Sensor properties for indoor vehicle testing (SPICE)

Public report

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Contents

1 Summary

The amount of test track testing required to develop and validate coming active safety and autonomous vehicle functionality is forecast to increase. To facilitate this development AstaZero needs to offer more track time with appropriate conditions. One major enabler is a covered, or indoor, track. With an indoor test track completely stable weather, friction, and light conditions can be offered.

Work is needed both on required dimensions, lighting and relevant sensor properties. One area which requires prototyping and testing is sensor properties, mainly radar and vision system characteristics, of an indoor test track. The project gathered researchers, OEM's and TIER1's which gave a broad range of knowledge and experience.

First it was important to investigate worldwide if there are any indoor vehicle testing facilities present already and try to find out their strengths and weaknesses in order to learn from their experience. It turned out to be a large variety in construction type, dimension and area of use at the one found during the project.

Then mapping of all use cases that an indoor test track should be able to handle was needed, as well as required dimensions, geometry and other prerequisites. Many cases were found and an attempt to narrow it down to the most frequently used and important cases in the vehicle active safety testing today was made.

Radar absorber materials and construction beam geometry were tested and analyzed for sensor properties in a lab environment. Furthermore, extensive testing at different indoor construction alternatives were conducted together with vehicle testing equipment and TIER1 sensors used today. Some of these tests were also conducted at AstaZero outdoor test track in order to have reference measurements and properties for further analysis. Sensor response for possible indoor environments was investigated for GNSS, radar and camera. The tests in the indoor environment showed positive results which paves the way for continued work towards a final solution of an indoor test track.

2 Sammanfattning på svenska

Idag sker en ökning av provning av fordons aktiva säkerhetssystem (ADAS) och självkörande fordon (AD) vilket kommer kräva högre tillgänglighet av provbanor året runt. För AstaZero är den nordeuropeiska placeringen till nackdel då delar av året ger instabilt väder med mycket nederbörd och kyla och därför är en täckt provbana inomhus en möjliggörare för att förse kunder med mer bantid under stabila förhållanden. Många testmetoder inom aktiv säkerhet kräver nämligen torra vägbanor med viss friktion, plusgrader och särskilda ljusförhållanden.

Då detta är ett relativt nytt område behövs kunskap och specifikation på vilken dimension och geometri som krävs samt förståelse för sensorerna egenskaper i och påverkan av en inomhusmiljö. Sensorerna är beroende av miljön kring där fordonet färdas och det är viktigt att förstå dess påverkan.

Projektet består av personer från både forskningssidan, fordonstillverkare och underleverantörer med en stor gemensam kunskap och erfarenhet. Vårt första steg var att undersöka vilka befintliga inomhustestbanor det finns runt om i världen idag för att hitta styrkor, svagheter och lärdomar som kan vara till nytta för oss. Det finns en väldig variation av olika konstruktioner och användningsområden på de vi fann.

Vidare försökte vi kartlägga de testfall som skulle gynnas av en inomhustestbana och specificera deras krav på dimension, geometri, belysning och andra parametrar. Input från både lastbil- och personbilssidan togs in men även från sensorsidan, och vi försökte begränsa dem till de mest använda och viktiga testfallen inom provning av aktiv säkerhet.

I ett arbetspaket gjordes provning av radarabsorberande material och konstruktionsbalkars geometri i laboratoriemiljö för att undersöka dess egenskaper. Vi fann kostnadseffektiva material som kan användas för att minska radarreflektioner på utsatta platser i en inomhusmiljö. Det gjordes även omfattande och lyckade fältprov på två olika konstruktionsalternativ där vi tittade på GNSS-, radar- och kameraegenskaper. Ett av fältproven gjordes tillsammans med fullt utrustade testfordon med körrobot och sensorer och verkliga testfall och testmål från Euro NCAP. Detta repeterades senare utomhus på AstaZero för att ha som referensmätning mot inomhusproven. Analyser visar på goda förutsättningar för fortsatt arbete mot en slutlig lösning av en testbana inomhus.

3 Background

Today the testing of active safety and autonomous driving is mainly conducted on outdoor test tracks with test protocols demanding weather conditions with no rain- or snowfall, dry track surface and low wind speeds. Since we cannot control the outdoor weather and suffer from Scandinavian variable climate the test frequency drops rapidly during some parts of the year.

The amount of test track testing required to develop and validate present and coming active safety and autonomous vehicle functionality is forecast to increase. Therefore, a covered, or indoor, test facility which can offer stable weather, friction, and light conditions is a suitable way to go.

4 Purpose, research questions and method

The sensors used in ADAS and AD functions are depending on the environment where the vehicle travels and it is important to understand how the walls, roof, road surface and lightning system in an indoor facility affect them. This include gathering information about the present state of the art facilities worldwide today and summarize the dimension and geometry needed for an indoor test facility in order to maximize the possible uses cases.

The project method used is based on five work packages:

- Project management (WP1)
  Coordination, follow-up, planning and reporting.

- State of the art investigation (WP2)
  Use project parties experience, knowledge and connections in order to investigate capabilities and limitations of existing indoor test facilities worldwide.

- User cases (WP3)
  Define user cases for proper dimension and geometry of an indoor test facility at AstaZero. Investigate which test cases are most frequently conducted now and in the near future, and what is required for these regarding dimension and geometry etc.

- Material, optical and construction specification (WP4)
  Investigate different materials' optical and radar properties for the construction of an indoor test facility. Examine present indoor construction possibilities available on the market.

- Testing and verifying (WP5)
  Conduct vehicle sensor testing in indoor environment to compare with reference measurements from testing outdoors at AstaZero.

5 Objective

The main goal of the project is to collect and build necessary knowledge, experience and specifications about user cases, sensor properties and building material making it possible for AstaZero to as the next step invest in an indoor test facility. One driver for this is the customers' requirements for controlled environment securing their vehicle and sensor testing ability throughout the whole year independent on weather forecasts. Another goal is to pave the way for indoor rating tests, e.g. for Euro NCAP.

Concerning FFIs high-level objectives SPICE will contribute as follows:

- Increase the Swedish capability for research and innovation through further development of AstaZero, thereby ensuring competitiveness and jobs in the field of vehicle industry
- Promoting cross-industrial cooperation between different OEMs, TIER1s and RISE
- Creating pre-requisites for having an indoor test facility, which will strengthen AstaZero's competence and capability, which is an absolutely necessity for market introduction and human acceptance of autonomous functionality in vehicles produced by Swedish OEMs and TIER1s.

On the FFI-program level, Traffic Safety and Automated Vehicles, the contribution will be:

- Program area A "Analysis, Knowledge and enabling technology"
    - ✓ Studies and analysis of essential input of existing indoor test facilities.
    - ✓ Studies and methods for deciding which use cases that are relevant for autonomous vehicles.
    - ✓ Studies of relevant material for sensor testing required to copy outdoor conditions
- Program area C "Collision safety"
    - ✓ Verifying that integrated active safety solutions are being taken into consideration
- Program area D "Driver support and related interfaces between the driver and the vehicle, as well as interfaces with other road users"
    - ✓ Understanding and management of the interaction between road users and vehicles with different degrees of automation
    - ✓ Development of testing models for verification and validation
- Program area E "Intelligent and collision avoidance systems and vehicles"
    - ✓ Use of analyzed use case scenarios to increase the understanding of indoor requirements.
    - ✓ Use of test scenarios for verification and validation of autonomous vehicles.
- Program area G "Automated vehicles in the transport system"
    - ✓ Use of test scenarios for verification and validation of autonomous vehicles.

Program area D was not investigated due to priority and importance of other areas.

6 Result and deliverables

The result and deliverables are presented in this section for each work package separately.

6.1 State of the art investigation (WP2)

The following information in this section is based on presently published material for each test site and should be seen as a summary.

CEREMA and Sandia National Labs (Item 1-2 below) was investigated as part of Vinnova project Spray 2 (ref. 2015-04837) from a rain and fog perspective. A short summary of the indoors tracks from facility point of view has been included, please consult original source for additional information. During the SPICE project, the following additional sites was investigated (No 3-11 below).

1	CEREMA, Clermont-Ferrand laboratory France
2	Sandia National Labs, Albuquerque, New Mexico, USA
3	Insurance Institute for Highway Safety, IIHS
4	Test World, Ivalo – Finland
5	Arctic falls Piteå, Sweden
6	Karlstad Airdome, Sweden
7	Nukata, Japan
8	Shielded chambers RISE, Sweden
9	American Center for Mobility – Detroit area
10	CATARC, China
11	JARI, Japan

6.1.1 CEREMA, Clermont-Ferrand laboratory France:

Capability: The laboratory is built to produce fog and rain. It also has the possibility simulate different light conditions by using different degrees of transparent material as roof including:

a) “Completely” black to represent night
b) “Completely” transparent to represent daytime

Geometry: The laboratory is composed by two parts, one tunnel element attached to a wider “greenhouse” where transparency can be changed. The tunnel is 15 [m] long, 2.6 [m] internal height and 5.5 [m] wide while greenhouse section is 16 [m] long, 2.4 [m] internal height and 8.5 [m] wide.

6.1.2 Sandia National Labs, Albuquerque, New Mexico, USA:

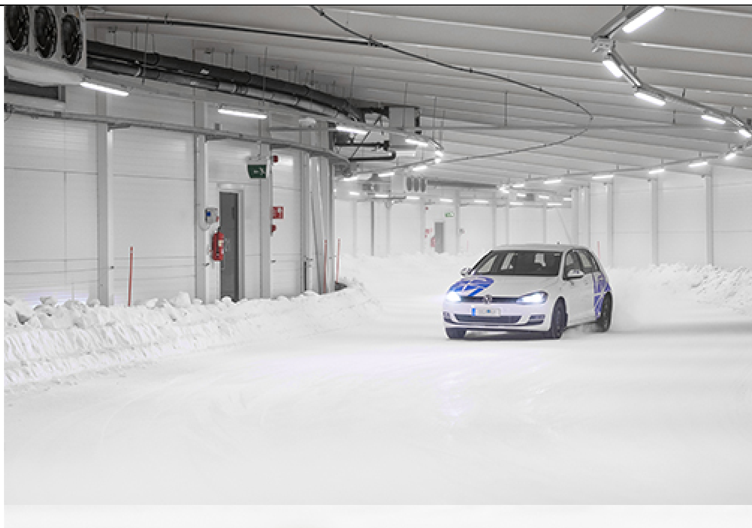
Capability: The facility is built to produce and control foggy weather condition inside chamber. Air curtains and rubber baffles are used to keep fog inside chamber. The walls of the chamber are painted with a special, black, paint to reduce unwanted reflectivity.
Geometry: The fog chamber is 54.86 [m] long, 3.05 [m] internal height and 3.35 [m] wide.

6.1.3 IIHS, Ruckersville – USA:

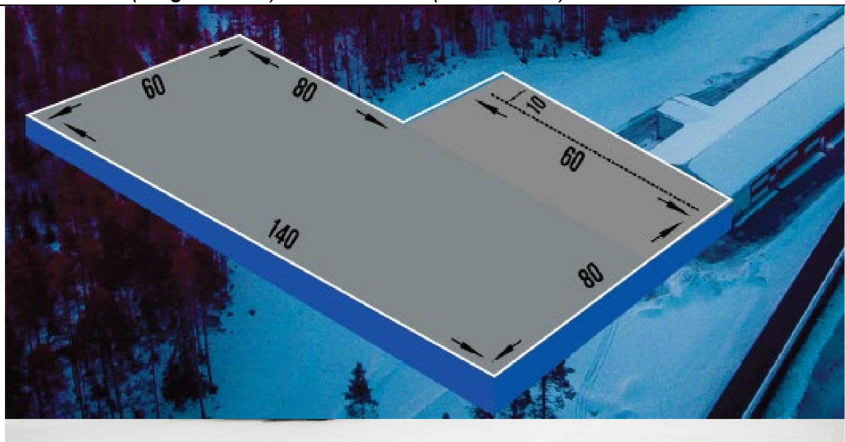
Test track name	*IIHS (Insurance Institute for Highway Safety)*
URL	http://www.iihs.org/iihs
Country City	*USA* *Ruckersville (near Baltimore)*
Indoor/Outdoor	*Semi-indoor*
Primary test activity	*Testing of front crash preventing systems and rating of headlight systems*
Construction of indoor element	*Steel trusses arcs, supported by large concrete piers, support the roof panels which covers the test track. No walls exist.*

Camera properties	*Might give strange light effects on sunny days with very bright areas around the building sides and less bright underneath the roof.*
Radar properties	*Large concrete piers might obstruct the radar. The track is however quite wide so it might have small impact when testing in middle.*
Track area	*213x91 [m]; height 35 [m]*
Picture	

6.1.4 Test World, Ivalo – Finland:

Test track name	*Test World*
URL	http://www.testworld.fi/tracks-and-facilities/indoor/
Country City	*Finland* *Ivalo*
Indoor/Outdoor	*Indoor*
Primary test activity	*Indoor 1 is flat with ice and snow for acceleration and braking work.* *Indoor 2 is a closed-circuit loop for snow handling tests.*
Construction of indoor element	*Walls (and ceiling in Indoor 2) appear to be covered in sheet metal. The ceiling in Indoor 1 has steel beams and frame work.* *Lightning system consists of fluorescent lamps.*
Camera properties	*Does not seem to have been taken into account.*
Radar properties	*Does not seem to have been taken into account.*
Track area	*Indoor 1: 160 x 16 m. Indoor 2: 350 x 9 m.*
Picture	

6.1.5 Arctic falls Piteå, Sweden:

Test track name	*Arctic Falls*
URL	http://www.arcticfalls.se/proving-grounds/indoor/
Country City	*Sweden* *Piteå*
Indoor/Outdoor	*Indoor*
Primary test activity	*Tyre development and testing. ABS braking test on ice and snow. Test on some driver assist systems.*
Construction of indoor element	*The first indoor track from March 2016 has wooden glulam beams and prewall isolation blocks in between. Low concrete frame in the bottom.* *New Indoor Flex (ready in June 2018) has the same prewalls but is built with steel body and is built in connection with the first indoor track. There are seven pillars inside the track area.*
Camera properties	*Sensor properties has not been taken into account for Indoor Flex.*
Radar properties	*Sensor properties has not been taken into account for Indoor Flex.*
Track area	*400 x 15 m (height 4.5 m) + 140 x 80 m (Indoor Flex)*
Picture	

6.1.6 Karlstad Airdome, Sweden:

Test track name	*Karlstad Airdome*
URL	http://www.karlstadairdome.com
Country City	*Sweden* *Karlstad*
Indoor/Outdoor	*Indoor*
Primary test activity	*Soccer*
Construction of indoor element	*The Airdome is built with tent-like walls/roof made from a double layer of a polymer composite membrane mainly consisting of layered PVC and polyethylene structures.* *The structure is held together each ≈12-15 m by metal clips along the seam.* *The Airdome is held up by overpressure inside the building maintained by big fans.*
Camera properties	*Not tested during visit the 17th of April 2018 but the lightning system used gave some glare on the walls' lower parts which could affect the vehicle camera systems badly.* *The present lightning system is developed for this specific site and it is up to the owner to produce its own system.*
Radar properties	*Measurements were taken by RISE in the Airdome and the results are predominantly positive with little obstacles disturbing the radar.*
Track area	*112 x 75 m (height 23 m)*

Picture	

6.1.7 *Nukata, Japan:*

Test track name	*Nukata Test track*
URL	Not available
Country City	*Japan* *30 min outside Kariya*
Indoor/Outdoor	*Indoors and outdoors. Information below refers to indoors facility (except pictures)*
Primary test activity	*ADAS development testing, especially for adverse weather (rain) at day time and night time condition.*
Construction of indoor element	*Walls covered with radar absorbent material till height of 3 [m]. Pedestrian area covered with radar absorbent material complete height of walls and ceiling. Water pipes with nozzles and lightning system all covered with radar absorbent material towards direction of vehicle approach. Lightning system consisting of 76 devices. Drainage system offseted to right side of approach. Drainage system made of stone tiles and not meta.*
Camera properties Radar properties	*Care taken to account for radar and camera properties. Despite this effort, engineer informed that some influence on sensor which made area unsuitable for rating testing but perfect for development testing.*
Track area	*Indoor: 150 x 10 m (approach); widens up into 26 x 48 m (ADAS test area). Height at approach from celling to radar absorbing material lower limit 3.0 [m]. At pedestrian test area at least twice as high as approach.*

Picture	

6.1.8 Shielded chambers RISE, Sweden:

Test track name	*RISE semi anechoic chambers Faraday and AWITAR*
URL	https://www.sp.se/en/index/services/emc-vehicle/sidor/default.aspx
Country City	*Sweden* *Borås*
Indoor/Outdoor	*Indoor*
Primary test activity	*EMC testing*
Construction of indoor element	*There are two large semi anechoic chambers with rolling highway at the RISE facilities in Borås. The walls and floors are made of metal and the inside of the walls are covered in RF absorbers on top of ferrite plates.*
Camera properties	*The camera properties have not been taken into account when constructing the chambers. All the light in the chambers is coming from the ceiling. In the old chamber, Faraday, the RF absorbers are dark and give little reflection even from the headlights of a car. In the newer chamber, AWITAR, the RF absorbers are largely made of styrofoam and white, but there appears to be very little risk of glare from them as well.*
Radar properties	*Testing with ADAS functions relying on an activated radar has been performed. The large, and rather flat, surface that is the walls of the chamber are quite well hidden behind the RF absorbers used, but still detectable by radar. As the dynamic range of most radars is limited this can be fixed by adding highly reflective targets in the perifery of the radar, a trick which cannot be considered a viable options for a more versatile test track. RF absorbers could however still be used to keep the background noise to a minimum.*
Track area	*AWITAR – 28 x 18 x 12 m (LxWxH), Faraday – 20 x 12 x 8 m (LxWxH)*

Picture	

6.1.9 *American Center for Mobility – Detroit area, USA:*

Test track name	*American Center for Mobility*
URL	*http://www.acmwillowrun.org/*
Country City	*USA* Willow Run in Ypsilanti Township, Michigan
Indoor/Outdoor	*Both*
Primary test activity	*Center for testing and validation, product development, education and standards work for connected and automated vehicles (CAV) and other technologies.* *ACM is one of the 10 proving ground pilot sites that the U.S. Department of Transportation (DOT) has designated to encourage testing and information sharing around automated vehicle technologies. To date, $110 million has been secured to construct the first two phases, and additional private investment announcements are expected soon. The next phase of construction will begin in the spring of 2018 and will feature an urban driving environment.* *The site is under building, with an ambitious final state, offering test possibilities in almost all areas, from off road, rural, highway, urban.* • *Very interesting site if all phases are done, due to diversity of infrastructure; interest for Trucks testing is TBC due to some weight limitation in several areas. Sounds that they ultimately will get a lot of driving situation available and possibility (driving robots as well).* • *But what's really differentiating/ on interest is that they have a will for a global approach* • *Testing infrastructure, including V2X capability, huge garage, office space* • *Work with Standard body (SAE, ITE, IEEE) in order to define scenarios for AVs validation. ACM have signed formal agreements with ITE and SAE to expedite the creation of voluntary standards for connected and automated vehicles, as well as associated technologies and infrastructure*
Construction of indoor element	*From movie, looks like ~200 [m] long slightly curved metal shell construction. Width estimated to ~3,6 x 2 + 1 + 1 [m] = 9.2 [m] and height 5 [m]*
Camera properties	
Radar properties	

Track area	*Length estimated to ~200 [m] slightly curved.* *Width estimated to ~3,6 x 2 + 1 + 1 [m] = 9.2 [m]* *Height estimated to 5 [m]*
Picture	

6.1.10 CATARC:

Chinese market was investigated but no information found

6.1.11 JARI - Japan:

No information.

6.2 User case (WP3)

The idea in this work package is to take the smallest common denominator from the rating protocols from now until 2025, add other stakeholders needs and get a list of dimensions and other requirements on the facility. Input is among other things the roll-out plan for Euro NCAP. As reason why so much focus on the Euro NCAP is that, that protocol is the protocol with highest demands today for vehicle rating and therefore here used as dimensioning.

6.2.1 Collision avoidance longitudinal - Cars

Functions regarded by input: AEB, AES, FCW
Taken into consideration is the following rating protocols: Euro NCAP, NHTSA, IIHS, CNCAP, and JNCAP.

Test track:
Area: >400 x 40 m + 400 x 8 m acceleration path (straight, aligned to test area and centered)
Friction: >0.9
Slope: <1%
Surface: no markings or irregularities
Visual Background: Contrast to target and homogeneous

6.2.2 Collision avoidance longitudinal – Trucks

Functions regarded by input: AEBS (Advanced emergency braking system)
Taken into consideration is the following legal requirements in ECE-131-01.

Test track:
Temperature: 0°C - 45°C.
Test surface: flat, dry concrete or asphalt surface affording good adhesion.
Area: 400 m acceleration + 240 m (straight, aligned to test area and centered)
Friction: >0.9 (TBD)

Slope: <1% (TBD)
Surface: as of testing today, lines are needed. For testing in future where robots might be more present no specific requirements
Visual Background: Contrast to target and homogeneous

Testing conducts of mainly two parts. Subject vehicle (VUT, vehicle under test) always with a speed of 80 kph, and target vehicle sometimes stationary, sometimes with the speed of 12 kph.

For the high-volume truck (460 hp) and loaded to a weight agreed between the manufacturer and the technical service (20 tons total weight), the distance needed for acceleration is 400 m (according to simulations and roughly estimate from test track).

It is the moving target test that will take the longest distance to perform. After correct speed have been acquired for the truck, some time for stabilization is needed and after that regulation states a stable scenario needs to be kept for 2 s, and the distance to target should be at least 120 m. That adds 160 m to the 400 m for acceleration. The whole AEBS test seems to take about 60 m (according to some logfiles from certification testing). Total distance as best estimation: 400 + 20 + 160 + 60 = 640 m

The width of the test is normally just one lane. For safety reason if the truck needs to steer away, at least two lanes are preferable. Testing today is done at AstaZero Multilane track.

6.2.3 Collision avoidance lateral – Cars

Functions regarded by input: LDW, LSS, EMA.
Taken into consideration is the following rating protocols: Euro NCAP, NHTSA, IIHS, CNCAP, and JNCAP.

Test track:
Area: >300 x 20 m + 400 x 20 m acceleration path (straight)
Friction: >0.9
Slope: <1%
Visual Background: Contrast to target and homogeneous

6.2.4 Collision avoidance lateral – Trucks

Functions regarded by input: LKS, (Lane Keep Support)
Taken into consideration is the following rating protocols: ECE-130-00

Test track:
Area: 300 m acceleration path (straight), and 400 m for test (both in a minimum 250 m radius curve, and in a straight)
Test surface: flat, dry concrete or asphalt surface affording good adhesion.
Friction: >0.9 (TBD)
Slope: <1% (TBD)
Visual Background: Contrast to target and homogeneous. Visibility conditions that allow safe driving at the required test speed. The test lane width shall be greater than 3.5 m.

The regulation states that the LDWS shall warn the driver if the vehicle crosses over a visible lane marking for the lane in which it is running, on a road with a directional form that varies between straight and a curve having an inner lane marking with a minimum radius of 250 m. That is the certification consist of two parts, straight line and in a curve. The velocity should be 65 kph and drift over the lines with different rate of departures. Both to right and left.

Test weight may be decided by manufacturer. If tests are done in conjunction with AEBS-certification, probably the same weight will be used as for those tests, that is 20 tons total weight. If that load is used, the distance for acceleration is 250 m, and for comfortable deceleration 55 m (with 3 m/s² deceleration), in total 300 m. The test sequence itself is estimated to be about 400 m to get some test result, in total roughly 700 m long. 2 lanes needs to be able to cross the line. The entire 700 m does not need to be in a minimum 250 m radius curve and the acceleration and braking can be at a straight line.

For the test in a straight line the entire 700 m needs to be straight (those requirements already set by AEBS-certification. Testing in curve is today made at curve on Rural road at AstaZero, radius is 320 m.

6.2.5 Lane markers - Cars

All alternatives below are of interest.

Euro NCAP LSS ELKx 2018 Surface: Lane markers 9 x 3 x 0.1 m dashed lane marking, continues lane marker 0.1 m wide, all lane markings shall be white, lane markers shall create lane widths of 3.5-3.7 m.

NHTSA LDW/LKS Surface: White/Yellow Dashed EU standard lane markers (3 x 0.1 m with 9 m separation). White/Yellow continues EU standard lane markers (0.1 m width). Bots dots type and pattern according to California Standard Plan A20A. Markers shall create lanes with 3.5-3.7 m width.

6.2.6 Lane markers - Trucks

The visible lane markings used in the lane departure warning tests shall be those of one of the Contracting Parties, with the markings being in good condition and of a material conforming to the standard for visible lane markings of that Contracting Party.

The visible lane markings identified below are assumed to be white, unless otherwise indicated. The Spanish lines are most difficult to detect and therefor those lines have been used for certification reasons.

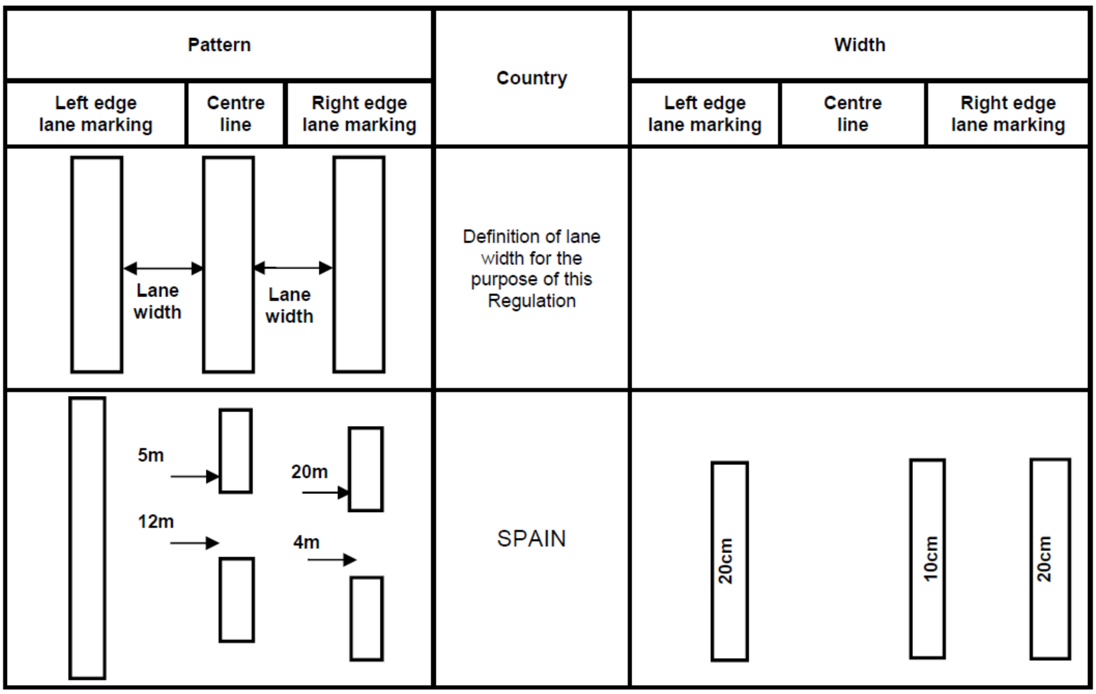


Figure 1. Lane marker patterns.

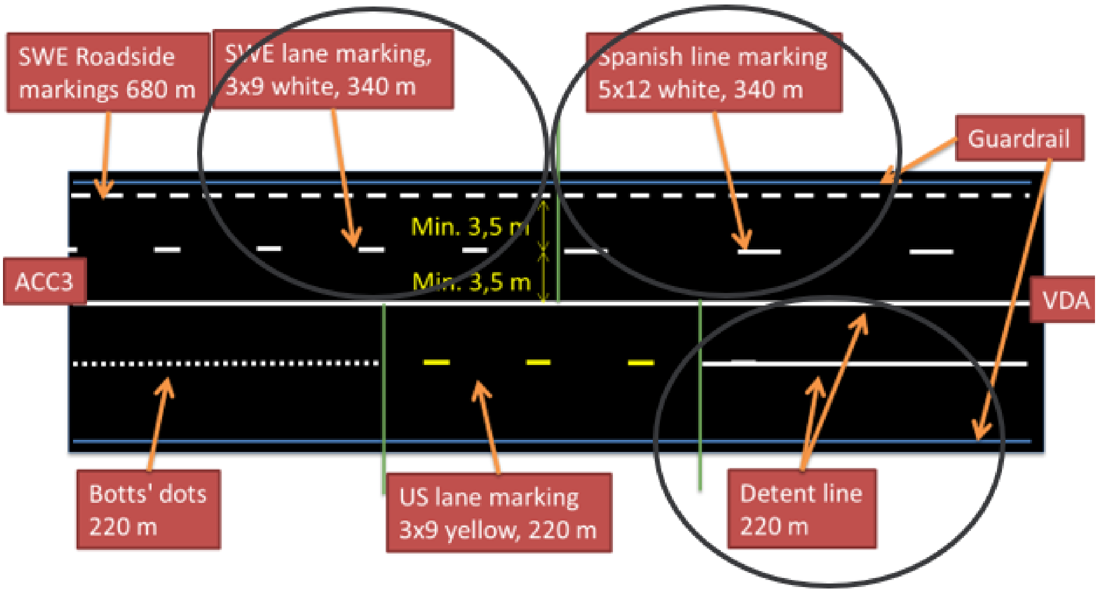


Figure 2. More lane marker patterns.

6.2.7 Intersections - Cars

Prio 1: Area for two paths:
1. 700 m x 20 m
2. 500 m x 10 m intersects path 1 in 90 deg angle

Path 1 crosses path 2 in the middle. When path 2 crosses path 1 it is at least 100 m left.

Prio 2: Not only 90 deg angles are of interest, including multi path intersection

Speed of target: 90 kph
Speed of Host: 130 kph
Friction: >0.9
Slope: <1%
Surface: Not completely defined yet, no markings or irregularities
Visual Background: Contrast to target and homogeneous

6.2.8 Parking

Prio 1:
The possibility to stage the facility as an in-door parking area with pillars and parking spots.

Prio 2:
Parking test area dimension 50x15m, see picture below.

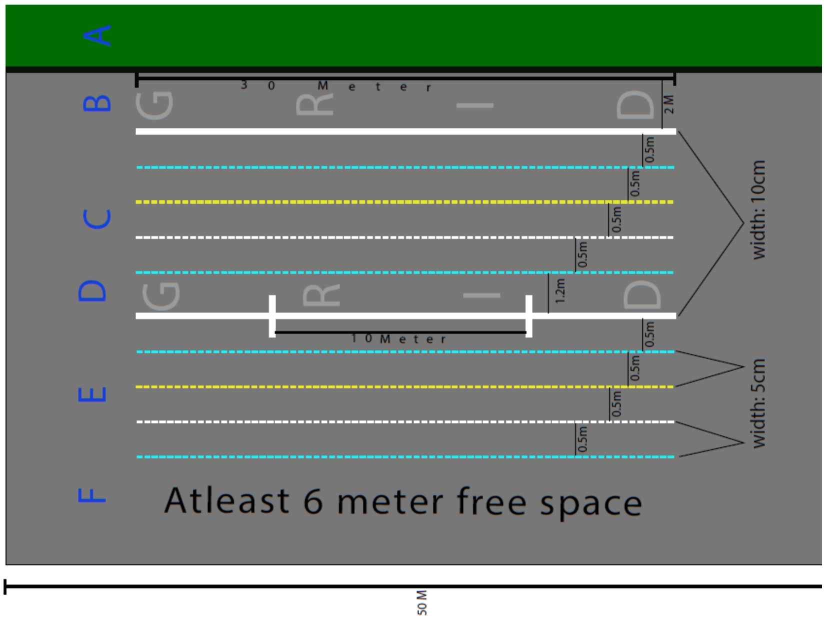


Figure 3. Parking test area.

6.2.9 ISO standards (curvature)

ISO standards mention demands for testing in different curvature radius (125 m, 250 m and 500 m) depending on vehicle performance class. Does not need to be performed in an indoor environment. Summary of different test cases' limitations/demands are presented below:

ACC (SS-ISO 15622:2010):
Speed demand up to 113 kph (radius 500 m)

FCW (ISO 15623:2002):
Speed demand up to the FCW system active speed maximum

LDW (SS-ISO 17361:2017):
Speed demand up to 80 kph

Need for national standardized lane marks

Testing for both right and left turn

LCDAS (SS-ISO 17387:2008):
Speed demand up to 72 kph for Target vehicle

Target vehicle is motorcycle with driver

FSRA (SS-ISO 22179:2009):
Similar to ACC above.

6.2.10 IIHS Head light

Area: 150 m radius curve (both left and right) for a length of 120 m at 65 kph, 250 m radius curve (both left and right) for a length of 120 m at 80 kph, and straightaway for a length of 250 m at any constant speed + 100 m acceleration. Speeds mentioned are valid for vehicles with active lighting systems only. Vehicles with static systems are tested at any constant speed.

Friction: >0.9
Slope: <1%
Surface: no markings or irregularities
Visual Background: less than 0.5 Lux

6.2.11 VRU blind spot information – Trucks

As of today, the regulations are not set, only a proposal, and therefore no certification test has been performed, and only a very rough estimation can be made. This will probably not be dimensioning for the test arena, since the speed will probably be low.

An estimation of acceleration up to 60 kph (250 m) plus some time for testing 200 m? and then perform a right turn (three lanes wide?). Rough total estimate: 500 m in three lanes?

6.2.12 Adaptive (glare free) head lights – Trucks

Functions regarded by input: glare free lights

Taken into consideration is the following rating protocols: ECE-48-06.

Test track area: 250 m acceleration path (straight), and 950 m for testing

As of today, no certification test for these regulations has been performed, and only estimations can be made. The test that requires the longest test track is to show that for oncoming traffic, we don't adjust high beam at longer distances than 750 m for. Test track longer than 750 m is needed, and at that instance need speed of around 60-70 kph is required for both vehicles. The test distance needed is at least 750 m, plus some more (200 m?), plus acceleration for truck (200 m?) and acceleration for car (50 m?). Total distance of around 1200 m.

We don't know anything about load on vehicles but guess that only subject vehicle needs to be a truck, and one passenger car can be used.

Will not go into detail of other tests needed for this. Will be covered within the distance of for example AEBS test.

6.2.13 AD SAE Level 2 systems

AD rating is still under development, so the following constitutes the best knowledge at the time being. In general, the discussions mention speeds from 60 kph to 130 kph for normal tests and a steering capability test where the vehicle shall be able to follow a 180 deg curve with radius of approximately 500 m. The radius might be lowered to 450 m to adopt to the existing test tracks. Different sources of information give speed between 80-130 kph. Normal tests are follow lead vehicle and cut –in/out scenarios method are under development.

6.2.14 Resulting requirements and dimensions

Light in the test facility shall resemble out door light in the respect that the sensors believe them to experience day, night, dawn or dusk. The rating protocol requires light condition as min lux and night with defined lighting. No unnatural shadows from the building or uneven light conditions that disturbs the sensors. Possibility to use street lights.

The sensors to take into consideration are the following automotive sensors:

- Radar (24 GHz and 77GHz) i.e. Automotive frequencies
- Camera
- Lidar
- Ultrasonic
- IR

It shall be possible to run tests with the precision and accuracy as stated in the protocols (RTK Integer). Also ground truth data from the test shall be available at the accuracy stated in the protocols. Robot equipped vehicles and other active safety equipment like pedestrian rigs etc., shall work in the indoor environment. Communication if applicable between the different test objects and target equipment shall work in all parts of the facility.

Other requirements:

- Friction: > 0,9 µ
- Slope: < 1 %
- Temperature:5 deg C – 40 deg C
- Surface: no markings, irregularities or metal parts except for lane markers or other road furniture when requested for test.
- Possibility to run EMC test on complete vehicle is a bonus.

A summary of the above protocols and test are presented in the table below.

User case	VUT	Test code	Frequency (% per year)	Importance (1-10)	Rating	Radius	Test area length (m)	Acceleration length (m)	Total length (m)	Test area width (m)	Lines needed	Requirement on surface and weather
AEBS	Truck	ECE-131-01	20%	10	2	No	240	400	640	15	Yes	yes
LKS (straight)	Truck	ECE-130-00	40%	10	4	No	400	300	700	15	Yes	yes
LKS (radius minimum 250m for 400m)	Truck	ECE-130-00	30%	10	3	Yes	400	300	700	200	Yes	yes
Adaptive head lights	Truck	ECE-48-06	20%	10	2	No	950	250	1200	15	No	yes
VRU blind spot (information only, not regulated today)	Truck	-	50%	8	4	No	250	250	500	15	No	yes
AD SAE level 2 systems (not regulated today, radius 500m)	Car	EuroNCAP	50%	6	3	Yes	1600	400	2000	500	Yes	
AEB, AES, FCW	Car	EuroNCAP	50%	10	5	No	400	400	800	40	No	
LDW, LSS, EMA	Car	EuroNCAP	50%	10	5	No	300	400	700	40	Yes	
AEB (90° crossing)	Car	EuroNCAP	50%	10	5	No	100	600 / 400	700 / 500	20 / 10	No	
Parking	Car	-	5%	1	0,05	No	50	0	50	15	Yes	
ACC, FCW, LDW, LCDAS, FSRA (curvature 125, 250 and 500m)	Car	ISO	5%	2	0,1	Yes	150	400	550	15	Yes	No
IIHS head light (straight)	Car	-	50%	10	5	No	250	100	350	15	No	
IIHS head light (curvature 150 and 250m both right and left turn)	Car	-	50%	10	5	Yes	150	100	250	15	No	

6.3 Material, optical and construction specification (WP4)

This work package was intended to investigate different possible materials and construction geometries and how these could affect the radar and optical sensors of vehicles tested on an indoor test track. Since some activities in the project were postponed there was a lack of input on demands and specifications for a long time in the project. The lack of limitations as to what structure types and sizes, as well as building materials, were feasible for the final indoor test facility also posed difficulties in setting up relevant simulations of candidate structures to identify possibly problematic properties thereof. For these reasons focus was instead put towards more generalized ways of suppressing or minimizing issues that might occur for indoor testing so that issues that might arise in the finally chosen structure could to the best extent be countered as they are uncovered.

Measurement methods for simple evaluation of radar absorbing materials were developed by RISE and some materials, that should be possible to easily add to existing structures for improved properties, were evaluated. Some analytical evaluation of the effect of geometry of typical construction elements, such as load carrying beams, was performed in a generalized way as to be able to work as a recommendation for the final construction.

One structure type which was at an early stage identified as interesting was the Karlstad Airdome mentioned in WP2. This was characterized more thoroughly both for radar and optical properties by RISE with the help of AstaZero. Furthermore, the availability of GNSS signals for positioning inside the structure was evaluated as this could eliminate the need of a separate positioning system for the indoor test track.

Another structure type found interesting was a traditional storage tent with steel framework. Together with Hallbyggarna Jonsereds we found a large example under construction for us to visit for testing and evaluation just prior to handover to their customer.

6.3.1 *Radar Absorber materials*

Most Radio Frequency (RF) absorbing materials are not specified up to the frequencies used for automotive radars. A measurement method for simple estimation of radar reflectance and absorption of different materials was thus developed at RISE in Borås. Some low-cost RF absorbers were acquired and evaluated and compared. The materials acquired were also chosen on the fact that they were relatively thin, flexible and thus likely possible to add to, attach to or dress specific structures of any shape and size, if said structures would show too high radar reflectance.

The low-cost flexible absorbers were compared to some other, more rigid, commercially available RF absorber, which is used e.g. in anechoic chambers, and that has been claimed to show high attenuation of radar signals. The best performing flexible RF absorber showed an attenuation of the radar signal of ~22 dB while the more rigid absorber showed an attenuation of at least ~41 dB (limit of the measurement set up). The application of the two could however differ and the flexible materials would likely be easier to work with and available at a lower cost and thus preferable in situations where it is deemed enough or the space is limited and larger, more rigid absorber are not feasible to use.

6.3.2 *Analytical evaluation of effect of construction beam geometries on RCS*

Analysis of structural elements was entirely made with regard only to the RCS (radar cross section) of plausible beams and girders as the length of these were not known. It was assumed that the most common types would be either H-/I- or T-shaped, with the resulting corners posing possible points of interest from a radar perspective, some form of square beam or round beam, such as structural tubing or pipes. The worst case for radar reflectance would probably be a perfect conductor, and since the material is not known this was assumed. As an example, for easy comparison, the analytical RCS of an H-beam measuring 0.4 x 0.4 x 5 m is calculated and compared to geometries where that same element is somehow covered. No analysis to the structural capacity of the different structures has been made and this should only be seen as an indicator of how the geometry chosen could affect the radar properties. The RCS is only calculated for angles of incidence between 0-90° as they are assumed to be placed along the walls and have symmetry along the possible viewing angles.

Beam profile	**Minimum RCS (approx.) [dBsm]**	**Maximum RCS (approx.) [dBsm]**
H	60	70
Circular	40	50
Rectangular	-9	65
Triangular (equilateral)	-7	70

As can be seen there is quite a large difference in maximum and minimum RCS for some profiles. This largely depends on the angle of incidence. If there are some angles where a large reflection is acceptable these could thus be of interest. The circular- and H-profiles however would likely yield large reflections in all direction, even though they would be significantly smaller for the circular profile. Triangular beams oriented with one corner pointed directly towards the outside of the wall would likely only yield a large reflection when the radar is looking straight into the wall. If triangular beams (or covered T-beams) are not feasible, structural elements with a trapezoid profile could perhaps be constructed. They would be a compromise between the rectangular and triangular shape likely giving smaller reflections than the rectangular profile for most angles.

As a comparison typical Radar Cross Section values are show in the table below.

Target	**Typical RCS [dBsm]**
Person	0
Bicycle	3

Car	20
Truck	23

It should be noted that the reflections calculated for the theoretical structural elements only account for the directly backscattered energy. If e.g. there are several vehicles on the test track, they could in turn also act as radar reflectors sometimes yielding secondary reflections and thus still be detected by the radar.

6.3.3 Radar measurements – Karlstad Airdome

The Karlstad Airdome was evaluated using an automotive grade radar that was placed at stationary positions and connected to a computer recording what it was detecting. Measurements were made both looking straight into the walls of the structure as well as looking along the walls at different distances to get a grasp of how much the structure that could be visible in different scenarios as well as set up some form of minimum distance to the walls where at which radar tests could be expected to give accurate results.

The measurements showed that the structure itself appeared to yield only small reflections with the concrete anchoring seemingly being the biggest contributor to reflections. The anchoring at the Karlstad site is made of concrete and sticks up about 0.6 m above the ground. According to the manufacturer the entire anchoring could instead be placed in the ground in which case it should likely not pose an issue. Any test track (indoor or outdoor) would also likely be surrounded by a safety barrier which would also yield large radar reflections and as this apparently is not an issue for the outdoor test tracks it would be unreasonable to expect stricter demands on an indoor equivalent. Buildings and structures on the outside of the Airdome were also clearly visible by radar from the inside indicating good radar transparency of the membrane, but also emphasizing the need to plan the layout of structures around the indoor test track so that other buildings do not disturb the testing.

Other parts of the structure that proved to yield large radar reflections were the air locks and the ventilation structure which also supports the entire Airdome. If this type of structure would be chosen those parts would have to be placed in areas where they would not disturb the tests or testing would have to be planned with those parts in mind. This issue has been discussed with the manufacturer and should be possible to solve.

6.3.4 Optical – Karlstad Airdome

A light blocking version of the membrane material similar to that in the Karlstad Airdome was evaluated for transmittance and reflectance at the optics lab at RISE in Borås. The results showed that the transmittance of the material was low enough to, at least on cloudy days, block enough light to reach light levels specified in WP3. On very bright and sunny days there is however a risk of it not being sufficient to create night like conditions. The reflectance of the inside of the membrane is also quite high (80-90% in the visible range) which perhaps could pose a problem if it e.g. through reflection helps to spread the light from vehicle head lights, possibly causing glare or destroying the dark conditions of the entire track.

6.3.5 GNSS – Karlstad Airdome

The GNSS signal inside the Karlstad Airdome was evaluated by driving a small radio-controlled car, initially developed by RISE in the FFI project iTransit, with a GNSS-receiver around the inside of the structure and recording the signal to noise ratio (SNR) for the different GNSS satellite systems. This was in turn compared to the SNR recorded by the same system on the outside of the structure. The results do not indicate any large difference in signal between the inside and outside of the structure.

6.3.6 *Comparison of indoor and outdoor testing - Lysekil*

Indoor tests were executed in the tent building in Lysekil (Hallbyggarna) to look for what kind of issues indoor environment might cause to sensor functions. Some tests were repeated at an outdoor proving ground (AstaZero) in order to compare results and understand what differences there might be between indoor and outdoor environment. The results should be considered at designing an indoor test facility.

Indoor tests – car

A sensor car (Host vehicle) equipped with forward looking radar (FLR), four side radars (one radar positioned in each corner of the car) and a vision system, executed tests described in EuroNCAP 2018, 2020 and (likely) 2022 year's protocol.

Pedestrian/bicyclist dummy was travelling in longitudinal direction or crossing the Host vehicle path.

Turning scenarios crossing pedestrian/bicyclist path were executed.

Driving towards stationary vehicle dummy was also tested.

A robot system did control Host vehicle speed and steering as well as the VRU propulsion in order to maintain a collision scenario in a highly repeatable way. The robot system was configured to brake and stop the vehicle to avoid impacting the dummy.

Indoor tests – car – Results

Looking at radar analysis, a more cluttered target signature was observed in comparison with the outdoor test, probably caused by the indoor environment.

There is also an increased "multi-path reflection phenomena", such that the radar return also travels other paths than straight back, reflected by obstacles in the environment.

Looking at the Vision analysis, the bumpy road (or slope variations) caused issues to the position estimation.

Indoor tests – truck

A sensor truck (Host vehicle) equipped with side radars and vision system executed tests involving a bicyclist.

The sensors are mounted at higher level on the truck compared to a car.

Indoor tests – truck – Results

No issues impacting the major test case result were experienced during these tests.

At analysis, radar returns coming from the structure of the building, mainly metal parts in the walls, but also other wall parts, can however clearly be seen.

Since no issues different from indoor test with car was seen, no outdoor truck tests were executed.

Outdoor tests – car

Some of the Euro NCAP VRU tests executed by car indoor were repeated at an outdoor proving ground (High Speed Area at AstaZero). The weather was clear, giving proper daylight. Temperature was however low causing some parts of the test track having a thin layer of ice. So, EuroNCAP required conditions were not fully met.

Outdoor tests – car – Results
The radar results were different compared to indoor tests, e.g. a more reasonable RCS (Radar Cross Section) response across range was observed.

The vision result for position estimation was not distorted since the road was more flat and non-bumpy, compared to the indoor tests.

Summary and conclusion
The three main conclusions from running and comparing indoor and outdoor tests using radar and vision detection systems are:

- Radar noise level may be higher in indoor facility. Some radar systems might fail to detect some objects or detect the objects late.
- Radar multi-path reflection phenomena are seen indoor. Some radar systems might falsely report several objects at different positions that truly is one and the same object.
- A bumpy road or slope variations may impact the position estimation in a vision system and deviate from outdoor EuroNCAP radar signature.

Recommendations
Further investigation should aim for understanding how to keep the radar noise level low in the indoor test facility. There should potentially be several methods, like using radar absorbing material, covering critical parts with radar absorbance material/paint, or designing the shape of construction parts to avoid radar critical reflections.

The road should be flat to avoid vision position estimation as well as having a similar radar signature to the outdoor environment, were the road surface is flat.

6.4 Testing and verifying (WP5)

This work package has involved visits to potential tent alternatives from two different manufacturers, DUOL Airdome and Hallbyggarna Jonsereds. Both have the ability to build tents potentially large and wide enough for an indoor vehicle testing facility. Measurements and analysis have been made from both sites. No temporary test area has been built up on AstaZero during the project as was intended from the beginning. Since real tent alternatives were found it was decided that closer investigation of existing structures was a more rational use of resources and would benefit the project more.

6.4.1 Karlstad Airdome

The Karlstad Airdome was in WP2 found to be a possible candidate for a structure type usable for indoor testing. For this reason, AstaZero and RISE went there to do a field investigation. The main property of interest was the radar performance and what the radar properties of the structure itself were. On top of this there was an additional investigation of how well GNSS signals inside the structure compared to ones outside it.

The Airdome is an air supported structure manufactured by the company DUOL. Air supported means there are no real supporting structures and the entire structure is dependent on an over pressure supplied by a constant inflow of air through a system of fans. The Structure is thus tent-like with the walls/roof made from a double layer of a polymer composite membrane mainly consisting of layered PVC and Polyethylene structures. The membrane appears to be made in quite large sheets, but in some places, it is stitched/bolted together by metal clips.

Normally the Karlstad site is used for football and the ground there is some form of AstroTurf with the slight curvature usually found on football fields to lead water from the center of the field towards the edges.


Figure 4. Inside the Karlstad Airdome.

The results from this site visit regarding radar and GNSS properties are presented in section 6.3.3-6.3.5.

The cost for this type of tent is unfortunately quite high due to a large area of expensive membrane material and concrete anchor all the way around the tent in order to support the large stretch forces. Additionally, the lighting system required must be ground based and provide indirect lightening since the ceiling and walls cannot carry any load. This increases the number of lighting sources needed to achieve Euro NCAP lighting requirements.

6.4.2 Hallbyggarna Jonsereds

A colleague at AstaZero drove by a large tent on the countryside and we contacted the company where it stood. They rented the tent from Hallbyggarna Jonsereds who were thus contacted, and a site visit was arranged. The tent was 40 m wide, 200 m long and about 12 m high (in the middle) covered in two layers of polymer composite membrane held up by steel frame work. This looked like a good alternative for conducting test, however the tent was full of goods so Hallbyggarna Jonsereds looked for other options. The radar and camera results from Lysekil are presented in section 6.3.6.

Finally, they found a tent under construction in Lysekil constructed like the other one we've visited but also with isolation material in between the two membrane layers.

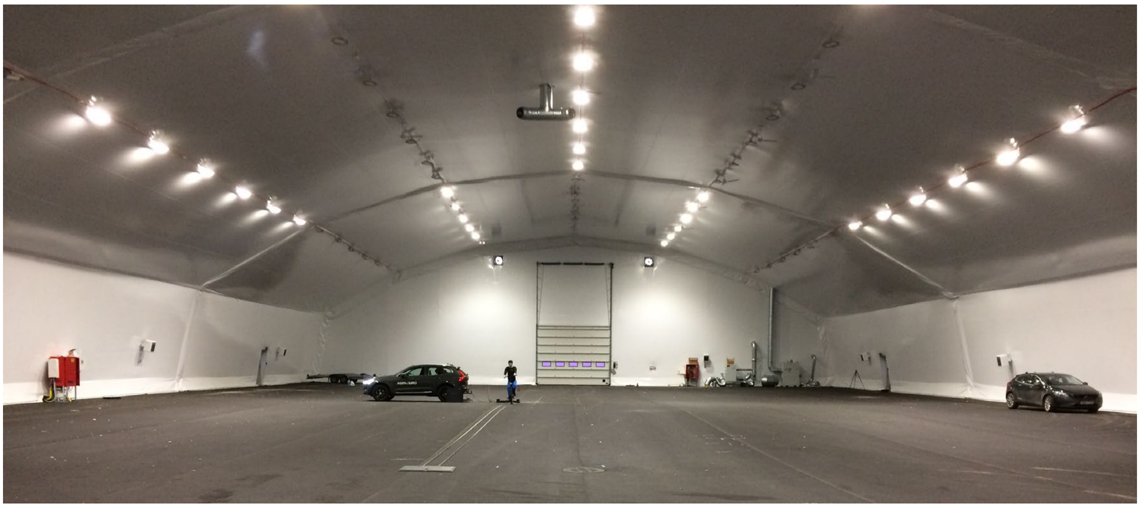


Figure 5. Inside the storage tent tested in Lysekil.

In mid-December we could spend a full week there together with Aptiv, performing lots of different Euro NCAP tests with a fully equipped Volvo V40. It had an ABD steering/acceleration/braking robot, GPS positioning system and camera and radar sensors installed. We drove against stationary ADAC target and DRI target and moving pedestrian and bicycle target pulled by an ABD soft pedestrian target rig.

The performance of the RTK motion pack from OxTS is of great interest since we depend on high GPS accuracy during our tests for controlling the ABD robot. It had some issues getting proper GPS signal probably due to the steel frame work in the ceiling resulting in multipathing GPS signals. Also, the two layers of membrane and isolation in between could result in poor signal strength The RT3003 creates an RD file each time it powers up and logs all data here while operating.

Two RD files (from Dec. 11 and Dec. 12) were extracted from the motion pack, and one was analyzed here. We've looked at two random tests; AEB at 10 kph and VRU at 20 kph, driving along the tent about 5 m from the center line. The signals of most interest are position accuracy [m] and UMAC signal [-]. The UMAC signal is sent to the ABD robot and indicates the status and accuracy of the RT3003 combining a number of signals. The UMAC status value nine (9) indicates best position accuracy which is needed for e.g. Euro NCAP tests.

The green line in the pictures below are the forward speed [kph] of the VUT. The red line is the GPS accuracy [m] and the red dotted line is the UMAC status.

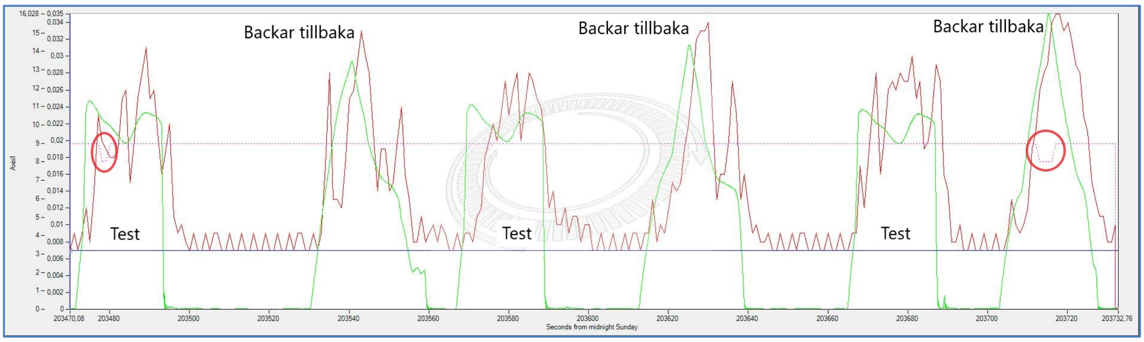


Figure 6. GPS analysis for AEB tests at 10 kph. See explanation below.

Figure 6 shows three tests including the movement back to the start position. UMAC status is kept at value 9 during all three tests except for two occasions where it goes down to value 8. The position accuracy north is below 0.01 m while standing still and goes up to about 0.03 m during movement.

Figure 7 show five tests including the movement back to the start position. UMAC status is kept at value 9 during test 1, 2 and 4 but goes down to value 8 for the remaining tests and also in between. Probable cause is multipath GPS signal and disturbance from metal construction and obstacles inside the tent (e.g. parked construction lifts and vehicles). The position accuracy north is below 0.01 m while standing still and goes up to about 0.04-0.06 m during movement.

Despite that the GPS system had some issues, the ABD robot worked quite well in this environment with path error and robot control within expected intervals. Path following was very good for all test cases except for Ped tap radius 9 m. This is however a very hard test with a tight turn on a small radius. The path following error stayed within 5 cm. We did not perform any extensive robot tuning on site due to time constraints but might have gotten a bit better result if we would have had time. High speed accuracy and low speed error was difficult to obtain due to

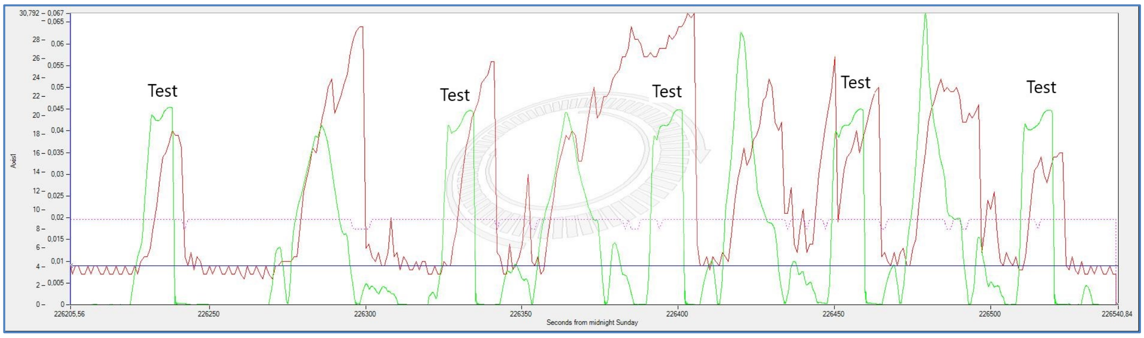


Figure 7. GPS analysis for VRU tests at 20 kph.

the two manholes located in the middle of each half of the tent which caused large tilt on the surface. It can also be seen in the roll and pitch angle diagrams for the AEB tests that were driven on both right and left side of the tent center line. The surface and insufficient tuning might also have influenced SR velocity (°/s) which is shifting.

In Figure 8 below taken from AEB tests in 10 kph shows:

- Path error within ±5 cm is shown in the diagram in upper left corner
- Speed control in the upper right corner shows large variations due to ground surface irregularities, as expected since the ground tilt toward the draining gutters. This can also be seen in the two diagrams down to the right that shows the car's pitch and roll.
- Steering robot velocity is seen in the lower left diagram

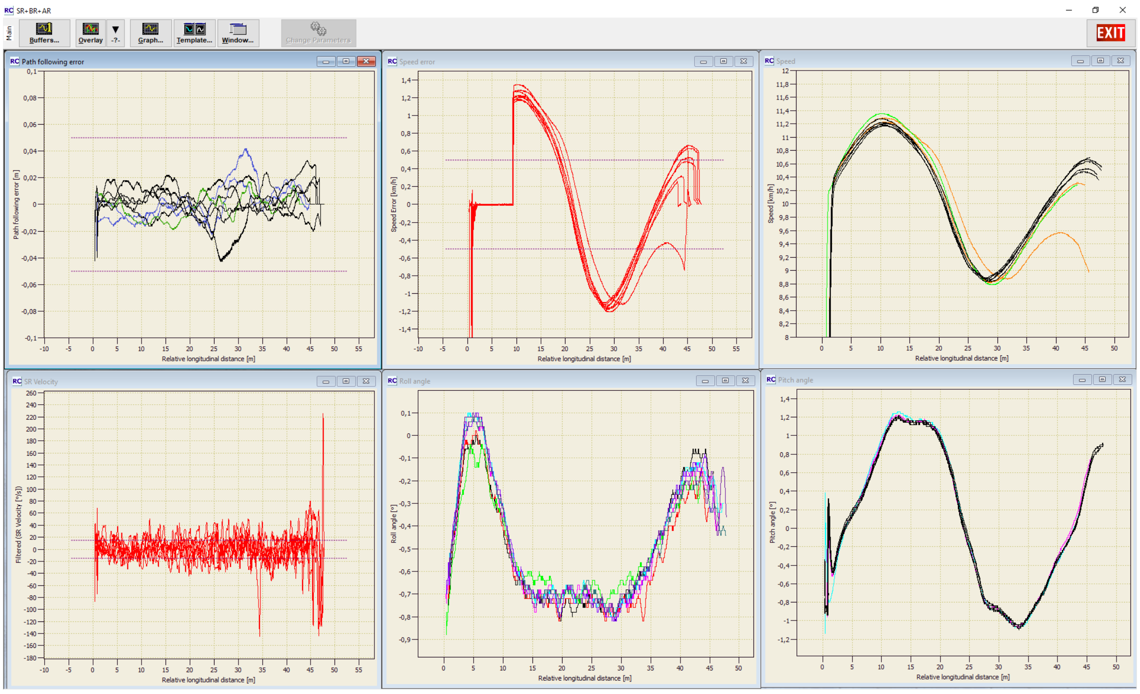


Figure 8. ABD robot data analysis for AEB tests at 10 kph.

6.4.3 Example of track dimension and geometry

After having all input from use cases, we tried to suggest of track dimension and geometry that would cover most use cases. The example shown below is very large and complex and it would require expensive construction designs. In the end, after more work, it might result in a simple rectangular facility if the costs become too high. It is important to consider which use cases that are of highest importance and most frequently performed.

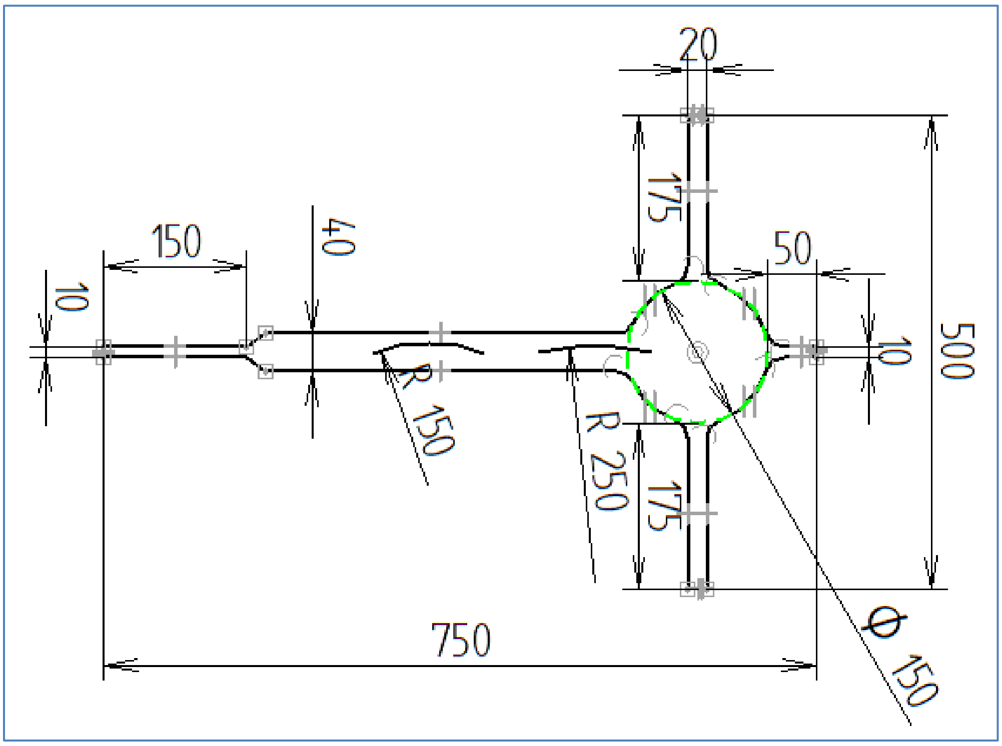


Figure 9. Example of indoor track dimension and geometry.

7 Dissemination and publications

7.1 Dissemination

How are the project results planned to be used and disseminated?	Mark with X	Comment
Increase knowledge in the field	X	
Be passed on to other advanced technical development projects	X	Continued planning and specification of a permanent indoor facility for verification of active safety.
Be passed on to product development projects	X	
Introduced on the market		
Used in investigations / regulatory / licensing / political decisions		

7.2 Publications

No publications from the project have been made.

8 Conclusions and future research

The project has generated valuable knowledge and information regarding sensor properties, dimensions, geometry and equipment needed for indoor vehicle testing. This will contribute when conducting further investigation of solutions for an indoor vehicle test track investment. We will take measures for providing the proper, optimal and cost-efficient construction and equipment solution in order to have outdoor-like properties and environment.

Further research must be done within the area of having high accuracy on positioning system so the vehicles can operate properly and make testing repeatable and accurate. Systems for simulating/repeating GNSS position is available from e.g. Locata and will be further investigated. It might also be investigated on how to make our own inhouse system for this purpose.

How to keep radar noise levels low in an indoor environment must also be further investigated. Solutions might be radar absorbing material, absorbance paint or construction designs.

9 Participating parties and persons

The following companies and persons have been part of the project:

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