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Intelligent transport systems — Partially Automated In-Lane Driving Systems (PADS) — Performance requirements and test procedures

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso .org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 204, *Intelligent transport systems*.

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.

Introduction

PADS is fundamentally intended to provide partially automated driving by longitudinal and lateral control of equipped vehicles while travelling on roads where non-motorized vehicles and pedestrians are prohibited. Free-flowing as well as congested traffic conditions could be addressed by PADS. The functionality of the longitudinal control is standardized in accordance with ISO 15622. The intention of the lateral control is to keep the vehicle in the lane and not to perform lane changes.

The main system function of a Partially Automated In-Lane Driving System (PADS) is to support the driver in keeping the vehicle within the current lane and to keep the vehicle speed below a set maximum or to control vehicle speed adaptively to a forward vehicle by using information about:

a)   distance to forward vehicles,

b)   the motion of the subject (PADS equipped) vehicle,

c)   the position of the subject vehicle within the lane, and

d)   driver commands (see Figure 1).

Based upon the information acquired, PADS sends commands to actuators that carry out its longitudinal and lateral control strategy, and sends status information to the driver.

The goal of PADS is partial automation of longitudinal and lateral vehicle control to reduce drivers' workload.

This document may be used as a system level standard by other standards, which extend the PADS standard to a more detailed standard, e.g. for specific detection and ranging sensor concepts or higher levels of functionality. Specific requirements for the detection and ranging sensor function and performance or communication links for co-operative solutions are not considered in this document.

Intelligent transport systems — Partially Automated In-Lane Driving Systems (PADS) — Performance requirements and test procedures

1 Scope

This document contains the basic control strategy, minimum functionality requirements, basic driver interface elements, minimum requirements for diagnostics and reaction to failure, and performance test procedures for Partially Automated In-Lane Driving Systems (PADS).

This document is applicable to passenger cars, commercial vehicles and buses. It is not applicable to automated driving systems of level 3 or higher (as defined in SAE J3016:2016).

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 15622, *Intelligent transport systems — Adaptive cruise control systems — Performance requirements and test procedures*

3 Terms and definitions

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

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
subject vehicle
vehicle equipped with PADS

3.2
forward vehicle
vehicle in front of and moving in the same direction and travelling on the same roadway as the subject vehicle

3.3
system states
one of several stages or phases of system operation

Note 1 to entry: See Figure 1.

3.3.1
PADS off state
state in which the system is switched off

3.3.2
PADS stand-by state
state in which the system is ready for activation by the driver

3.3.3
PADS active state

state in which the system is activated

3.3.4
PADS longit state

state in which the system controls speed and distance to a forward vehicle

3.3.5
PADS longit-lat state

state in which the system controls speed and distance to a forward vehicle and performs steering actions

3.4
lane

area of roadway that a vehicle would be expected to travel along in the absence of any obstruction without the driver's desire to change the path of travel

3.5
visible lane marking

delineators intentionally placed on the borderline of the lane that are directly visible by the driver while driving, e.g. not covered by snow

3.6
incidental visible road feature

visible patterns on the road surface that were not explicitly intended to delineate the boundaries of the lane but which are indicative of the position of the lane

Note 1 to entry: These may include such features as pavement seams or edges, curbs.

3.7
lane boundary

borderline of the lane that is determined by a visible lane marking and, in the absence of a visible lane marking, by incidental visible road features or other means such as GPS, magnetic nails

Note 1 to entry: In the case of a visible lane marking, the boundary shall be at the centre thereof.

3.8
suppression request

driver request or a system feature intended to prevent PADS action if an intentional lane departure is detected

3.9
steering action

steering manoeuvre which the system performs to influence the lateral movement of the subject vehicle with the intention of keeping the vehicle within the lane

3.10
visibility

distance at which the illuminance of a non-diffusive beam of white light with a colour temperature of 2 700 K is decreased to 5 % of its original light source illuminance

3.11
failure

mechanical or electronic malfunction which causes a persistent loss of performance or function

Note 1 to entry: Temporary performance reductions, e.g. due to bad weather conditions, bad lane markings or temporarily occurring sensor blindness are not a failure.

3.12
straight

segment of road on which curvature is less than 1/5 000 m

4 Symbols

Table 1 — Symbols and definitions

Symbol	Definition
PADS_curvature_rate_max	maximum rate of change of curvature which is allowed for the curve test track
PADS_Lat_Acel_max	maximum lateral acceleration which is allowed to be induced by a steering action
PADS_Lat_Jerk_max	maximum lateral jerk which is allowed to be induced by a steering action
Vmax	maximum speed at which PADS is designed to function
Vmin	minimum speed at which PADS is designed to function
PADS_lat_test_speed	speed, at which the function is tested

5 Requirements for longitudinal control

Depending on the minimum speed, *Vmin*, PADS shall fulfil the following requirements of specific ACC types:

— PADS with *Vmin* less than 5 m/s shall fulfil the requirements of ACC type FSRA according to ISO 15622.

— PADS with *Vmin* of at least 5 m/s shall fulfil the requirements of ACC type FSRA or LSRA2 according to ISO 15622.

6 Requirements

6.1 Functionality

The responsibility for safe operation of the vehicle always remains with the driver. The driver shall have means to override the PADS at any time.

Within its system limitations, PADS provide the following subfunctions:

— Keeps the speed below a selected maximum speed.

— Keeps a safe distance to forward vehicles in the same lane as specified within the ACC standard.

— Allows the vehicle to follow the current subject vehicle's lane if the lane is defined with lane boundaries.

— Allows the vehicle to follow an estimated lane for the current subject vehicle. The position of the lane may be estimated using the locations of the forward vehicles which are not necessarily driving in the same lane as the subject vehicle.
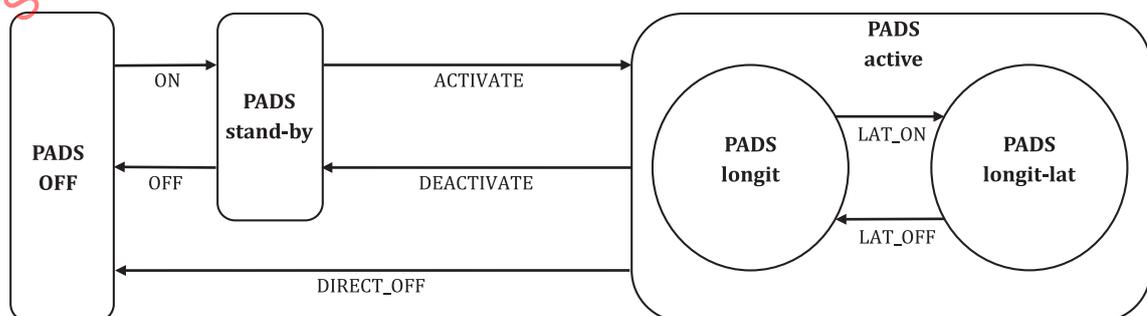

Figure 1 — PADS states and transitions

The responsibility for the safe operation of the vehicle always remains with the driver. PADS shall as a minimum, provide the following operations and state transitions. The following constitutes the fundamental behaviour of PADS:

— The speed range wherein PADS is operational is selected by the OEM. The difference between *Vmin* and *Vmax* shall be at least 8 m/s.

6.1.1 off state

— In off state PADS shall not perform any action.

— The ON transition from PADS off to PADS stand-by can be performed by the driver or automatically, e.g. after the ignition is switched on and no system failure has occurred.

6.1.2 stand-by state

— In off state PADS shall not perform any action.

— The transition ACTIVATE from stand-by to active state shall only be done when initiated by the driver. The transition ACTIVATE may lead to PADS longit or to PADS longit-lat state.

— The transition OFF from PADS stand-by to PADS off can be performed by the driver or automatically, e.g. after the ignition is switched off or a system failure has occurred.

6.1.3 active state

— In both states of the PADS active state the system shall provide speed and distance control in accordance with ISO 15622. Therefore ACC shall be in active state when PADS is in PADS active state.

— In both states of the PADS active state the system shall evaluate the activation criteria for lateral control. One of the activation criteria for PADS longit-lat shall be that the system has determined the position of the vehicle within the lane relative to the lane boundaries of the subject vehicle's lane or relative to a forward vehicle. It is up to the manufacturer to decide whether it is necessary to detect the position of the subject vehicle's lane by one or both lane boundaries of the lane and/or relative to forward vehicles. Other criteria to be selected by the manufacturer may be the type of the lane boundaries (e.g. incidental road feature or solid or dashed lane marking), a minimum vehicle speed, driver actions, steering angle and other vehicle conditions. At least under the conditions of the test defined in Clause 7 the activation criteria shall be fulfilled.

— The transition DEACTIVATE from PADS active to PADS stand-by can be performed by the driver or automatically, for instance after a system failure has occurred.

— For conditions in which ACC would transition to stand-by state PADS shall perform the transition DEACTIVATE to PADS stand-by state or the transition DIRECT_OFF to PADS off state.

— The transition DIRECT_OFF from PADS active to PADS off can be performed by the driver or automatically, for instance after the ignition is switched off or a system failure has occurred.

6.1.4 longit state

— In PADS longit state the system shall not perform steering actions.

— If all of the selected activation criteria for lateral control are met the system shall perform the transition LAT_ON to PADS longit-lat state.

6.1.5 longit-lat state

— In PADS longit-lat state the system shall perform steering actions to influence the lateral movement of the subject vehicle with the intention to keep the vehicle within the lane (unless the driver

overrides the system). The system may detect suppression requests to minimise nuisance steering actions. The suppression request may be issued, e.g. if the driver operates a turn signal.

— In PADS longit-lat state the system shall evaluate the deactivation criteria for lateral control. One of the deactivation criteria for PADS longit-lat shall be that the system cannot determine the position of the vehicle within the lane relative to the lane boundaries of its own lane nor relative to a forward vehicle. It is up to the manufacturer to define additional deactivation criteria.

— If one of the selected deactivation criteria for lateral control is met the system shall perform the transition LAT_OFF to PADS longit state.

6.2 Basic driver interface and intervention capabilities

6.2.1 General

The system shall provide the basic driver interface and intervention capabilities in accordance with ISO 15622 and additionally the following controls and intervention capabilities:

6.2.2 Operation elements and system reactions

— The driver shall be provided with means to override the steering action at any time. Such means shall include turning the steering wheel.

— The driver shall be provided with means to override the longitudinal control in accordance to ISO 15622.

— Specific driver actions can be considered as a suppression request.

— The driver shall be provided with the means to transition (DEACTIVATE in Figure 1) from PADS active to PADS stand-by.

— The driver shall be provided with the means to transition (ACTIVATE in Figure 1) from PADS stand-by to PADS active.

— Drivers shall be informed of the conditions that result in PADS activation and deactivation by the vehicle owner's manual.

6.2.3 Display elements

— The information about whether the PADS is in PADS stand-by state shall be accessible to the driver.

— If PADS is in active state, PADS longit or longit_lat state shall be displayed.

— If PADS is not available due to a failure, the driver shall be informed.

6.2.4 Driver monitoring

PADS shall have means to recognize whether the driver is in principle able to take over the vehicle control and if the driver can supervise the system behaviour. How this is done in detail is up to the OEM. Examples for such means are a hands-off detection, a driver recognition camera or other suitable means. If those means give indication that the driver may not be able to take over the vehicle control or supervise the system behaviour, the system shall notify the driver. The system shall perform the transition LAT_OFF to longit_state or DEACTIVATE to stand-by state or off state (see Figure 1) if the driver does not react on the notification in an appropriate amount of time.

6.2.5 Symbols

— If symbols are used to identify PADS function or malfunction, standardized symbols in accordance with ISO 2575 are recommended to be employed.

6.3   Minimum functionality

6.3.1   General

PADS should be designed to handle normal traffic situations while travelling on roads where non-motorized vehicles and pedestrians are prohibited. They are not required to handle special situations like entries and exits, turning, construction zones, ramps and narrow curves.

6.3.2   Longitudinal control

To cover the main purpose to keep a safe distance to forward vehicles in the same lane, PADS shall pass the test procedures defined in ISO 15622.

6.3.3   Lateral control

PADS shall be able to keep the vehicle in the subject vehicle's lane as long as the curve radius is larger than 500 m and the rate of change of curvature is continuous and does not exceed *PADS_curvature_rate_max.* The PADS may operate also at curve radii below 500 m.

PADS_curvature_rate_max = $4*10^{-5}$ 1/m^2

PADS shall pass the test procedures in Clause 7.

6.4   Operational limits

The operational limits of the speed and distance control are described in ISO 15622.

The steering actions of the lateral control should be designed in a way that the driver is able to use the PADS safely. Therefore the vehicle movements which are induced by the steering actions shall be limited.

— The magnitude of the lateral acceleration which is induced by the steering action shall not exceed *PADS_Lat_Acel_max.* Also the moving average over half a second of the lateral jerk should be limited to *PADS_Lat_Jerk_max.*

  PADS_Lat_Acel_max = 3 m/s^2 for speeds greater than 8 m/s

  PADS_Lat_Acel_max = 5 m/s^2 for speeds less than 8 m/s

  PADS_Lat_Jerk_max = 5 m/s^3

— In case of a transition from PADS active state to PADS stand-by state the steering action shall not end suddenly but shall be faded out smoothly.

— These operational limit requirements shall be fulfilled under all conditions.

— The vehicle owner's manual shall inform the driver that PADS operation is not guaranteed to be the same as on a dry, flat road if it is under low traction conditions, on roads with lateral bend, super elevation, or under adverse weather conditions.

6.5   Failure reactions

— Failures in PADS components shall result in immediate notification to the driver and PADS shall behave as stated in Table 2. The notification shall remain active until the system is switched off.

— The reactivation of PADS shall be prohibited until a successful self-test, initiated by either ignition off/on or PADS-off/on, is accomplished.

Table 2 — Failure reactions

	Failure in subsystem	Failure reaction of the lateral control	Failure reaction of the longitudinal control
1	Steering actuator	Lateral control shall be stopped. If the actuator is still able to fade out smoothly, this is allowed before the lateral control is stopped completely.	A failure reaction is not required if PADS transitions to PADS longit state. Optionally a reaction according to an engine failure as described in ISO 15622 is allowed if PADS transitions to PADS off state.
2	Lane recognition system	The steering action shall not be ended suddenly but shall be faded out smoothly.	A failure reaction is not required if PADS transitions to PADS longit state. Optionally a reaction according to an engine failure as described in ISO 15622 is allowed if PADS transitions to PADS off state.
3	PADS controller	Lateral control shall be stopped. If it is possible to fade out smoothly, this is recommended before the lateral control is stopped completely.	Longitudinal control shall be stopped. If it is possible to fade out smoothly, this is recommended before the longitudinal control is stopped completely.
4	Speed or distance control	The steering action shall not be ended suddenly but shall be faded out smoothly.	As described in ISO 15622.

7 Performance evaluation test methods

7.1 Environmental conditions

— Test location shall be on a flat, dry and clean asphalt or concrete surface.

— Temperature range shall be between –20 °C and +40 °C.

— The wind speed shall be less than 3 m/s.

— Horizontal visibility range shall be greater than 1 km.

— Visible lane markings of the test location shall be in good condition in accordance with the nationally defined visible lane markings. Also, they shall be marked in accordance with applicable standards for lane marking design and materials.

7.2 Test course conditions

The course shall be long enough to maintain the test speed and to perform the whole test.

The width of the lane marking shall be in the range of 0,1 m to 0,3 m according to applicable regulations for highway like roads.

The width of the lane relative to the centre of the lane markings shall be in the range of 3,4 m to 3,9 m according to applicable regulations for highway like roads.

7.3 Test vehicle conditions

The test vehicle mass shall be between complete vehicle kerb mass (including lubricants, coolant, washer fluid, fuel, spare wheel, fire extinguisher, standard spare parts, chocks and standard tool-kit) plus driver and test equipment (combined mass of driver and test equipment shall not exceed 150 kg) and maximum authorised total mass (as determined as a maximum by the administrative authority). See ISO 15037. No alterations shall be made once the test procedure has begun.

7.4 Test system installation and configuration

The PADS shall be installed and configured in accordance with the instructions provided by the manufacturer. No alterations to the system shall be made once the test procedure has begun.

7.5 Test procedure

7.5.1 Parameters recoverable from data record

a) Lateral acceleration.

b) Lateral distance between the centreline of the vehicle and the centreline of the lane.

c) Vehicle speed.

During the whole test the above listed data shall be recorded. The data shall be recovered by a device other than the system. The precision of the test device shall be noted in the test report.

7.5.2 Test track

The tests shall be conducted on a road which is straight entering a curve. It is not necessary for the curve radius to be constant during the whole test. During the whole test the rate of change of curvature should be continuous and should not exceed *PADS_curvature_rate_max*. The test track shall have a curve radius below 550 m at least for 50 m. The test must at least be passed on a track that has a radius that is not less than 500 m. The minimum requirements are also fulfilled if the test is successfully performed on a test track which has lower curve radii or higher or discontinuous rate of change of curvature than stated above.

7.5.3 Procedure

The test procedure consists of two tests, a low-speed test and a mid-speed test. A high-speed test close to the upper PADS speed limit is not required as it is difficult to find an adequately long test track.

For the low-speed test, *PADS_lat_test_speed* shall be 8 m/s.

For the mid-speed test, *PADS_lat_test_speed* shall be 20 m/s.

The vehicle speed shall be between *PADS_lat_test_speed* and *PADS_lat_test_speed* +2 m/s during the whole test run.

Precondition: At the straight section, the test vehicle shall be adjusted near the middle of the lane such that it moves straight and parallel to the lane with the steering wheel angle being zero. After doing this, PADS shall be activated and the steering wheel shall be set free.

Test: After entering the curve, the test shall last for at least 100 m. At least for the last 50 m of the test the test track shall have a radius below 800 m. Both low-speed and mid-speed tests shall be done twice, once entering a left curve and once entering a right curve.

Result: A single test is successful if the outer edges of the tires of the vehicle do not exceed the lane boundary.

The test procedure is successfully passed if both tests in a right and a left curve are successful.

If PADS is not working without a forward vehicle it is allowed to perform the tests with a forward vehicle.

If the lower limit of the PADS speed range is higher than 8 m/s the low-speed test shall be conducted with the specified speed minimum. If the upper limit of the PADS speed range is lower than 20 m/s the mid-speed test shall be conducted with the specified speed maximum.