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## Introduction

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| 1  | 2                                          | (3)                          | 4               | 5                                                                                                                                  | (6)                                                                      | 7                                                  |
|----|--------------------------------------------|------------------------------|-----------------|------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------|----------------------------------------------------|
| MB | Clause No./ Subclause No./Annex (e.g. 3.1) | Paragraph/ Figure/Table/Note | Type of comment | Comment (justification for change) by the MB                                                                                       | Proposed change by the MB                                                | Secretariat observations on each comment submitted |
|    | 3.1                                        | Definition 1                 | ed              | Definition is ambiguous and needs clarifying.                                                                                      | Amend to read '...so that the mains connector to which no connection...' |                                                    |
|    | 6.4                                        | Paragraph 2                  | te              | The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK. | Delete reference to UV photometer.                                       |                                                    |



# DRAFT International Standard

## ISO/DIS 22133

### Road vehicles — Test object monitoring and control for active safety and automated/autonomous vehicle testing — Functional requirements, specifications and communication protocol

*Véhicules routiers — Surveillance et contrôle des objets de  
test pour l'évaluation de la sécurité active et des véhicules  
automatisés/autonomes — Exigences fonctionnelles,  
caractéristiques et protocole de communication*

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## Foreword

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This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 33, *Vehicle dynamics, chassis components and driving automation systems testing*.

This document cancels and replaces ISO/TS 22133:2023 which has been technically revised.

The main changes are as follows:

- Test coordinate system updated ([6.3.2](#))
- Local test object and global geofence updated ([7.2](#))
- Redesign of test object and control centre state diagram ([9.2](#) and [9.3](#)))
- Extended MONR-struct with StopTrigger, ObjectAction, etc
- Increased position accuracy (MONR, TRAJ, GEOF)
- Monitoring mode
- DRES message increased (added supported modes)
- Update diagrams (Estop, NormalStop, ...)
- Introduced normal stop by a test object
- Object discovery detection
- Added dynamic position point message

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at [www.iso.org/members.html](http://www.iso.org/members.html).

## Introduction

Testing of collision avoidance systems, active safety functions and more advanced autonomous functions in vehicles require testing on proving grounds. The purpose is to expose the vehicle under test to potentially dangerous traffic situations in a safe manner. The evaluation is done during development and in voluntary and mandatory test procedures.

To orchestrate these traffic scenarios, various impactable targets representing traffic actors are controlled. The number of controlled targets can be one or many depending on the required traffic situation scenario. Several requirements are important ranging from safety to position and speed precision, to logging capabilities.

This document specifies requirements, functionality and a protocol allowing for multivendor target carrier systems to be controlled according to the required traffic situation scenario, to report expected information for logging purposes and other functions required.



# Road vehicles — Test object monitoring and control for active safety and automated/autonomous vehicle testing — Functional requirements, specifications and communication protocol

## 1 Scope

This document specifies requirements, procedures and message formats for controlling and monitoring of test objects, used for testing of active safety functions and autonomous vehicles.

This document specifies functionality and messaging for monitoring and controlling of test objects by a control centre facilitating an interoperable test object environment. This document defines a communication protocol which allows for the control centre to safely execute tests using test objects from multiple vendors.

This document does not specify the internal architecture of the test object nor control centre.

This document does not specify how testing of the vehicles shall be performed.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 8601 (all parts), *Date and time — Representations for information interchange*

ISO 8855, *Road vehicles — Vehicle dynamics and road-holding ability — Vocabulary*

## 3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

### 3.1 test object

entity, as defined in ISO 34501, part of a traffic scenario under monitoring and control by the *control centre* (3.5)

Note 1 to entry: Two types of test objects exist; moveable and *stationary test objects* (3.4).

Note 2 to entry: A test object can have several attributes, see [Figure 1](#).

[SOURCE: ISO 34501:2022, 3.7]

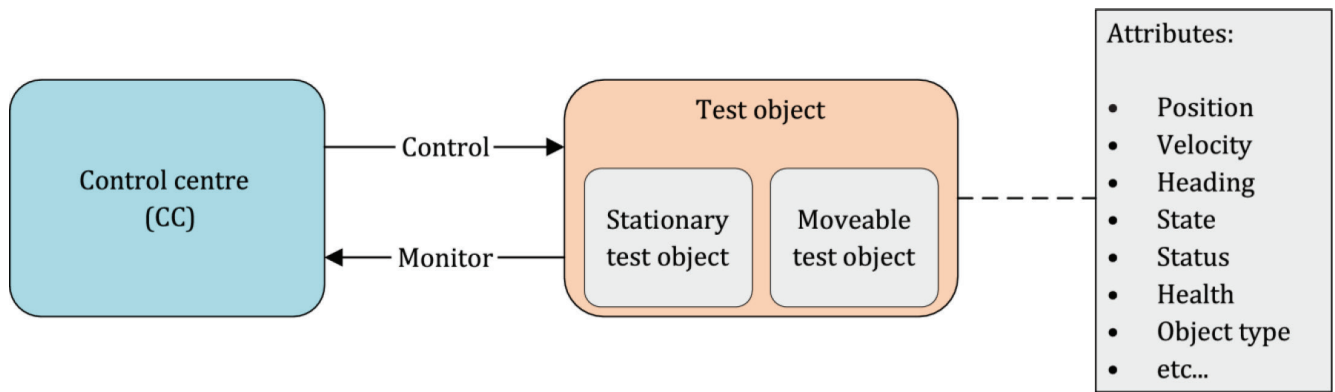


Figure 1 — Relations and inheritance view

### 3.2 subject vehicle SV

vehicle with active safety system to be tested and evaluated

Note 1 to entry: The subject vehicle, SV, is also known as vehicle under test, VUT.

Note 2 to entry: There can be one subject vehicle (standard setup) or a set of subject vehicles in the specific traffic scenario.

Note 3 to entry: The subject vehicle can be under safety-driver control and/or under *control-centre* (3.5) control.

Note 4 to entry: The subject vehicle is an instantiated *test object* (3.1) in either type of: *stationary test object* (3.4) or *moveable test object* (3.3).

### 3.3 moveable test object

object under control by the *control centre* (3.5) which has the capability of activation of physical movement

Note 1 to entry: Various levels of control are possible: open-loop control (using no feedback from the real-time activities of other *test objects* (3.1) or environment) and closed-loop control (taking into account activities of other test objects in real-time and environment). One other type of controlling/triggering is related to test object unique features like: turn indicator, headlight beam, etc.

### 3.4 stationary test object

part of a traffic scenario, which is not moveable but can be under control by the *control centre* (3.5)

Note 1 to entry: Different stationary test objects can exist. Normally they are divided in to two groups: Active and passive stationary test objects.

EXAMPLE 1 Active stationary test object: Traffic light, lighting, rain/snow/fog simulator.

EXAMPLE 2 Passive stationary test object: Elements of construction area such as road signs, guardrails.

### 3.5 control centre CC

centralized or distributed service for *test object* (3.1) control and safety monitoring including provision of communication services to the test objects

### 3.6 path

set of local or global positions in respect to a point of origin and in respect to the orientation to the axes of a defined coordinate system (x,y,z)

**3.7****lateral path deviation**

position error of the target vehicle relative to the planned *path* (3.6) measured perpendicular from the planned path direction

[SOURCE: ISO 19206-3:2021, 3.8, modified — Notes to entry and figure removed.]

**3.8****trajectory**

*path* (3.6) where a *test object* (3.1) is or is intended to move along including test object dynamics

Note 1 to entry: A trajectory contains a path and additionally the test object dynamics (such as time, yaw, velocity, acceleration, etc.) for each position on the path.

Note 2 to entry: All test object parameters related to test object dynamic (e.g. limitations in acceleration) are described in the corresponding DIDX file.

**3.9****static trajectory**

offline pre-planned *trajectory* (3.8) including *test object* (3.1) position and test object motion dynamics for a single *moveable test object* (3.3) as part of the *test scenario* (3.11)

Note 1 to entry: The trajectory is downloaded to the test object utilizing the trajectory object message (TRAJ).

Note 2 to entry: The parameters used by the test object are described in the DIDX file.

Note 3 to entry: The *control centre* (3.5) can extract information from the trajectory file and builds a trajectory message, TRAJ, that is received by the test object before start of test.

**3.10****dynamic trajectory**

*trajectory* (3.8) which at the start of the scenario execution is not known by the *test object* (3.1) nor the *control centre (CC)* (3.5)

Note 1 to entry: The dynamic trajectory is created based on events and actions during the ongoing test.

Note 2 to entry: The dynamic trajectory is continuously sent by the CC or gated through the CC in smaller pieces/fragments utilizing the trajectory object message (TRAJ).

Note 3 to entry: In the case where the test object or other system (e.g. a simulation environment) is generating the dynamic trajectory, this information is sent to the CC and then from the CC to the test object.

**3.11****test scenario**

scenario, as defined in ISO 34501, including all *test objects* (3.1), moveable and stationary, and the definition of the planned activities over time or/and location

Note 1 to entry: The traffic scenario can be formally represented by two complementary descriptions enabling test execution, a *scenario description* (3.12), and a map of the test area.

[SOURCE: ISO 34501:2022, 3.4]

**3.12****scenario description**

textual representation of a scenario

Note 1 to entry: A scenario description can be used in combination with a *scenery description* (3.13) to generate *trajectories* (3.8) (static or dynamic) by the *control centre* (3.5) or a *test object* (3.1).

EXAMPLE      *Test scenario* (3.11) described using OpenSCENARIO or iSCAML [17].

### 3.13

#### scenery description

representation of the test area limited to the road geometry (e.g. lanes and junctions) and *stationary test objects* (3.4) (e.g. road signs and markings)

Note 1 to entry: A scenery description can be used in combination with a *scenario description* (3.12) to generate *trajectories* (3.8) (static or dynamic) by the *control centre* (3.5) or a *test object* (3.1).

EXAMPLE Temporary lane-setup on a proving ground, described using OpenDRIVE.

### 3.14

#### safety speed limit

maximum allowed speed when repositioning *moveable test objects* (3.3) while not participating in ongoing test

Note 1 to entry: The *test object* (3.1) is manually driven with the remote control functionality or automatically driven when outside the test execution phase.

### 3.15

#### device ID

unique identifier for each *test object* (3.1) and *control centre* (3.5) in the test setup

Note 1 to entry: The device ID number is used as transmitter ID or receiver ID in every message except when tunnelling data.

### 3.16

#### message gating

mechanism to gate messages from a sender to a receiver defined by the transmitter ID and receiver ID in the message header

### 3.17

#### dynamic position point

#### DPP

position that moves in time relative an origin and defines the momentary destination

Note 1 to entry: Further explanation is given in [Annex E](#).

## 4 Abbreviated terms

|       |                                                             |
|-------|-------------------------------------------------------------|
| ASP   | Adaptive Synchronization Point                              |
| DIDX  | Device Interface Description XML                            |
| CC    | Control Centre                                              |
| DPP   | Dynamic Position Point                                      |
| ECEF  | Earth-Centred, Earth-Fixed (geographical coordinate system) |
| GNSS  | Global Navigation Satellite System                          |
| GPS   | Global Positioning System (one constellation of GNSS)       |
| ISE   | Infrastructure Elements                                     |
| NTP   | Network Time Protocol                                       |
| NTRIP | Networked Transport of RTCM via Internet Protocol           |
| OWD   | One-Way Delay / End-to-end delay                            |
| PGRS  | Proving Ground Reference System                             |

|       |                                                                                                                         |
|-------|-------------------------------------------------------------------------------------------------------------------------|
| PTP   | Precision Time Protocol                                                                                                 |
| RPM   | Reference Point Marker (geographic reference point on the proving ground)                                               |
| RTK   | Real Time Kinematic                                                                                                     |
| SCT   | Soft Crash Targets                                                                                                      |
| SOW   | Second Of Week (in respect to GPS time)                                                                                 |
| SV    | Subject Vehicle, also known as VUT                                                                                      |
| TAI   | International Atomic Time                                                                                               |
| TCP   | Transmission Control Protocol – Connection oriented communication between a server and client                           |
| TSV   | Traffic Simulation Vehicles                                                                                             |
| TRUE  | Equal to 1 in bitwise operation                                                                                         |
| UDP   | Used Datagram Protocol - Connectionless communication model                                                             |
| UTM   | Universal Transverse Mercator (a two-dimensional Cartesian coordinate system for locations on the surface of the Earth) |
| VUT   | Vehicle Under Test                                                                                                      |
| WGS84 | World Geodetic System 1984                                                                                              |

## 5 Test scenario illustration

The illustration of a test scenario in [Figure 2](#) is used as an example to explain a possible test scenario with various test objects. The test objects present in the example scenario are categorised in types and sub types in [Table 1](#). The example does not include all possible test objects and scenarios referred to in this document.

To be able to achieve the following scenario, several different mechanisms can be used to control and monitor all different test objects, which will be described later in this document. Some or all test objects can be controlled by a CC but may also be controlled by a safety driver or by an integrated controller. All test objects are always monitored by the CC.

A test scenario is normally described in a story board or segment description.

**Table 1 — Test object type categorization example**

| Test object type        | Test object sub type                            | Illustration                                                                          |
|-------------------------|-------------------------------------------------|---------------------------------------------------------------------------------------|
| Stationary test objects | Active infrastructure elements (A-ISE)          |  |
|                         | Passive infrastructure elements (P-ISE)         |  |
| Moveable test objects   | Object controlled/monitored by the CC (TSV/SCT) |  |
|                         | Subject vehicle (SV/VUT)                        |  |

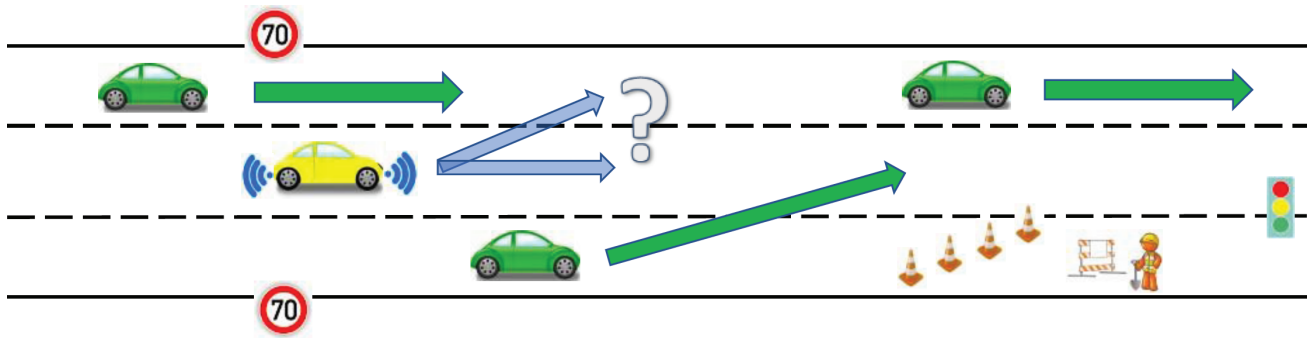


Figure 2 — Example of test scenario

## 6 General requirements and recommendations

### 6.1 Function overview

Several techniques and methods used for function and safety testing of autonomous moving test objects are covered by this document and listed below:

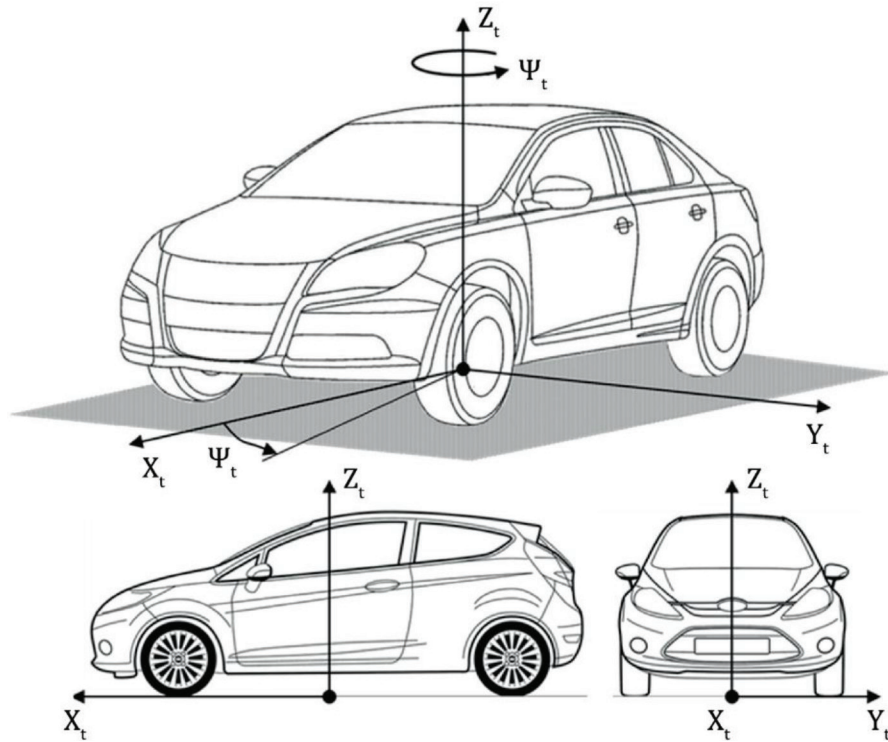
- a) test scenario execution,
- b) static and dynamic trajectory following,
- c) trigger and actions,
- d) adaptive synchronization points (master/slave),
- e) remote control driving,
- f) object-to-object communication,
- g) safety features:
  - emergency stop,
  - arm/disarm,
  - time synchronization,
  - geofencing,
  - centralized control.

### 6.2 Test object coordinate system

#### 6.2.1 Vehicle

Vehicle coordinate system orientation shall follow ISO 8855. See [Figure 3](#).

If not otherwise stated, the geometrical centre which is the centre of the bounding box of the test object projected on the ground is used as the origin of the coordinate system.



NOTE  $\psi_t$  is the rotation about the  $z_t$  axis.

Figure 3 — Vehicle reference coordinate system (Source: ISO 19206-3:2021, Figure 2)

## 6.2.2 Moveable test objects other than vehicle

### 6.2.2.1 Bicyclist

Origin is the centre of pedal crankshaft, projected on the ground, see [Figure 4](#) (see also ISO 19206-4:2020, Figure A.1).

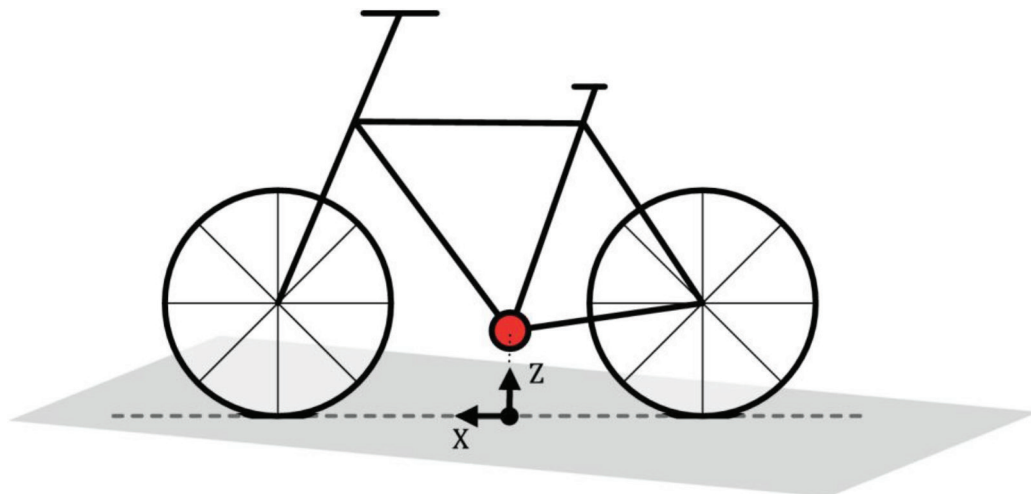


Figure 4 — Bicyclist reference coordinate system

### 6.2.2.2 Pedestrian

Origin is the centre between the hips, projected on the ground, see [Figure 5](#) (see also ISO 19206-2:2018, Figure A.1).

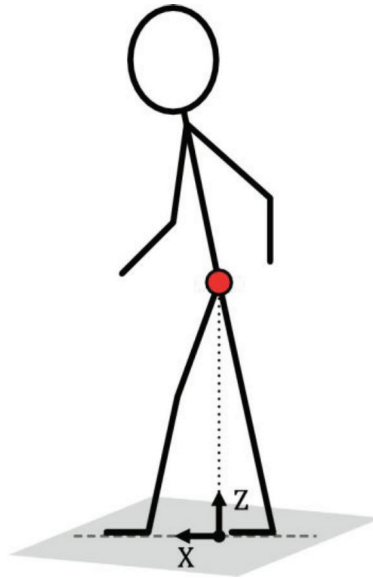


Figure 5 — Pedestrian reference coordinate system

### 6.2.2.3 Airborne test objects

For test objects not located directly on the ground of the test area such as drones or other aircrafts, the origin shall not be projected on the ground but on the correct altitude/height on the z-axis, see [Figure 6](#).

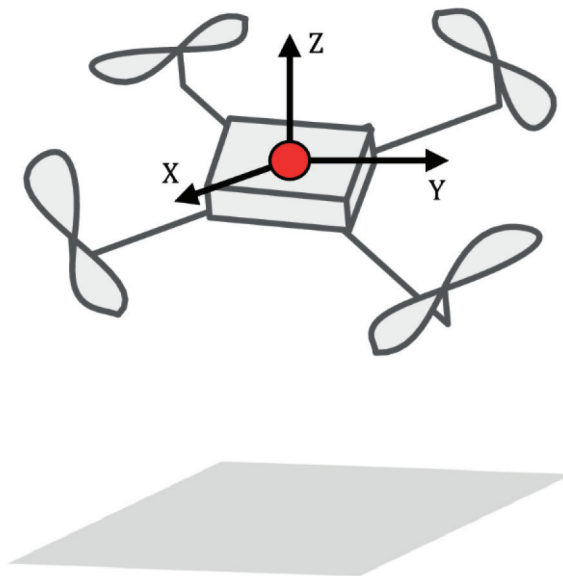


Figure 6 — Aerial test object reference coordinate system

### 6.2.2.4 Other

Origin on the geometrical centre of the test object, see [Figure 7](#).

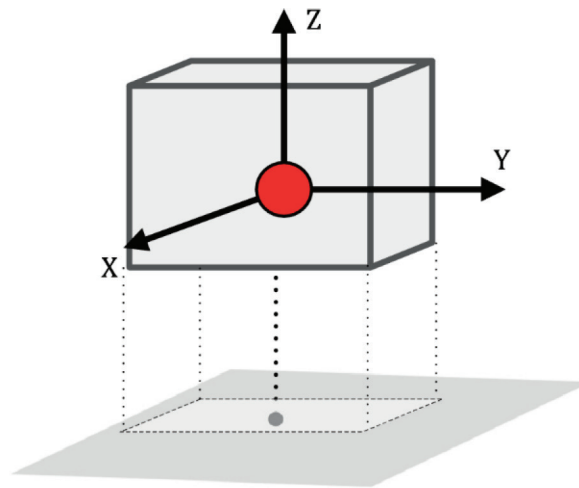


Figure 7 — Other geometrical test object reference coordinate system

### 6.3 Test scenario coordinate system

#### 6.3.1 Background info: tectonic/continental plate drift

Test object trajectory planning shall take place within a PGRS, proving ground reference system, which is not affected by any creeping or sudden tectonic movements, but referenced to a local reference point.

**EXAMPLE** In Europe, the absolute movement of the tectonic plate as whole is about 1 cm / year, in the Pacific area values of 10 cm / year are known [15] and after earthquakes sudden significant shifts along faults within the tectonic plate, and/or its margins are observed [11][12].

WGS84 (as an output of uncorrected GNSS) shall not be used. If used, the infrastructure elements would "move" against the planned trajectory due to the continental plate drift, resulting in significant risk of collision between test objects.

#### 6.3.2 Coordinate system – Tests on proving ground

Test objects shall report their position in the MONR-message with local cartesian coordinates (PGRS) in (x,y,z) in relation to the local test origin defined in the OSEM message. Only one test origin shall be defined per test.

A top-down view of the coordinate system can be found in Figure 8 where the yaw angle  $\Psi$  (psi) is measured counterclockwise in degrees, starting with  $0^\circ$  pointing to the local x-direction. If rotation of the origin is set to  $0^\circ$  the PGRS system is defined as a cartesian local coordinate system with its x-axis to east, y-axis to true north and z-axis upwards (ENU). Rotation of the origin is a parameter available in the OSEM message.

**NOTE** GNSS *Heading* is usually measured clockwise in degrees, starting with  $0^\circ$  pointing to north. The relation between yaw and heading is  $\Psi = 90^\circ - \text{Heading}$  (when the rotation of the origin zero).

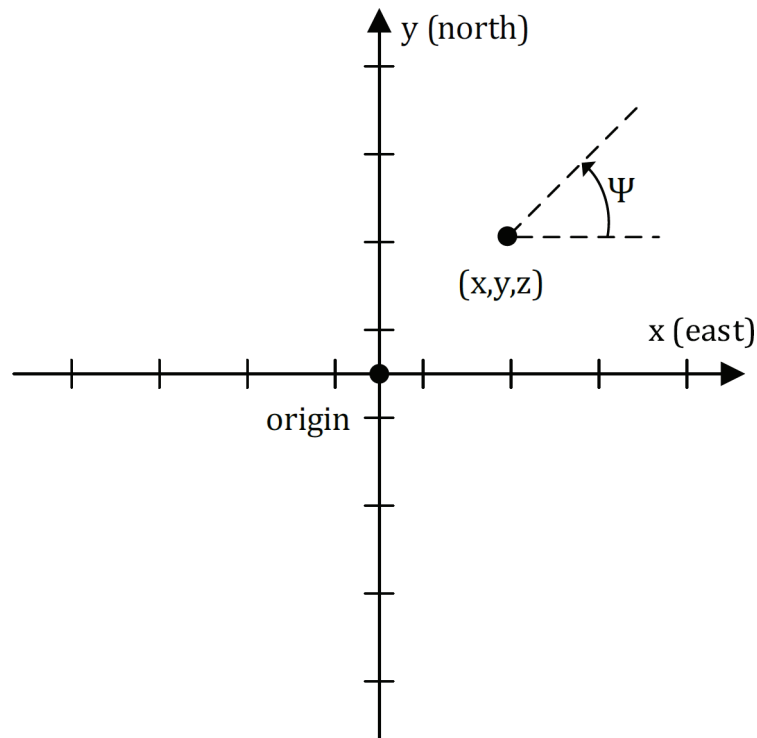


**Figure 8 — RPM in PGRS and yaw explanation (rotation is zero)**

### 6.3.3 Coordinate system – Test on other test areas

For larger areas, or areas outside a limited test area, a global coordinate system using UTM/ECEF shall be used.

Test objects shall report their position in the MONR2-message with global, absolute, coordinates.

Depending on where (on which tectonic plate) the test is executed, a different plate-drift-free coordinate system shall be used according to [Table 2](#).

**Table 2 — Geodetic systems on specific tectonic plates**

| Geographical location of test                     | Geodetic system                      |
|---------------------------------------------------|--------------------------------------|
| Eurasian plate                                    | ETRS89                               |
| North American plate                              | NAD83                                |
| South American plate                              | ITRF2000                             |
| African plate                                     | ITRF2000                             |
| Australian plate                                  | ITRF2000                             |
| Indian plate                                      | ITRF2000                             |
| Arabian plate                                     | ITRF2000                             |
| Other plates/fallback /local GNSS correction data | WGS84, locally corrected (see below) |

The CC shall transmit information to the test objects about the base coordinate system that shall be used for the test scenario. If this is not applicable or if the CC did not send the information, then the fallback solution is to use either:

- WGS84 (for tests as described in [6.3.3](#)), or
- A local coordinate system (for tests as described in [6.3.2](#)).

It is recommended to use a local GNSS reference station to provide RTK correction data, which is located close to the proving ground's local RPM, using as its initial position the local coordinates being corrected

by tectonic plate drift (i.e. taken from the same map, which also provides the coordinates of all other infrastructure elements during the traffic scenario).

This local GNSS reference station shall transmit its RTK correction data to each participating moveable test object. This guarantees that all moveable test objects are located within the same, tectonic plate drift invariant coordinate system.

## 6.4 Time requirements

### 6.4.1 General time requirements

All test objects and the CC shall have the same understanding and perception of time. Therefore, it is important that time representation, time resolution, time accuracy and time synchronisation is commonly shared.

### 6.4.2 Time representation

GPS time shall be used as time base. GPS time is monotonous and does not get affected by leap seconds.

NOTE UTC time is affected by leap seconds, hence is not monotonous and not useable for surveying and control applications with high timing precision requirements.

### 6.4.3 Absolute time

To represent absolute time, the time is defined as the number of elapsed milliseconds since GPS time began on midnight (00:00:00 UTC) between January 5<sup>th</sup> and January 6<sup>th</sup>, 1980.

NOTE The difference between GPS-time and TAI-time is always 19 s (TAI is always 19 s ahead of GPS).

TAI is currently 37 s ahead of UTC (as to date 2021-12-31).

GPS is currently 18 s ahead of UTC (as per date 2021-12-31).

### 6.4.4 Relative time

The GPS second of week (SOW) shall be used when representing relative time (e.g. during test execution). The GPS week starts at midnight (00h00m00s GPS time) between Saturday and Sunday and consists of 604 800 s [16].

All transmitted times shall be in relation to the start of the given GPS week.

### 6.4.5 Time resolution

When using 32 bits for representing the GPS seconds of week in milliseconds, the time resolution for transmission is 0,25 ms. See [Formula \(1\)](#).

$$604\,800 \times 1\,000 \times 4 = 2\,419\,200\,000 \text{ quarters of ms per week} \quad (1)$$

Representation:

```
GPSSecondOfWeek := INTEGER {startOfWeek(0), oneMillisecAfterStartOfWeek(4), unavailable(4294967295)}
(0... 2419199999)
```

NOTE 1 For each millisecond since start of the week, the GPSSecondOfWeek-value increases with 4 due to the 0,25 ms resolution.

NOTE 2 The unavailable value 4294967295 (dec) corresponds to 0xFFFFFFFF (hex).

EXAMPLE The GPS week roll-over behaviour for the GPSSecondOfWeek looks like this at midnight between Saturday and Sunday:

|                          |                            |
|--------------------------|----------------------------|
| Saturday@23:59:59,99900  | GPSSecondOfWeek=2419199996 |
| Saturday @23:59:59,99925 | GPSSecondOfWeek=2419199997 |
| Saturday @23:59:59,99950 | GPSSecondOfWeek=2419199998 |
| Saturday @23:59:59,99975 | GPSSecondOfWeek=2419199999 |
| Sunday@00:00:00,00000    | GPSSecondOfWeek=0          |
| Sunday @00:00:00,00025   | GPSSecondOfWeek=1          |
| Sunday @00:00:00,00050   | GPSSecondOfWeek=2          |
| Sunday @00:00:00,00075   | GPSSecondOfWeek=3          |
| Sunday @00:00:00,00100   | GPSSecondOfWeek=4          |
| ...                      |                            |
| Sunday @00:00:01         | GPSSecondOfWeek=4000       |
| ...                      |                            |
| Sunday @00:01:00         | GPSSecondOfWeek=240000     |

#### 6.4.6 Time accuracy (and precision)

Control centre and test object internal clocks shall not deviate from the GPS second of week more than:

- $\pm 125 \mu\text{s}$  for moveable test objects;
- $\pm 10 \text{ ms}$  for infrastructure elements (or slow-moving test objects).

This requires that each test object uses the GPS time for its own time synchronisation or uses a network time server (PTP / NTP) for time synchronisation.

#### 6.4.7 Time synchronization

The time reference for test objects as well as for the CC shall be GPS time. This time is available to all participants operating their own GPS receiver and having sufficient GPS observations available. The GPS observations shall preferably be direct communication with satellites, but for GPS-denied areas a GPS-repeater may be used as a substitute.

For moving test objects in GPS-denied areas (such as indoor) and if the duration of loss of GPS time is outside the stability duration of the clock on the test object shall the time be retrieved from the PTP-server hosted by the CC.

For static or slow-moving test objects in GPS-denied areas (such as indoor), and if the duration of loss of GPS time is outside of the stability duration of the clock on the test object, the time shall be retrieved from the NTP or PTP-server hosted by the CC.

If different time sources are available to the CC and test objects they shall retrieve their time according to the following priority, further visualised in [Figure 9](#):

- a) GNSS source (GPS time),
- b) PTP,
- c) NTP.

If no time source is currently available, `unavailable` shall be sent in messages transmitting time stamped information.

NOTE PTP is using UDP port 319 and 320. NTP is using UDP port 123.

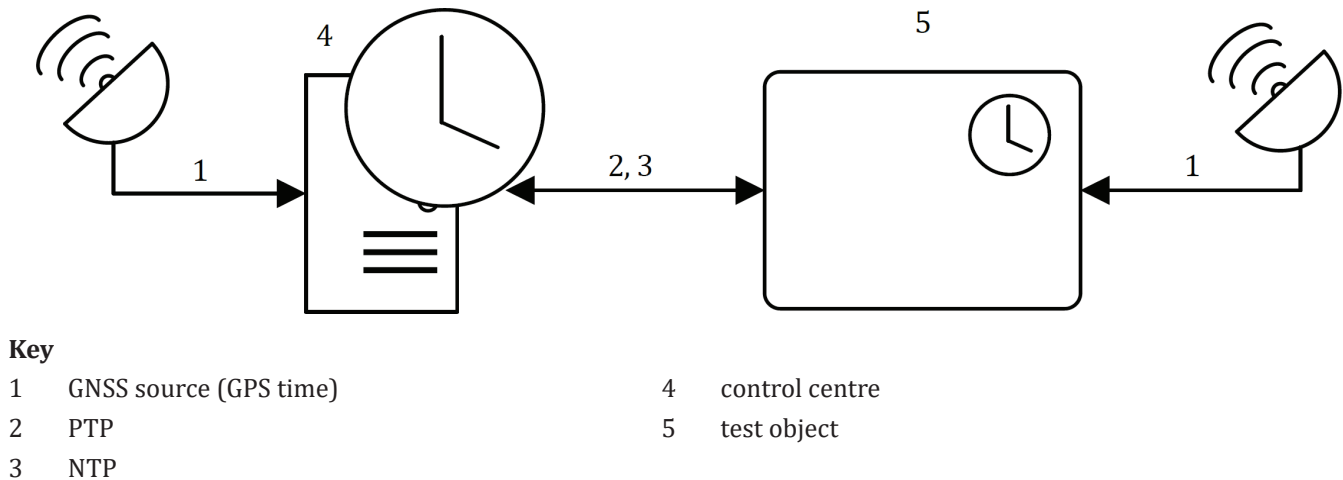


**Figure 9 — Schematic view of time source priority and NTP/PTP service allocation**

#### 6.4.8 Date synchronization

During configuration/setup of a test, the CC shall transmit the current date, using the test object setting (OSEM)-message to the test objects. The test object shall use this time as reference for the test to be executed. The following date and time information shall be included in the message:

[Date, GPSWeek, GPSSecondOfWeek, LeapSeconds]

The date format shall be in accordance with the ISO 8601 series (YYYYMMDD).

The CC shall transmit the week-roll-over message to the test objects if a new GPS-week is entered during execution of a test. This message is called GPS second of week roll over message – SOWM.

#### 6.4.9 Network delay

A one-way-delay (OWD) [13] shall be determined after the network has been set up. The determination inside the network is easy because the true time reference is distributed via PTP/NTP (for test objects without GNSS receiver) or the OSEM. Each data packet, being transmitted between any test object and the control centre, contains in its header a timestamp of the time when the data content has been generated.

It is important to recognize, that the OWD is not important for the application, if the total time between data generation on the sender's site and data receiving at the other site is lower than a defined threshold. This threshold is defined, for example, by the heartbeat timeout.

The heartbeat or monitor packets can therefore be used directly for an online monitoring of the over-all latencies of the network.

Current measured network delay can be retrieved from the test object (or from CC) by reading the network-delay-parameter (if available). Other network parameters may also be retrieved. All available parameters are specified in the device interface description XML file (DIDX).

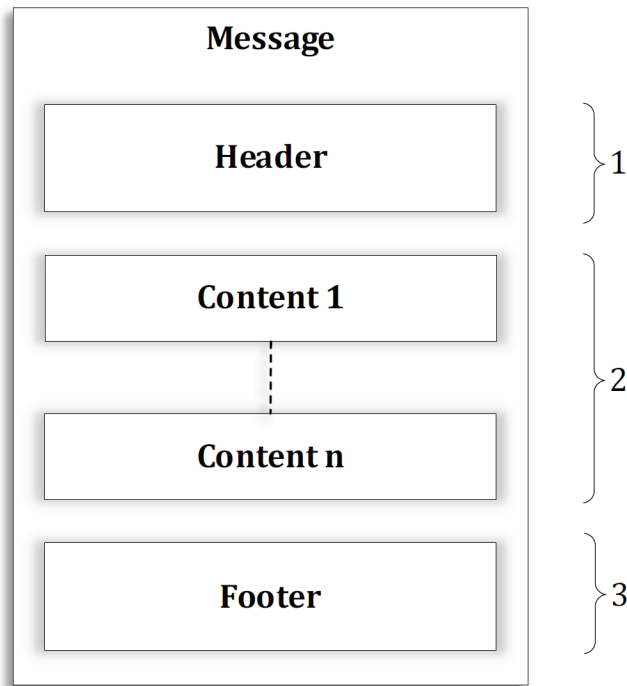
## 6.5 Communication requirements, recommendations and permissions

The following requirements, recommendations and permissions apply.

- a) Network IPs shall be used for communication among the CC and test objects. The CC and all test objects being part of the same traffic scenario shall operate on the same logical IP network and being addressable (able to communicate with each other).
- b) Logical sub-networks should be supported to allow the execution of several independent traffic scenario tests on the same proving ground without conflicts.
- c) Test object status collection provides the CC with current information about all available test objects, such as battery level, current faults, etc.
- d) The subject vehicle shall support sending monitor information to the CC.
- e) A traffic scenario may include one or more subject vehicles in a single scenario.
- f) Each test object shall be able to report its capabilities via request from the CC.
- g) Multicasting of information may be applied if the underlaying network and all entities in the test setup support this.
- h) Test objects shall be capable of reading the heartbeat message (see [12.3.6](#)) and send monitor message (see [12.3.7](#)).

Structure and package of data are done according to [Figure 10](#). A message is the highest element consisting of header, content data and footer. This is called flexible message structure.

A message can contain one or more content(s). Each message can be built up to contain dynamic content, meaning that addition to a defined message is possible. Pre-defined content is specified further down in this document, and addition to this should be used with care, since it may affect the latency of communication timing expected.

**Key**

- 1 message header metadata: ID, counter, version, length, etc...
- 2 one or several message content(s) containing: valueID, length, data
- 3 message footer: CRC checksum

**Figure 10 — Message structure****7 Safety and risk assessment requirements and recommendations****7.1 General**

The control centre shall support safety monitoring of moveable test objects. This includes support for emergency stop of all moveable test objects.

The following requirements, recommendations and permissions apply:

- a) The system should support a safe low-speed mode for remote transport.
- b) The system should support a safe low-speed mode for safe return/re-position.
- c) The system shall support an arming function (ready to start test – active).
- d) The system shall support an emergency stop.
- e) The system may support `soft stop` – controlled braking – also called `normal stop`.

If a test object receives an emergency stop signal or the condition for initiating an emergency stop is fulfilled, the test object shall stop as quickly as possible without considering extensive usage of tires, etc. This type of stopping should only be used for emergency stop, compared to a soft stop where test object can use a longer period for stopping, if preferred.

## 7.2 Local test object fence and global geofence

### 7.2.1 Common requirements and recommendations

The control centre as well as all moveable test objects shall have support to enforce one or more virtual fences.

For every virtual fence an appropriate function shall be supported, for example low speed fence, stop fence, shutdown fence and a geofence.

Virtual fences are used as criteria of whether a moveable test object meets certain safety requirements.

The `global geofence` defines the area on the proving ground (or on the public road or other test area) where the moveable test objects are allowed, or not allowed, to move.

The `local test object fence` is defined individually for each moveable test object and defines criteria (such as position, speed, type of test) which shall be fulfilled by each moveable test object in respect to its trajectory.

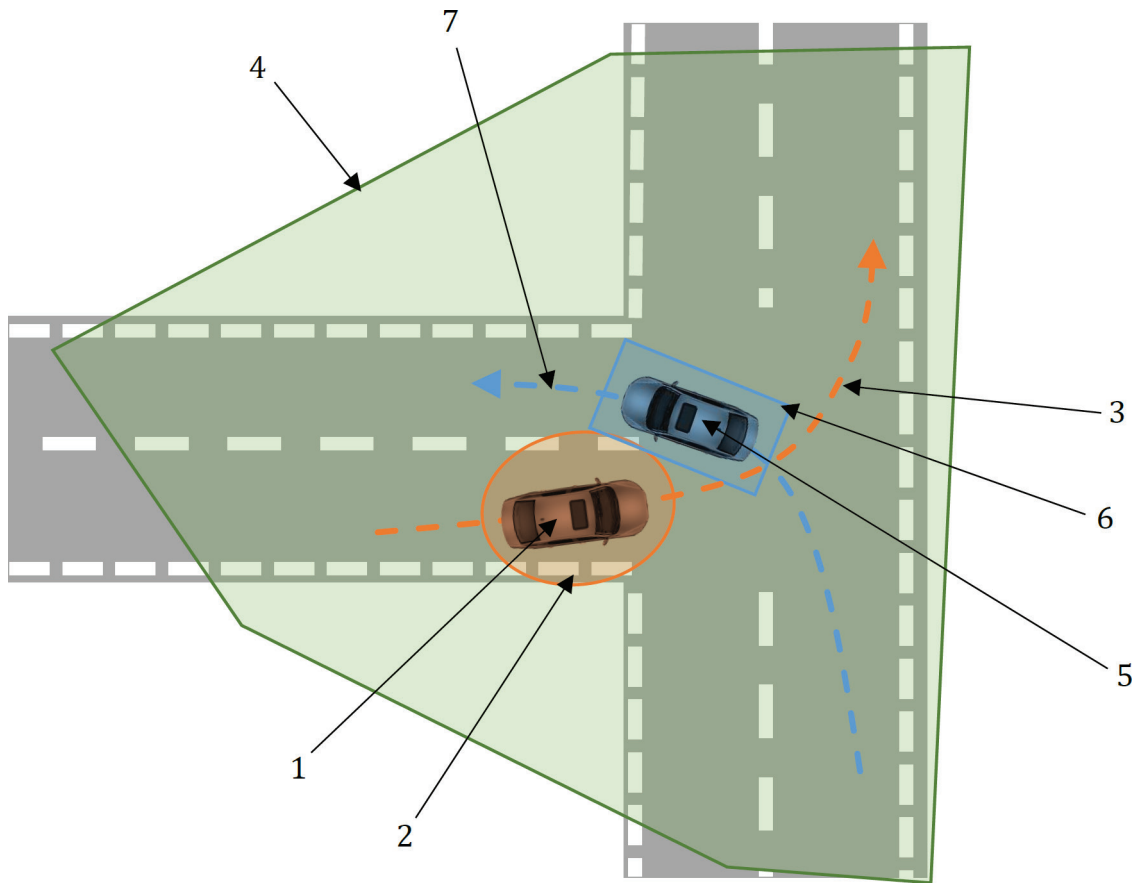
NOTE Local test object fence is the maximum allowed deviation from the intended path.

### 7.2.2 Global geofence

The virtual boundary around the allowed test area is called global geofence. The test object shall evaluate the position of itself in real-time against the geofence. If the test object exceeds (enters or exits) the boundary, a related measure shall be executed, stop and request an abort. The control centre may additionally evaluate the position of each test object against the geofence.

### 7.2.3 Local test object fence

The CC shall inform moveable test objects how much deviation from their trajectories is allowed. This information is sent to the test object before the test is executed, but in principle the local fence can also depend on specific situations and scenarios and the fence-tolerances may be updated during a running test scenario. [Figure 11](#) illustrates a combination of both global and local virtual fences during a test scenario.



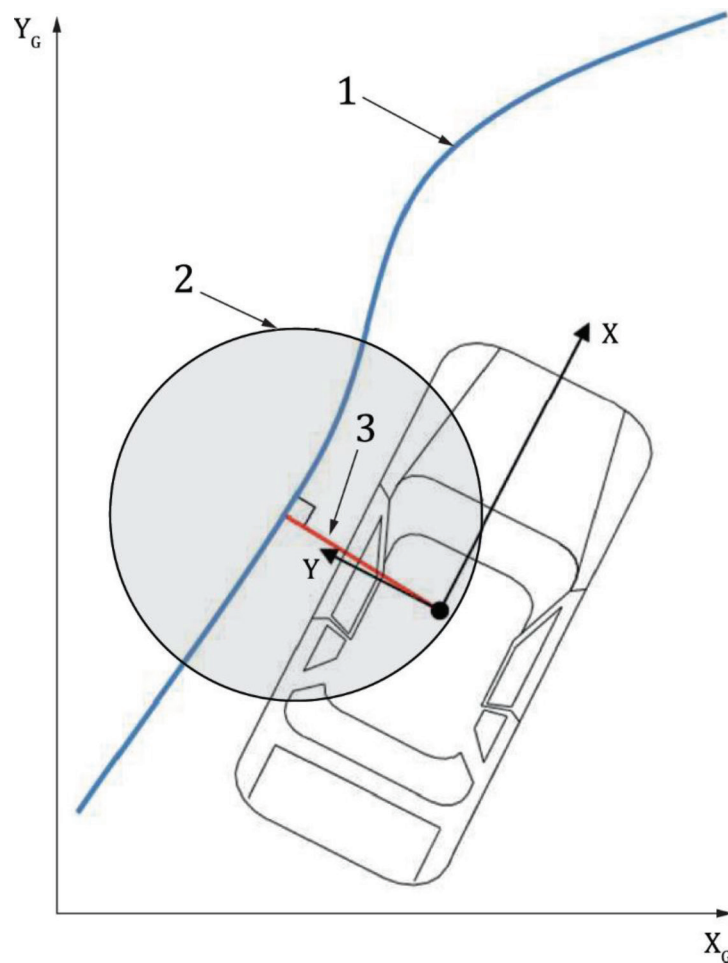
**Key**

- 1 test object 1
- 2 test object 1 – local test object fence
- 3 test object 1 – trajectory
- 4 global geofence
- 5 test object 2
- 6 test object 2 – local test object fence
- 7 test object 2 – trajectory

**Figure 11 — Test scenario with geofence and local test object fences**

The test object trajectory deviation shall not exceed the maximum value(s) as sent in the configuration message for local fences (e.g. *MaxWayDeviation*, *MaxLateralDeviation*, *MaxYawDeviation*). If such deviation is identified by the test object, it shall abort the test, it shall perform an emergency stop action and send an *requestEmergencyStop* to the control centre .

[Figure 12](#) illustrates the lateral path deviation in the context of geofencing.

**Key**

- 1 planned path
- 2 local test object fence
- 3 lateral path deviation

**Figure 12 — Lateral path deviation (Source ISO 19206-3:2021, Figure 1)**

**NOTE** The position error is the deviation between the desired position and the current position for each specific time stamp.

If the current moveable test object positioning accuracy (measured by the test object itself by its estimated position standard deviation) exceeds the threshold  $\text{MinPosAccuracy}$  (i.e. its estimated local position error is larger than the required accuracy), then this shall be reported to the CC.

## 8 Communication security requirements

To avoid unauthorised access and control of the CC or test objects by any untrusted source, encryption over the communication layer between all test objects and the CC may be implemented, but a non-encrypted mode shall be available for development and debugging purposes.

## 9 Architecture and interfaces

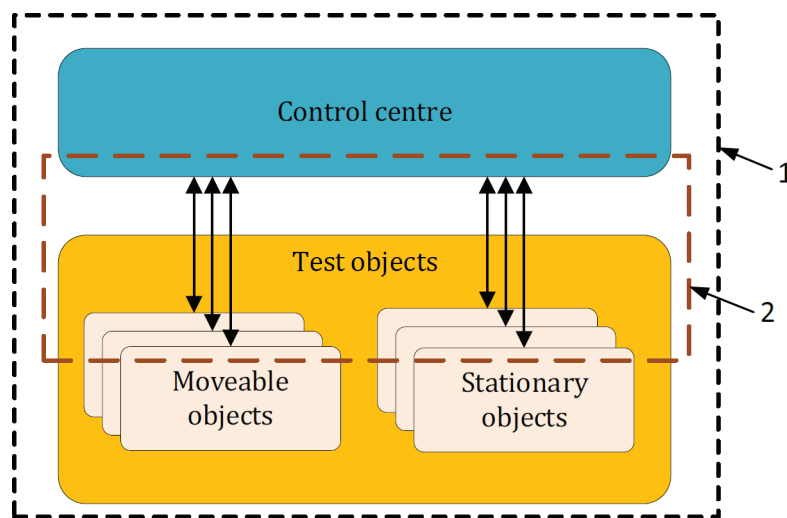
### 9.1 General

The test system consists of the control centre and test objects. Test objects can be of type `moveable` or `stationary`.

[Figure 13](#) shows basic communication setup between the CC and test objects and the boundary of this communication protocol document. Direct communication between test objects may also be implemented.

The supporting system such as communication networks and NTRIP caster and their respectively integration towards the test object or CC is not described in this document.

A fast, low latency data communication between the server and all test objects shall be assured by the architecture. Also, receiving of broadcasted GNSS correction data (via RTCM-SC104 format) from a NTRIP Caster shall be supported by all moveable test objects. NTRIP server is preferably part of the CC infrastructure.



#### Key

- 1 system boundary
- 2 communication protocol boundary

**Figure 13 — Overview of architecture**

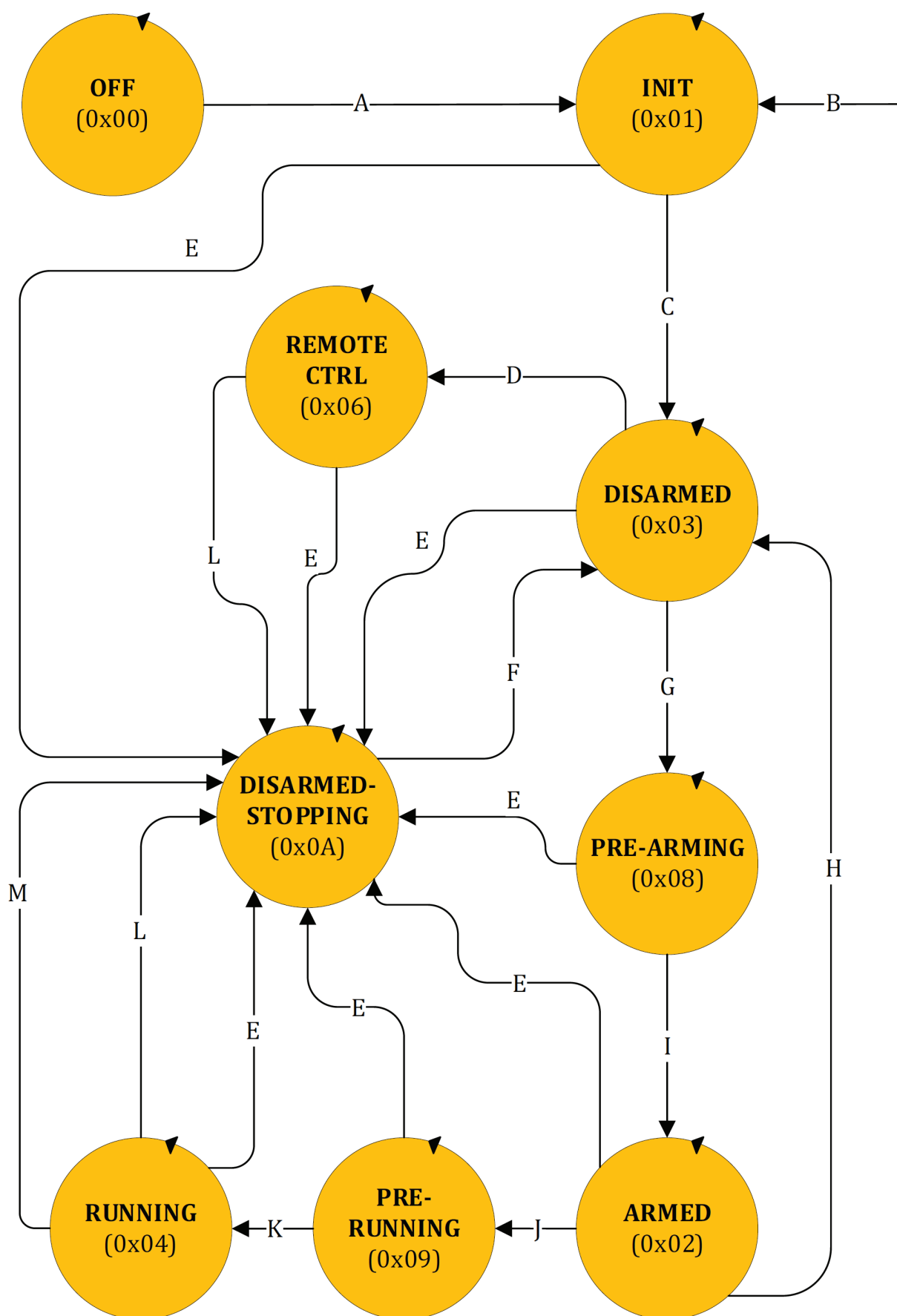
### 9.2 Control centre and test object states

#### 9.2.1 General

To describe the overall operational states and transitions between them, state diagrams are provided for test objects and the CC. Guard conditions are listed in the tables below to describe the condition that needs to be fulfilled to execute a dedicated transition.

#### 9.2.2 Test objects state diagram

The test object state diagram is illustrated in [Figure 14](#) and further detailed in [Tables 3](#) and [4](#). When a test object is in the OFF, INIT or DISARMED state, it shall be safe for a human user to approach the equipment.



### Figure 14 — Test object states

Table 3 — Test object state description

| State ID | State Name        | State Description                                                                                           |
|----------|-------------------|-------------------------------------------------------------------------------------------------------------|
| 0x00     | OFF               | Test object turned off                                                                                      |
| 0x01     | INIT              | Test object in initializing phase, e.g. setting up supporting system                                        |
| 0x02     | ARMED             | Test object ready to execute the test                                                                       |
| 0x03     | DISARMED          | Test object connected to the CC                                                                             |
| 0x04     | RUNNING           | Test scenario is executing                                                                                  |
| 0x06     | REMOTE CTRL       | Test object is manually driven by the CC or external remote control (allowed to be outside of the geofence) |
| 0x08     | PRE-ARMING        | Test object is currently preparing for arm                                                                  |
| 0x09     | PRE-RUNNING       | Test object is waiting for the start time specified in STRT message to be reached                           |
| 0x0A     | DISARMED-STOPPING | Test object is disarmed and shall decelerate towards zero speed if the test object is moving                |

### 9.2.3 Test object state change conditions

The following list corresponds to the state transition conditions in [Figure 14](#).

Table 4 — Test object state change description

| State transition ID | State change triggered by met condition                                                                                                                                                                                                                                                                                          |
|---------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| A                   | System powered on AND Booting has finished                                                                                                                                                                                                                                                                                       |
| B                   | TCP connection to CC lost OR<br>No consecutive HEAB received, i.e. if HEAB timeout expires                                                                                                                                                                                                                                       |
| C                   | Object initialized AND<br>OSEM received AND<br>Consecutive HEAB received from CC (connection established)                                                                                                                                                                                                                        |
| D                   | Test object disarmed AND<br><code>OSTM.StateChangeRequest(remoteControl)</code> received                                                                                                                                                                                                                                         |
| E                   | Test object is not in OFF state AND<br>(Emergency stop received in HEAB OR<br><code>OSTM.StateChangeRequest(emergencystop)</code> received OR<br>Test object internal error detected, test object shall request emergency stop to all test objects by sending <code>MONR.ObjectStatusRequestError(requestEmergencyStop)</code> ) |
| F                   | (Normal stop sequence completed OR Emergency stop sequence is completed) AND<br>Test object is standing still AND<br>No risk for harming the user AND<br>Emergency button is released AND <code>OSTM.StateChangeRequest(disarm)</code> received                                                                                  |
| G                   | Test object disarmed AND<br><code>OSTM.StateChangeRequest(arm)</code> received                                                                                                                                                                                                                                                   |
| H                   | Test object armed AND<br><code>OSTM.StateChangeRequest(disarm)</code> received                                                                                                                                                                                                                                                   |
| I                   | Test object disarmed AND<br>Test object pre-arming complete                                                                                                                                                                                                                                                                      |
| J                   | Test object armed AND<br>Start message (STRT) received by test object                                                                                                                                                                                                                                                            |

Table 4 (continued)

| State transition ID | State change triggered by met condition                                                                                                                                                                                                                   |
|---------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| K                   | Test object armed AND Countdown to start completed                                                                                                                                                                                                        |
| L                   | (Test object is running OR Test object is in remote control) AND (Normal stop in HEAB message received OR <code>OSTM.StateChangeRequest(normalstop)</code> received)                                                                                      |
| M                   | Test object is running AND (End of trajectory is reached, send <code>MONR.StopTrigger(End of trajectory reached)</code> OR Test object is performing normal, send <code>MONR.ObjectStatusRequestError(requestNormalstop)</code> stop to all test objects) |

### 9.2.4 Control centre state diagram

The control centre state diagram is illustrated in [Figure 15](#) and further detailed in [Tables 5](#) and [6](#).

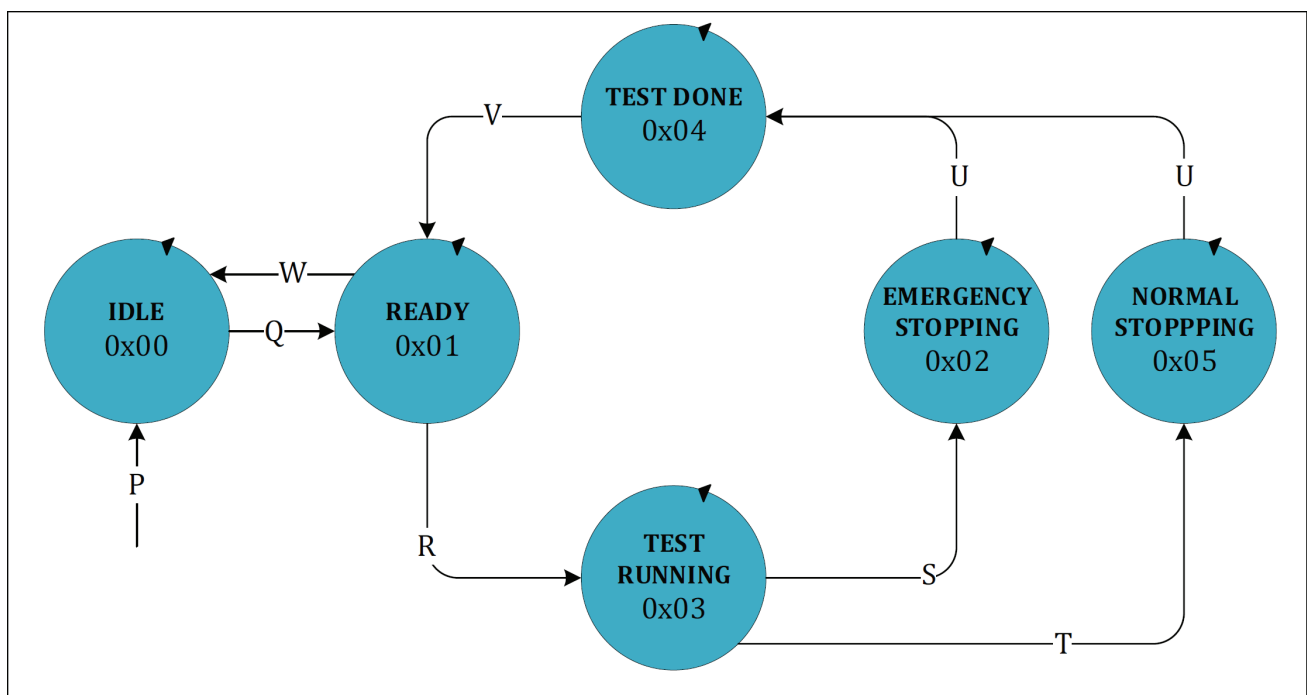


Figure 15 — Control centre states (with HEAB CCState value)

Table 5 — Control centre state description

| State ID | State name         | State description                                                                                                                                                   |
|----------|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0x00     | IDLE               | CC is initializing from booting.<br>Connection not established to all test objects.<br>CC change of test scenario setup.<br>CC is remote controlling a test object. |
| 0x01     | READY              | Connections to all test objects are established and<br>CC is ready to send ARM or DISARM to test objects.                                                           |
| 0x02     | EMERGENCY STOPPING | Emergency stop is sent to all test objects.                                                                                                                         |
| 0x03     | TEST RUNNING       | Test scenario is executing.                                                                                                                                         |
| 0x04     | TEST DONE          | Test scenario is finished.                                                                                                                                          |
| 0x05     | NORMAL STOPPING    | Normal stop is sent to test objects.                                                                                                                                |

### 9.2.5 Control centre state change triggers

The following list corresponds to the state change conditions in [Figure 15](#).

**Table 6 — Control centre state change description**

| State transition ID | State change triggered by met condition                                                                                                                                                                                                                                         |
|---------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| P                   | CC booting and initializing                                                                                                                                                                                                                                                     |
| Q                   | CC is idle AND<br>Test scenario initialized AND<br>Established connections to all test objects AND<br>All test objects are ready to be armed                                                                                                                                    |
| R                   | CC has sent arm to all test objects AND<br>All test objects are in <i>armed</i> state AND<br>STRT message is sent from CC                                                                                                                                                       |
| S                   | Test running AND<br>(Internal error in CC OR<br>Emergency stop signal is triggered in CC OR<br>One or more test objects disconnects from CC OR<br>Emergency stop is requested by a test object)                                                                                 |
| T                   | Test running AND<br>(Normal stop request is received by at least one test object OR<br>CC makes normal stop OR<br>All test objects are in <i>disarmed-stopping</i> state)                                                                                                       |
| U                   | (Test emergency stopped OR Normal stopped) AND<br>All test objects are in <i>disarmed-stopping</i> state                                                                                                                                                                        |
| V                   | Internal test data in CC is stored and processed by CC AND<br>All test objects stopped and are in <i>disarmed</i> state (F state transition for all test objects has occurred after <code>OSTM.StateChangeRequest(disarm)</code> was sent from CC, see <a href="#">9.2.3</a> ). |
| W                   | CC need to change test scenario setup OR<br>At least one test object disconnected from CC OR<br>All test objects are not ready to be armed                                                                                                                                      |

## 9.3 Communication setup

### 9.3.1 General

TCP communication is used to exchange commands between the CC and test objects. The TCP channel is called `control channel`.

UDP communication is used to exchange information (data) about status (position, health, etc.) periodically between the CC and test objects. The UDP channels is called `process channel`.

UDP communication is also used to discover the CC in the network and test objects that are compatible with this document. This UDP channel is called the `discovery channel`.

A test object shall consider the connection to the CC as *established* under the following conditions:

- a valid TCP connection to the CC;
- an OSEM message has been received;
- HEAB messages are consistently received from the CC.

Consistent reception of HEAB messages is defined as follows: the timestamp of the most recent HEAB message (the one with the latest timestamp, not necessarily the most recently received message) shall not be older than current time minus the HEAB timeout value.

When HEAB messages are no longer continuously received or the `control channel` is disconnected, shall the test object close the control channel and cease transmission of MONR messages. Depending on the `ComLost` setting in OSEM, it shall execute the appropriate action and transition to the DISARMED-STOPPING state. When stationary and standing still and no risk for harming the user, the test object shall transition the INIT state when a new connection from the CC is established.

The CC shall consider the connection to the test object as *established* under the following conditions:

- d) a valid TCP connection to the test object;
- e) MONR messages are consistently received from the test object.

Consistent reception of MONR messages is defined as follows: the timestamp of the most recent MONR message (the one with the latest timestamp, not necessarily the most recently received message) shall not be older than current time minus OSEM[Communication Timeout].

When MONR messages are no longer continuously received or the `control channel` is disconnected, the CC will close the `control channel` and cease transmission of HEAB messages. Following this, it can initiate a new connection to the test object.

The communication setup is summarised in [Table 7](#).

**Table 7 — Port numbers**

| Communication channel  | Port number | TCP or UDP | Description                           |
|------------------------|-------------|------------|---------------------------------------|
| Process channel port   | 53240       | UDP        | Periodically process data during test |
| Control channel port   | 53241       | TCP        | Exchange of control commands          |
| Discovery channel port | 53242       | UDP        | Test object and control discovery     |

### 9.3.2 Test object discovery

The discovery service is used for discovering test objects in the network and retrieve additional information about them and employed to assign the Device ID to test objects within the network. The CC initiates the process by broadcasting a discovery request (DREQ), to which one or more test objects respond with a discovery response (DRES). See [Figure 16](#).

The test object discovery service operates on port 53242, designated as the discovery channel.

**NOTE** In cases where the communication layer does not support broadcast messages, the CC has the option to send addressed (unicast or multicast) DREQ messages to the test objects. This can be accomplished by manually specifying the IP addresses of the test objects for the CC.

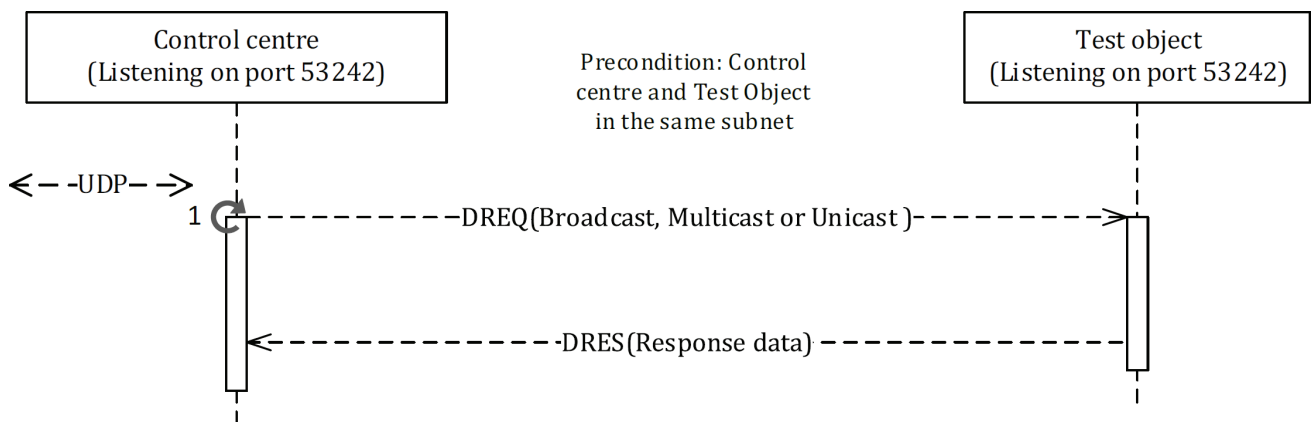


**Figure 16 — Discovery service**

**Key**

- 1 DREQ is sent continuously from CC up to 1Hz

In cases where multiple test objects coexist behind a network gateway or computer and share the same IP address, the gateway or computer should relay the DREQ message to each test object. Subsequently, each test object can then transmit a DRES response to the CC. The DRES response from each test object shall include its unique SubDevice ID. See [Figure 17](#).

Once the CC has found all the required objects, it shall cease searching and disable sending the DREQ message. A test object shall stop sending DRES responses while a connection is established to a CC.

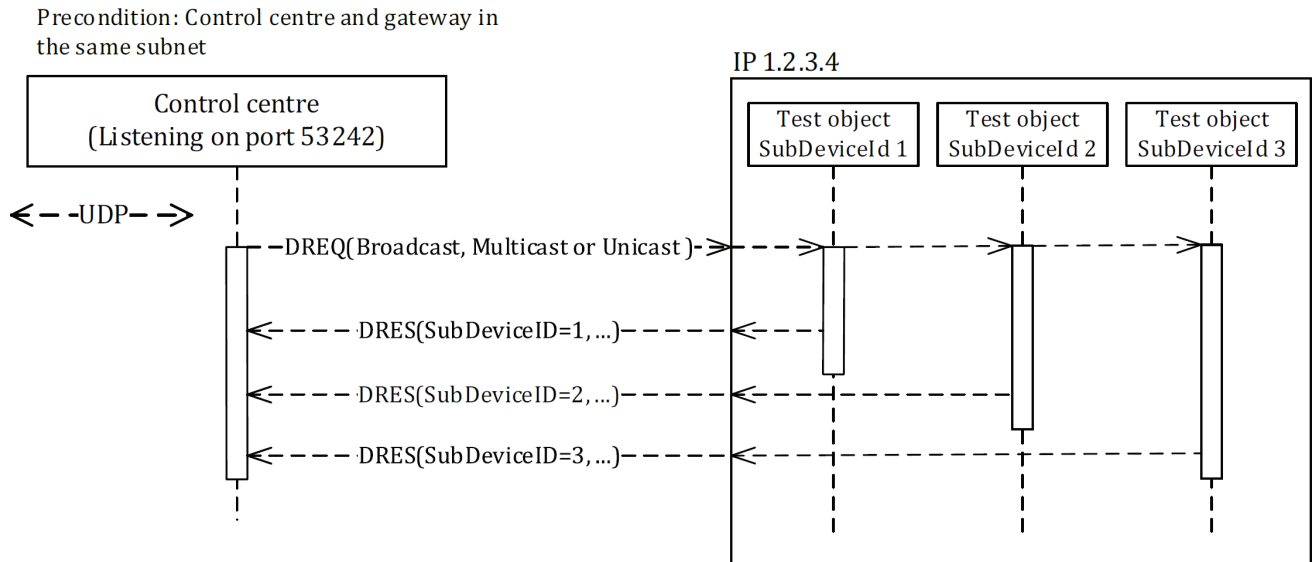


**Figure 17 — Discovery service in cases of test objects sharing the same IP address**

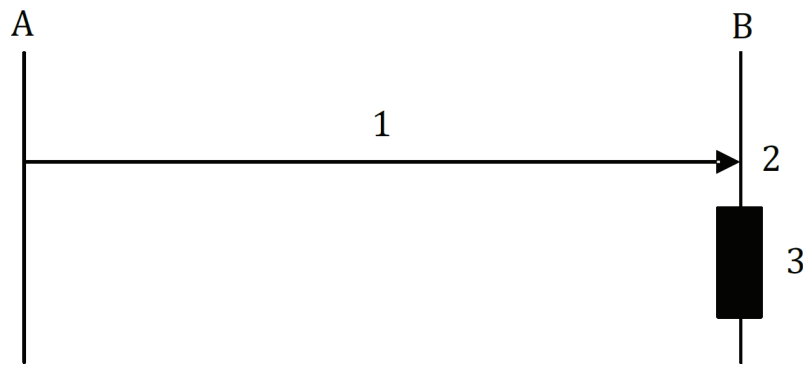
If SubDeviceID is not equal to `unavailable` in a DRES message shall CC populate the corresponding SubDeviceId value in the OSEM message when distributing the DeviceID to the test object hosted by the gateway or computer.

### 9.3.3 TCP communication setup (control channel)

The test object shall act as TCP server. The CC shall be the TCP client. The IP number of the test object shall be preconfigured and known by the CC before initiating the communication to test object. The IP number to the test object can be retrieved by using the discovery service.

- 1) The test object (server) shall listen for incoming connections.
- 2) The CC (client) shall send a connection request to the test object (server) to the default control channel port 53241. A different port can be used if required.
- 3) The test object (server) shall accept the connection and save the IP- and port number of the sender (client).

The above procedure is visualized in [Figure 18](#) and shall only be performed once per connection phase.

**Key**

- 1 TCP request
- 2 default TCP port is 53241
- 3 test object saves IP and port number of the control centre from the TCP request
- A control centre (TCP client)
- B test object (TCP server)

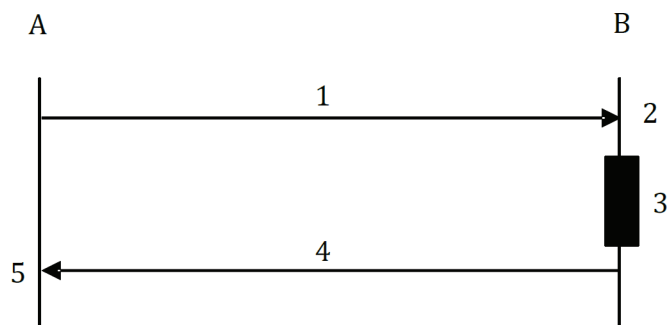
**Figure 18 — TCP communication setup****9.3.4 UDP communication setup (process channel)**

The UDP communication between the CC and a test object is initialized through the following procedure:

- 1) test object shall be idle, listening to incoming messages on port 53240;
- 2) CC shall send a HEAB (heartbeat) message to the test object on port 53240;
- 3) every test object shall save the IP- and port number of the sender;
- 4) test object starts sending MONR (Monitor) message to the CC.

This procedure (saving the IP address of CC) shall only be performed on the first received HEAB-message (since IP number is not expected to change during ongoing test).

The setup is visualized in [Figures 19](#) and [20](#).

**Key**

- 1 HEAB (UDP)
- 2 MONR (UDP)
- 3 default UDP port is 53240
- 4 test object saves IP and port number of the control centre in the HEAB message

- 5 return port number received in HEAB message  
 A control centre  
 B test object

Figure 19 — UDP communication setup

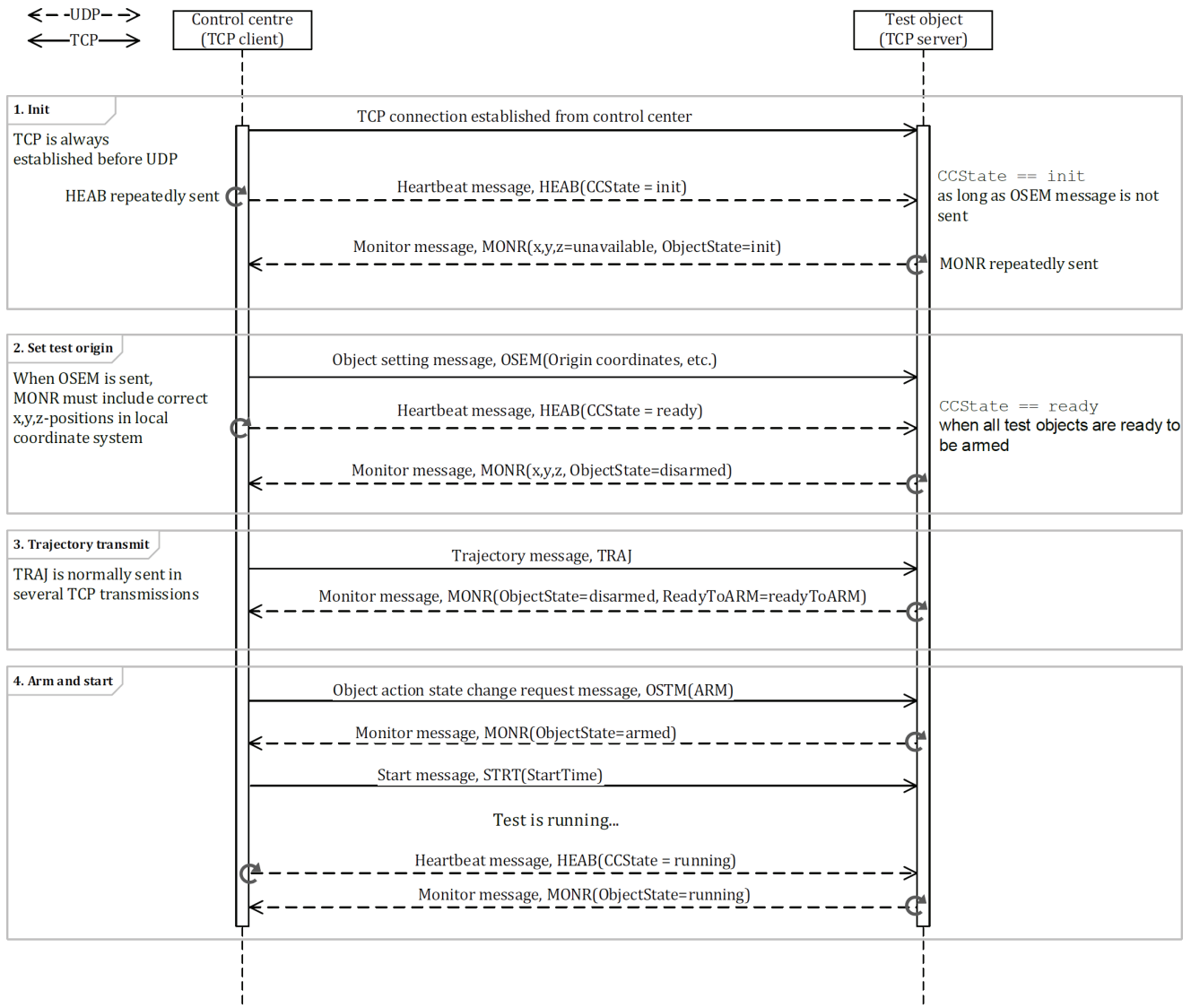


Figure 20 — Typical communication initialization setup and start procedure

### 9.3.5 File transfer protocol (FTP)

If a file transfer is required, FTP may be used.

For a file transfer, for example, to load a log file from the test object, the test object shall support FTP (file transfer protocol). For better security a test object may support FTPS (FTP over SSL).

It is recommended to not use FTP during ongoing test (RUNNING), since this would increase the network load.

**NOTE** The FTP is not intended to be used to transfer trajectory or other real time relevant information.

## 9.4 Control functionalities

### 9.4.1 Automated and non-automated drive

Control functionalities are separated in automated and non-automated drive. A drive is called automated once there are no human interactions required to change the dynamic state of a test object. A drive is called non-automated once there is human interaction required to change the dynamic state of a test object (e.g. during remote control manoeuvring). The automated drive and non-automated drive may be used by different scenarios according to [Clause 10](#).

Every non-stationary automatic driving test object shall be able to control its actuators without human remote control impact to follow a trajectory in time and space.

Non-automated driving test object is meant to move by safety driver or by remote control via the remote control manoeuvring message (RCMM), e.g. to or from the storage container.

### 9.4.2 Remote control manoeuvring

#### 9.4.2.1 Remote control manoeuvring - General information

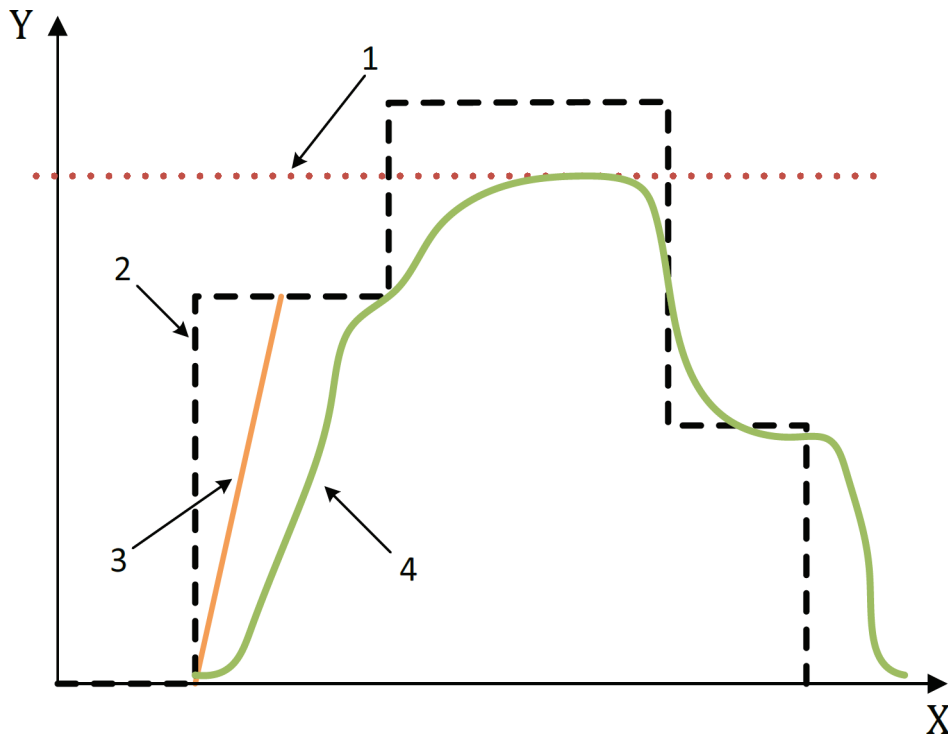
The remote control (or sometimes referred as low-level control) functionality is used to manually control the test object for transportation or relocation in non-test situations. The control message for this is continuously transmitted during operation and not via a planned trajectory.

The CC (or optionally the remote control) will repeatedly send control instructions to the test object online, which will change the current movement for throttle and steering.

The responsibility for keeping the speed limit below the safety speed limit (used during manual driving) lies on the test object and person controlling and configuring the test object.

The maximum allowed speed or safety speed limit, acceleration, etc. for each test object shall be specified in the DIDX file, see [Clause 11](#) and [Annex D](#).

The test object shall under no circumstances exceed the stipulated `safety speed limit`. Even if the CC is requesting a higher (faster) value than allowed, the test object shall keep its speed below the safety speed limit. The test object is also responsible for complying with the permissible acceleration. [Figure 21](#) illustrates an example of how the requested `SpeedValue` (dashed black line), the `safety speed limit` (dotted red line) and the `max acceleration` (solid orange line) is affecting the `actual speed` (solid green line).

**Key**

- X time (t)  
Y SpeedValue [%] or [m/s]  
1 safety speed limit / maximum allowed speed  
2 requested SpeedValue  
3 maximum allowed acceleration  
4 actual speed

**Figure 21 — Permissible acceleration and maximum speed in relation to requested SpeedValue**

The test object shall be in the state `remoteControlled` when performing remote manoeuvring.

Possible parameters to control shall include the following:

- speed and steering (absolute values);
- throttle, brake, steering and longitudinal direction (relative values).

The message for controlling this is the RCMM (remote control manoeuvring message). See [12.3.12](#) for details on how the message is structured.

The RCMM is a periodic message during remote control sessions. It shall be sent from the CC with a default period of 10 Hz. If message timeout occurs, or messages are lost, then the test object shall immediately perform a normal stop.

Due to operational safety, one person (operator) should only control one test object at the same time.

#### 9.4.2.2 Remote control manoeuvring - Absolute values

Test objects shall support using absolute values (in SI units) for controlling the speed (m/s) and steering angle (°) to be independent on arbitrary chosen relative limits.