iSWACO-ARGUS

Efficient Testing of PAD, HAD and FAD Vehicles on Public Roads and on Proving Grounds up to SAE Level 5

Company Confidential ☐
Commercial-in-Confidence ☒

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DOCUMENT CHECK & APPROVAL REQUIREMENTS

CHECK required	APPROVAL by iMAR required	APPROVAL by Customer required
Yes	No	No

Acronyms of Functions

Industrial/MIL Projects / Industrie- & MIL-Projekte

CEO	Chief Executive Officer (Geschäftsführer)
CUST	Customer (Kunde)
DE	Design Engineer / Development Engineer (Entwicklungsingenieur)
DMS	Director Marketing & Sales
HD	Head of Development (Entwicklungsleiter)
PJM	Project Manager (Projektleiter)
PM	Production Manager (Fertigungsleiter)
QA	Quality Assurance (Qualitätssicherung)
QM	Quality Manager (Qualitätsmanagementbeauftragter)

Aviation & Space Projects / Luft- und Raumfahrtprojekte

AM	Accountable Manager
CUST	Customer (Kunde)
DE	Design Engineer / Development Engineer (Entwicklungsingenieur)
HD	Head of Design (Entwicklungsleiter)
HoA	Head of Office of Airworthiness (Leiter Musterprüfleitstelle)
HoD	Head of Design Organisation
PJM	Project Manager (Projektleiter)
PM	Production Manager (Fertigungsleiter)
CVE	Compliance Verification Engineer (Musterprüfingenieur)
QA	Quality Assurance (Qualitätssicherung)
QM	Quality Manager (Qualitätsmanagementbeauftragter)

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RELATED DOCUMENTS

Table 1: Related Documents

Document Name	Content	Document Number
MAN_iXCOM-CMD.pdf	Manual iIXCOM-CMD User GUI for iNAT and iTracERT-MVT systems	DOC151112010
DMN_DynamicMeshNetwork.pdf	Datasheet iDMN	DOC180223165
ARGUS-CMD.pdf	Datasheet iARGUS-CMD	DOC180628151
XCOM-CMD-MVT.pdf	Datasheet iXCOM-CMD HMI for Multi Vehicle Tracking	DOC170808151
TSV-KIA-NIRO.pdf	Datasheet of iTSV-KIA fully automated vehicle	DOC180626028
iSWACO-ARGUS.pdf	Product Flyer iSWACO-ARGUS	DOC170531001

ABBREVIATIONS

CAD	Conditionally Automated Driving according to SAE Level 3 (hands off, eyes off - sometimes)
CAN	Controller Area Network – automotive bus for data exchange
DHCP	Dynamic Host Configuration Protocol
ETRS89 / ITRF	European / International Terrestrial Reference System / Frame
FAD	Fully Automated Driving according to SAE Level 5 (hands off, mind off - always)
GNSS	Global Navigation Satellite System (GPS, GLONASS, GALILEO, Beidou etc.)
HAD	Highly Automated Driving according to SAE Level 4 (hands off, eyes off, mind off - sometimes)
INS	Inertial Navigation System (also IMS, inertial Measurement System)
ISE	Infrastucture Element (active: traffic lights, rain simulator etc.; passive: guardrails, traffic signs etc.)
iARGUS-CC	Control Center of the iSWACO-ARGUS application incl. traffic scenario execution and trajectory planning & validation, computation hardware, screens
iARGUS-CC-TO	Control Center with “Tracking Only” functionality (no trajectory generation included)
iARGUS-CC-VAN	Moveable host (e.g. VW Transporter) for all iARGUS-CC equipment with desk, chairs for two operators, plugs for externally placed communication and GNSS antennas and optional external diesel generator. Optionally extended by a trailer, providing room for the diesel generator, antennas, tripods and most other stuff.
iARGUS-CMD	Software applied on the iARGUS-CC Control Center for Traffic Scenario planning, simulation, execution and visualization as well as for iDMN configuration
iARGUS-GTG	iMAR’s Global Trajectory Generator (applied on the iARGUS-CC Control Center within iARGUS-CMD software)
iARGUS-LTG	iMAR’s Local Trajectory Generator (applied on the Moveable Object within iARGUS-VCS)
iARGUS-MON	Monitoring software to monitor all Moveable Objects on broadcast level
iARGUS-MV	iMAR’s machine vision system for environment perception applications
iARGUS-RCS	iMAR’s roof mounted communication and sensor system (INS/GNSS and optional stereo camera system iARGUS-MV with cognitive/machine vision)
iARGUS-RIMS	iMAR’s roof mounted inertial measurement system (INS/GNSS with integrated GNSS antenna)
iARGUS-SDGT	iMAR’s Safety Driver Guidance Tool to guide a manned vehicle synchronized in space and time inside a traffic scenario (based on mixed reality)
iARGUS-UPS	Uninterrupted Power Supply for moveable objects or iARGUS-CC (option)
iARGUS-VCS	iMAR’s Vehicle Control System and Interface incl. vehicle controller to follow a desired trajectory
iDMN-MHS/FHS/THS	iMAR’s Dynamic Mesh Network with hotspots operated mast-mounted (iDMN-MHS), flying (iDMN-FHS) or/and tripod mounted (iDMN-THS)

iDMN-OHS	iMAR's Dynamic Mesh Network object mounted hotspot, i.e. those communication devices, which will provide the wireless communication on the Moveable Objects (VUT, TSV, SCT) and on the active Infrastructure Elements (traffic lights etc.) and acting simultaneously also as hotspot for the data of other participants.
iNAT	iMAR's INS/GNSS/ODO Navigation and Timing solutions for precise dynamic vehicle motion monitoring (see also iTraceRT-MVT)
iREF-GNSS	iMAR's GNSS Reference Station to provide RTK corrections via NTRIP or radio modem
iREF-LITE	iMAR's GNSS Reference Station "LITE" to provide RTK corrections via NTRIP or radio modem
iSWACO-ARGUS	iMAR's Swarm Control based observation and control application for proving grounds and public roads
iTraceRT-MVT	iMAR's INS/GNSS/ODO solutions for precise dynamic vehicle motion monitoring for localization and control (same hardware as iNAT devices, but with additional CAN logging function on 2nd CAN interface)
iXCOM-CMD	Graphical User Interface (GUI) to operate iNAT and iTraceRT-MVT systems
iXCOM-CSDK	Software Development Kit for customers to allow users to build their own GUI, based on iMAR's published iXCOM protocol
MRS	Map Reference System (e.g. ETRS89)
MVT	Multi Vehicle Tracking
NTRIP	Networked Transport of RTCM via Internet Protocol
OpenDRIVE	Standard to describe road infrastructure (https://www.asam.net/standards/detail/opendrive/)
OpenSCENARIO	Standard to descibe complex traffic scenarios (https://www.asam.net/standards/detail/openscenario/)
PAD	Partially Automated Driving
PGRS	Proving Ground Reference System (e.g. WGS84)
PTP	Precision Time Protocol fr precise time synchronization (iMAR equipent as time master)
rms	root mean sqaure
RPM	Reference Point Marker (physically marked reference point on the proving ground) as position reference (origin point)
RTK	Real Time Kinematic (GNSS centimeter performance level due to the usage of RTK based corrections, distributed via iREF-L1L2 or via GSM / GPRS)
SCT	Soft Crash Target (Moveable Object)
TGEN	Trajectory Generator
TSV	Traffic Simulation Vehicle (Moveable Object)
TTC	Time-to-Collision (mathematically it is the TTCD, Time-to-closest-Distance)
UTM	Universal Transverse Mercator (global, Cartesian based coordinate system)
VUT	Vehicle under Test (Subject Vehicle, also part of the group of Moveable Objects)
WGS84	World Geodetic System 1984

1 INTRODUCTION

iSWACO-ARGUS is the solution for the verification of the safety relevant features of highly automated and fully automated driving vehicles. It covers all SAE levels, i.e. from level 0 “hands on” up to level 5 “optional wheel”, with a single test infrastructure, operable on the proving ground as well as on public roads.

iSWACO-ARGUS controls and monitors the motion behavior of all vehicles on the proving ground simultaneously and in real-time (Figure 1) and gives the operator the unmatched flexibility to generate and execute repeatable as well as individual tests within real emulated traffic scenarios. It also allows to monitor the motion behavior of a set of vehicles performing maneuvers within a public traffic scenario, in real-time as well as in post-mission, e.g. to test highway chauffeur functionalities. Hence, **iSWACO-ARGUS** stays for **“Swa**rm **Co**ntrol & Continuous Surveillance with the reliability of the famous **Argus**’ Eyes**”**.

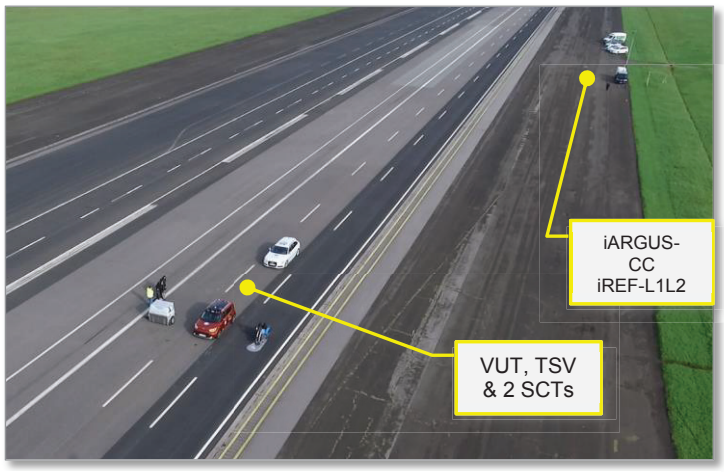


Figure 1: Typical Proving Ground Setup with iSWACO-ARGUS

iSWACO-ARGUS can be installed quickly, simply and safely on nearly arbitrary vehicles, on proving grounds and for public road applications. Thus, it is the testing solution for both, OEMs and testing / certification organizations, to be easily installed on existing or new proving grounds, worldwide.

This document describes the operation of iSWACO-ARGUS, which is used to guide several objects regarding to time and location on a proving ground. The task of iSWACO-ARGUS is to allow the user to verify the motion behavior of cars and trucks in respect to other moving objects or infrastructure elements under pre-defined Traffic Scenarios.

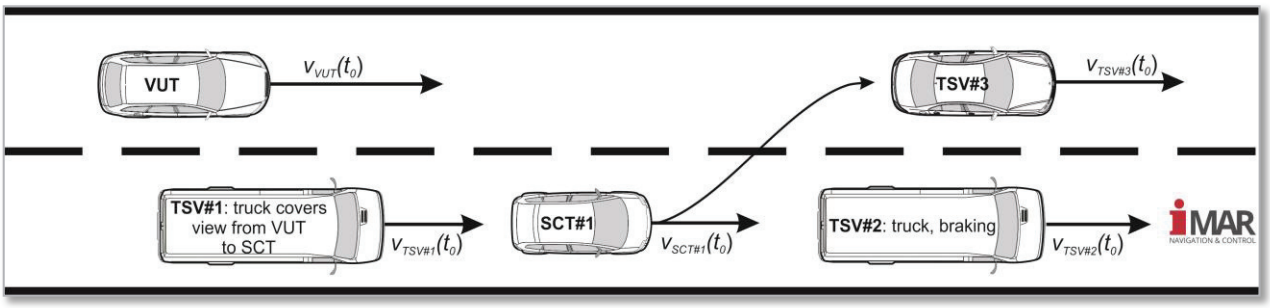


Figure 2: Typical Traffic Scenario

Details about the product iSWACO-ARGUS as well as the integrated components (like iNAT and iTraceRT-MVT INS/GNSS localization systems, iARGUS-VCS Vehicle Control System, iREF GNSS reference stations, iDMN Dynamic Mesh Network, iXCOM-CMD Operational Software etc.) can be found also in the datasheets (www.imar-navigation.de) or on request at iMAR’s sales and support engineers.

- iSWACO-ARGUS Overview
- iXCOM-CMD Software
- iTraceRT-MVT-2xx and iTraceRT-MVT-5xx: Automotive Vehicle Localization Systems for Trajectory Control
- Soft Crash Target (4a with integrated iNAT-M200)
- Video about iSWACO-ARGUS on YouTube
- iNAT-4C/SLx: Multi-redundant INS/GNSS on MEMS basis (up to 3 dissimilar IMUs and 4 CPUs inside)
- iDMN Dynamic Mesh Communication Network with low Latency

2 CAPABILITIES & FEATURES OF iSWACO-ARGUS

iSWACO-ARGUS provides the following advantages and features:

- iSWACO-ARGUS is used for the validation of entire PAD, HAD and FAD systems, for sensor testing (LiDAR, machine vision, radar etc.), for functionality testing of e.g. ADAS, collision avoidance systems, lane departure warning systems, park assist systems or braking and steering systems and can be applied e.g. for NCAP, IIHS and NHTSA tests.
- Flexible Architecture – easily applicable for existing & new proving grounds regarding infrastructure & topology.
- Cost savings due to the capability to execute individual & fully repeatable test scenarios with minimum personnel effort.
- No steering or driving robots required. Control of Traffic Simulation Vehicle's (TSV) steering / throttle / braking via vehicle's internal actuators or control loops. Therefore, iSWACO-ARGUS safes pretty much setting-up time, compared to competing systems and allows simple set-to-work on arbitrary proving grounds.
- With iTSV-KIA-NIRO a "ready-to-use" self driving Traffic Simulation Vehicle (fully equipped with iTraceRT-MVT INS/GNSS localization, iDMN communication, iARGUS-VCS vehicle control system) with the capability to follow trajectories within complex traffic scenarios on the proving ground is available as a turnkey solution.
- Capability due to modular architecture of iSWACO-ARGUS to integrate also "non-iMAR" components like brake robots or driving or steering robots from ABD, Vehico, Stähle or other manufacturers.
- Multiple Vehicle Tracking (MVT) – the measurement solution to track multiple targets (objects) in real-time on the proving ground and on public roads regarding absolute position, orientation and dynamic motion behavior of all targets in respect to any other object.
- The iSWACO-ARGUS package includes all you need on the proving ground for Highly Automated Driving (HAD) and Fully Automated Driving (FAD) verification (ongoing expansion of capabilities on demand at iMAR's development and testing department regarding hardware, software, algorithms and ergonomics), i.e.:
  - Mobile or stationary Control Center iARGUS-CC with software iARGUS-CMD for trajectory planning, simulation and test execution, test visualization, data storage and data analysis.
  - Powerful iARGUS-CMD software, which supports the operator to perform his planned traffic scenario tests without any overhead. A wizard assists the operator in all relevant steps during the entire testing.
  - Vehicle localization and control for multiple simultaneous moving objects like Traffic Simulation Vehicles (**TSV**), Soft Crash Targets (**SCT**), Vehicle under Test (**VUT**), based on iMAR's solutions for high accurate vehicle localization (iTraceRT-MVT), optionally combined with iMAR's cognitive vision technology (iARGUS-MV). This enables the operator to perform tests in traffic scenarios, which even include GNSS denied areas (e.g. driving through a tunnel) on the proving ground as well as on public roads and urban canyons (this allows also the testing of the VUT in traffic and environmental scenarios under real GNSS outage conditions). Also support of Virtual Elements (**VE**) with standardized interface
  - Vehicle guidance & control hardware and software (iARGUS-VCS) including vehicle interface.
  - Self driving vehicles as TSV or SCT, fully equipped with all components needed for fully automated driving and local trajectory adaptation to meet also complex traffic scenario requirements with dependencies between Master Objects and Slave Objects (iTSV-KIA-NIRO as a turnkey solution; integration of Soft Crash Targets from 4a-Systems or DSD as an example)
  - Collision warning and avoidance system iARGUS-RCS for each vehicle, based on INS/GNSS and machine vision technology.
  - GNSS RTK correction data acquisition and distribution via the reference station iREF-GNSS or iREF-LITE to meet position accuracy on centimeter level on each Moving Object on the proving ground.
  - Mobile iDMN Dynamic Mesh Network for multi vehicle communication with lowest latency, including several options for hotspots (mast mounted iDMN-MHS, flying iDMN-FHS, tripod mounted iDMN-THS), where also each Object itself (VUT, TSV, SCT, active ISEs) is acting with its own iDMN-OHS also as a hotspot.
  - Capability of monitoring and recording of additional visual and acoustic real-time data by inside and outside cameras (daylight and IR) and microphones with accurate timestamp. OBD data recording with precise timestamp via CAN bus as option.

- The implementation covers the recommendations of the future ISO/WD 22133-1 “Road Vehicles - Test Object Monitoring and Control for Active Safety and Automated/Autonomous Vehicle Testing” standard.
- Maintenance & Support Agreement available to participate in the fast evolution of HAD/FAD related testing technologies on the proving ground and on public roads. Ask your iMAR sales engineer for details.
- The development of iSWACO-ARGUS has been accompanied by one of the largest German testing organizations, intending to provide the homologation (type approval) for automated and autonomous Vehicles under Test (VUT) in the future.
- Due to a leading participation of iMAR Navigation in the well-known PEGASUS project regarding the test automation of traffic scenarios on proving grounds, iSWACO-ARGUS includes also the main features being elaborated in PEGASUS, where all leading German automobile manufacturers, suppliers and research institutes are involved.

The following figure shows a general system overview with the major components and information & data flow.

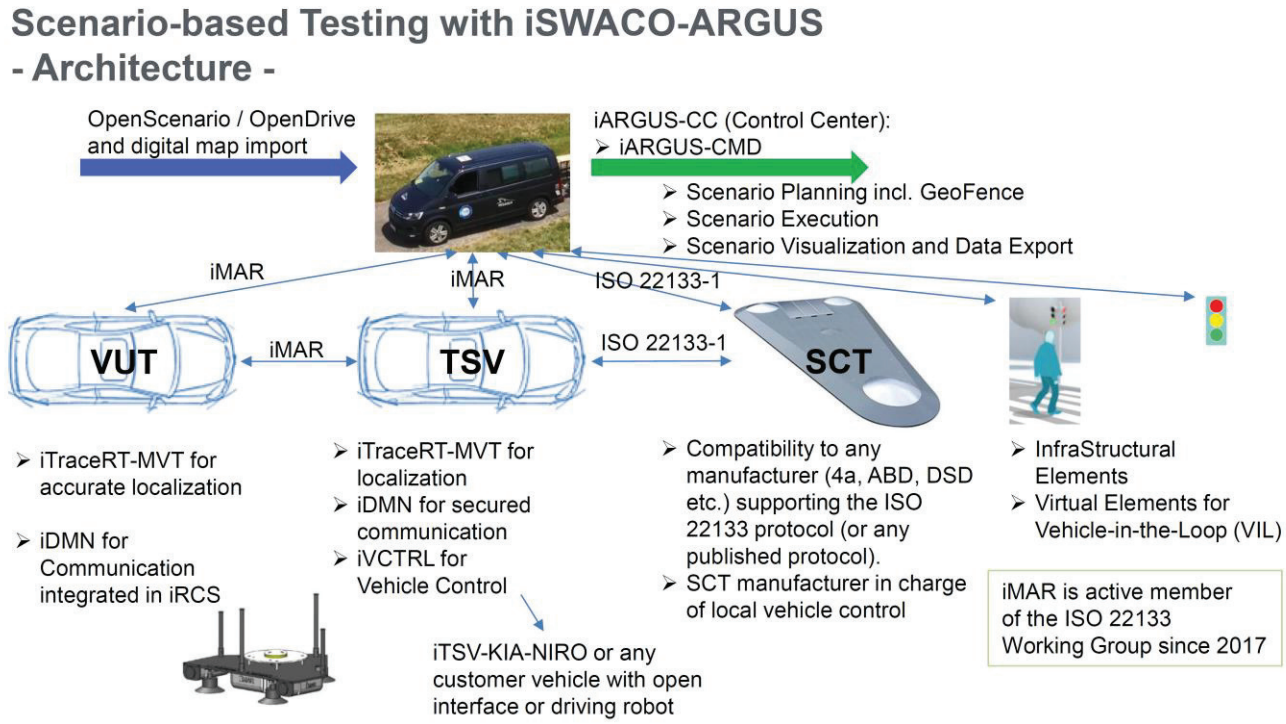


Figure 3: iSWACO-ARGUS System Overview

3 DEFINITIONS AND EXPLANATIONS

This chapter defines the components and expressions used within this manual. It is in accordance to the pre-draft of ISO/WD 22133-1.

3.1 Subject Vehicle (SV)

One or more vehicles to be tested with the system (also called **VUT** – Vehicle under Test)

Note 1 to entry: There may be one subject vehicle (standard setup) or a set of subject vehicles in the specific traffic scenario.

Note 2 to entry: Subject vehicle may be under safety driver control or/and under control center.

3.2 Object

Entity part of a Traffic Scenario under control by control center

Note 1: Two types of entities exist; moveable and stationary objects.

3.2.1 Moveable Object

Object under control by control center which has the capability of moving (mobile / non-stationary target)

Note 1: The SV is typically a Moveable Object.

Note 2: Various levels of control are possible (open-loop control [using no feedback from the real-time activities of other objects or environment], closed-loop control [taking into account activities of other objects in real-time]).

Example: Traffic Support Vehicles (**TSV**), Soft Crash Targets (**SCT**)

3.2.2 Stationary Object

Object, which is not moveable but may be under control by control center

Note 1: The SV may also be a Stationary Object case by case.

Example: active (controlled by control center) and passive Infrastructure Elements (ISE);

Active ISE: e.g. traffic lights, lighting, rain/snow/fog simulator

Passive ISE: e.g. elements of construction area, road signs, guardrails etc.

3.3 iARGUS-CC: Control Center

Centralized or distributed services for object control and safety monitoring including provision of communication services to the objects

3.4 Traffic Scenario

Complete scenario including all objects (moveable as well as stationary objects) and definition of the planned activities over time or/and location.

3.5 Moveable Object's Trajectory

Planned trajectory including object position, heading and object motion dynamics for each individual Moveable Object as part of the Traffic Scenario or for re-positioning.

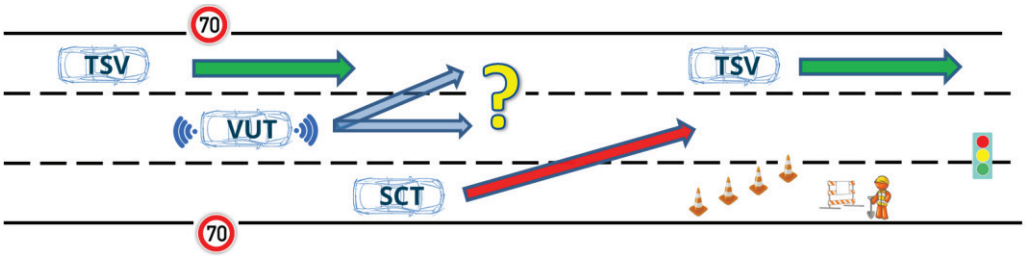
3.6 Safety Limited Speed

Maximum speed for repositioning moveable objects while not in testing mode (i.e. when outside of the Traffic Scenario)

4 TRAFFIC SCENARIO ILLUSTRATION

The illustration of a traffic scenario in Figure 4 is used as an example to explain a possible traffic scenario with various objects. The example does not include all possible objects and use cases referred to in the document.

To be able to achieve the following scenario, several different mechanisms can be used to control and monitor all different objects, which will be described later in this document. Some or all objects can be controlled by a server but may be controlled also by a safety driver if allowed by the hardware.



Type of Object	re-positioning and safe return function	longitudinal and lateral guidance during the test (SAE automation level)	collision avoidance during the test
TSV	iARGUS-VCS or Safety Driver	iARGUS-VCS (fully automated driving – SAE level 5)	iARGUS-VCS or Safety Driver
70	./.	./.	./.
VUT	Safety Driver or iARGUS-VCS	**PAD - Level 2: „partial“, hands off & eyes on CAD – Level 3: “conditional“, hands off & eyes off - sometimes HAD - Level 4: „high“, hands off & eyes off & mind off - sometimes FAD - Level 5: „full“, no human driver required anymore**	Safety Driver or iARGUS-VCS
SCT	iARGUS-CC	iARGUS-CC	iARGUS-CC

VUT = Vehicle under Test • TSV = Traffic Simulation Vehicle • SCT = Soft Crash Target • ISE = InfraStructure Element

Figure 4: Traffic Scenario example

5 COORDINATE SYSTEMS AND TIME REFERENCE

5.1 Vehicle Coordinate System (TSV, SCT, VUT)

The vehicle’s coordinate system orientation follows ISO 8855. See Figure 5 for explanation. If not otherwise stated, the geometrical center of the object, projected on the ground, is used as the origin of the coordinate system.

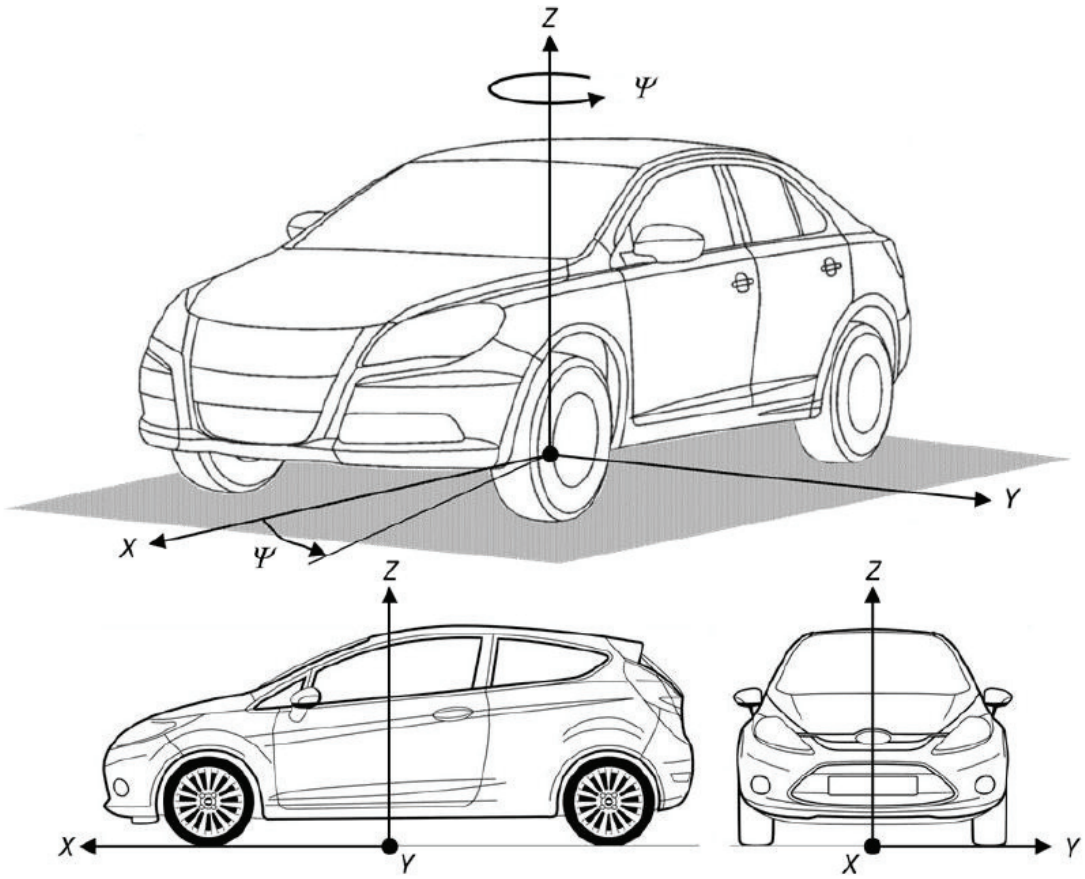


Figure 5: Vehicle reference coordinate system (from ISO 19206-3)

5.2 Moveable Objects other than Vehicles

Bicyclist: The origin is the center of pedal crankshaft, projected on the ground (see ISO 19206-4, Figure A.1)

Pedestrian: Origin is the center between the hips, projected on the ground

Others: Geometrical center, projected on the ground