the width of the pitch. There will be a total of five zones where this will be assessed, as shown in Figure 3, with the zones numbered from one to five: Zone One nearest to the camera, Zone Five furthest the camera.

The distance between the internal edge of the markers at each zone is 500mm, meaning an allowable tolerance of +/-250mm from the true offside plane at each zone. Should the leading edge of the virtual offside line fall within each 500mm zone, the scenario will be passed. Should the offside line fall out with any of the five zones, the scenario will be failed, and the zone(s) at which this occurred reported and penalty points recorded.

Figure 3 - Representation of the external marker layout for Full Width scenarios - all virtual offside line leading edges must fall within the 500mm channel at each of the five zones (or trailing edge if applicable).

Zoomed

The zoomed scenarios are assessed using the same method as full width analysis. The providers will be assessed on two separate tolerances as opposed to one: tighter accuracy of placement at the offside point as well as line offset over twenty metres.

In total, the leading edge of the virtual offside line will be evaluated through three zones, numbered one to three. Zone One nearest the camera, and Zone Three furthest from the camera.

The two markers placed in the region of the reference marker (i.e. the suspended football boot/ Zone 2) will be 400mm apart, meaning the virtual offside line must be placed within a tolerance of +/-200mm. The leading edge of the line must again fall in between the internal edges of the marker. The two markers at each of the outer zones will be 500mm between the internal edges of the markers, meaning an allowable tolerance of +/-250mm over the twenty-metre scenario. Should the leading edge of the virtual offside line fall within the tolerances at each of the three zones, the scenario will be passed. Should the offside line fall out with any of the three zones, the scenario will be failed, and the zone(s) at which this occurred reported and penalty points recorded.

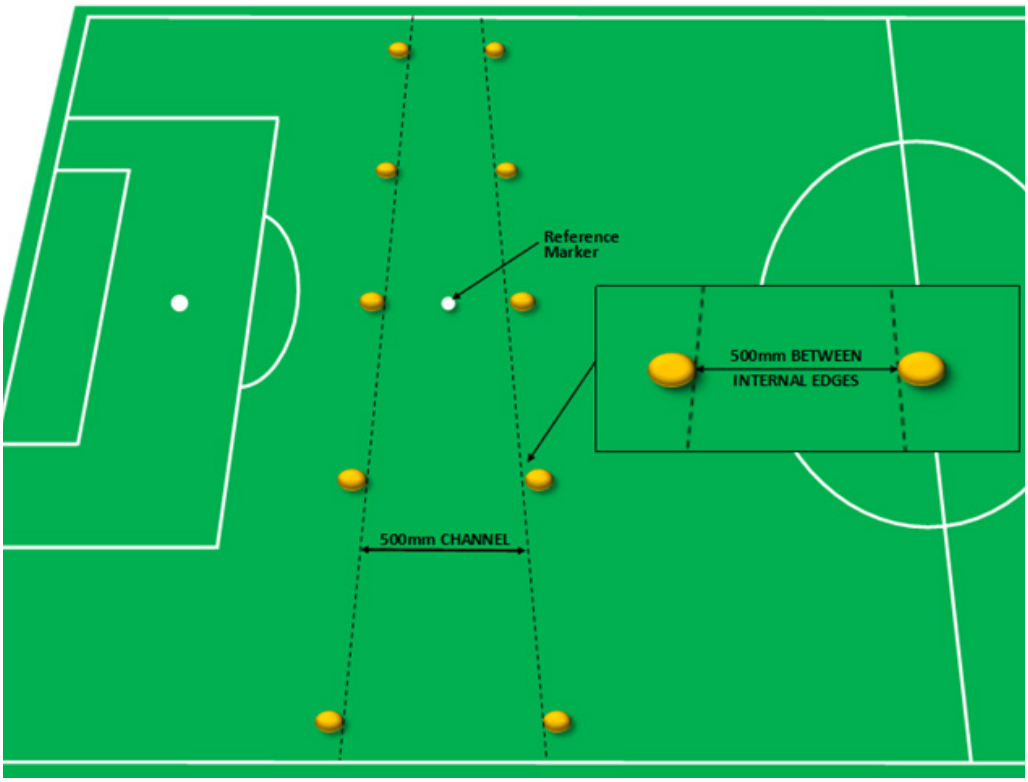

Figure 4 - Representation of the external marker layout for Zoomed scenarios - all virtual offside line leading edges must fall within the 400mm channel at the centre of the scenario to meet the tighter placement tolerance, and within the two 500mm channels in the outer zones.

3. Test Requirements

The following tables specify the requirements that must be met by VAR Virtual Offside Line providers.

3.1. Submission of Data by Providers

3.1.1. 2D Full Width Assessment

This test block consists of 10 test points. A marker is placed on the ground which should be correctly identified, and the validity of the offside line drawn through this marker will be assessed over a total distance of approximately sixty metres, whereby said marker may be anywhere within those sixty metres (offset). Two images will be recorded from two different camera angles (main and 16M by default) and will be assessed. The first image depicting the offside line on the marker and the second with the reference image to compare the line to.

Scenario + camera		Evaluation Zone				Pass / Fail
		Virtual line	Reference	Total images	Offset Tolerance over 60m	
Test Point 1 (right half)	16M	1	1	2	±250mm	
	Master	1	1	2	±250mm	
Test Point 2 (right half)	16M	1	1	2	±250mm	
	Master	1	1	2	±250mm	
Test Point 3 (right half)	16M	1	1	2	±250mm	
	Master	1	1	2	±250mm	
Test Point 4 (right half)	16M	1	1	2	±250mm	
	Master	1	1	2	±250mm	
Test Point 5 (right half)	16M	1	1	2	±250mm	
	Master	1	1	2	±250mm	
Test Point 6 (left half)	16M	1	1	2	±250mm	
	Master	1	1	2	±250mm	
Test Point 7 (left half)	16M	1	1	2	±250mm	
	Master	1	1	2	±250mm	
Test Point 8 (left half)	16M	1	1	2	±250mm	
	Master	1	1	2	±250mm	
Test Point 9 (left half)	16M	1	1	2	±250mm	
	Master	1	1	2	±250mm	
Test Point 10 (left half)	16M	1	1	2	±250mm	
	Master	1	1	2	±250mm	
Total score		20	20	40		

3.1.2. 3D Scenarios

This test block focusses on the 3-dimensional capability of the offside line system with a tighter camera set-up (where the touch lines will mostly not be visible). A suspended marker shall be used based on which the accuracy of the line offset shall be assessed on the surface, with a tighter placement tolerance than previous. The first image depicting the offside line on the marker and the second with the reference image to compare the line to.

Scenario + camera		Evaluation Zone					Pass / Fail
		Virtual line	Reference	Total image	Placement	Offset 20m	
Test Point 11 (right half)	16M	1	1	2	±200mm	±250mm	
	Master	1	1	2	±200mm	±250mm	
Test Point 12 (right half)	16M	1	1	2	±200mm	±250mm	
	Master	1	1	2	±200mm	±250mm	
Test Point 13 (right half)	16M	1	1	2	±200mm	±250mm	
	Master	1	1	2	±200mm	±250mm	
Test Point 14 (right half)	16M	1	1	2	±200mm	±250mm	
	Master	1	1	2	±200mm	±250mm	
Test Point 15 (right half)	16M	1	1	2	±200mm	±250mm	
	Master	1	1	2	±200mm	±250mm	
Test Point 16 (left half)	16M	1	1	2	±200mm	±250mm	
	Master	1	1	2	±200mm	±250mm	
Test Point 17 (left half)	16M	1	1	2	±200mm	±250mm	
	Master	1	1	2	±200mm	±250mm	
Test Point 18 (left half)	16M	1	1	2	±200mm	±250mm	
	Master	1	1	2	±200mm	±250mm	
Test Point 19 (left half)	16M	1	1	2	±200mm	±250mm	
	Master	1	1	2	±200mm	±250mm	
Test Point 20 (left half)	16M	1	1	2	±200mm	±250mm	
	Master	1	1	2	±200mm	±250mm	
Total score		20	20	40			

3.2. Evaluation Methods

Two different evaluation methods have been developed to account for more accurately depicting the performance of a system.

3.2.1. PASS/FAIL

The PASS/FAIL criterion evaluates all images submitted and identifies if the leading or trailing edge of the VOL is within the tolerance zone or not. Any system meeting this requirement at all zones, has passed the scenario. If an image is not submitted or a line with outside the tolerance, the scenario is failed.

In order to pass the test via the PASS/FAIL method as a whole, 95% of scenarios must have been submitted for analysis, with no fails recorded.

3.2.2. Scoring Systems

In addition to the PASS/FAIL system, a second method is used based on a scoring system according to the position of the VOL at each zone (depicted by a marker in the reference image), as shown in the diagram below. Each VOL is analysed in every zone spanning the width of each scenario, with a score of zero to three points at each zone depending on the accuracy. Zero points are awarded for VOLs which fall in between the markers at the zone, with increasing three points for lines which fall out with the marker zones. Where the VOL falls on the border between two zones, the smaller score is to be awarded. A total score for each scenario is calculated according to the accumulation of scores from each marker set. Only the leading edge (or trailing edge) of the VOL will be assessed in each zone.

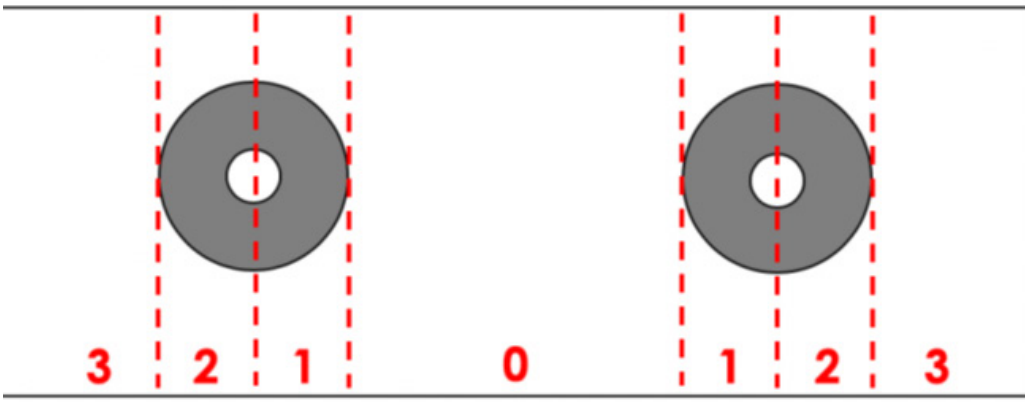

Figure 5 – Scoring system by areas

The scoring system will be depicted in the tables below highlighting the value of each position at each marker and according the score of 0, 1, 2 or 3 based on the position of the line in relation to the reference markers. An image that is not submitted will impact the submission percentage score (by default 40 out of 40 positions).
For test section one, each image has a total of 5 evaluation zones in which points are scored.

Test section 1: scoring template

Scenario + camera		Evaluation Zone					Overall
		Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	
1	16M						
	Master						
2	16M						
	Master						
3	16M						
	Master						
4	16M						
	Master						
5	16M						
	Master						
6	16M						
	Master						
7	16M						
	Master						
8	16M						
	Master						
9	16M						
	Master						
10	16M						
	Master						
Total score							

For test section two, each image has a total of 3 evaluation zones in which points are scored.

Test section 2: scoring template

Scenario + camera		Evaluation Zone			Overall
		Zone 1	Zone 2	Zone 3	
11	16M				
	Master				
12	16M				
	Master				
13	16M				
	Master				
14	16M				
	Master				
15	16M				
	Master				
16	16M				
	Master				
17	16M				
	Master				
18	16M				
	Master				
19	16M				
	Master				
20	16M				
	Master				
Total score					

3.3. Requirements for system approval

In order to be approved in accordance with the FIFA Quality Programme for Virtual Offside Line, each system must have passed two separate tests meeting either of the following requirements:

1. PASS on all scenarios in accordance with the method described in 3.2.1, with a submission rate of 95%;

2. Or, failing the above, a combination of the below
   a. A 95% submission of all tested scenarios

   and

   b. No more than a total of 10 points from all scored images

   and

   c. No individual scores at any given zone of 3 points.

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