INTERNATIONAL STANDARD

ISO 23375

First edition
2023-02

Intelligent transport systems — Collision evasive lateral manoeuvre systems (CELM) — Requirements and test procedures

Systèmes de transport intelligents — Systèmes de manœuvre latérale d'évitement de collision (CELM) — Exigences et procédures d'essai

Reference number
ISO 23375:2023(E)

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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

Reducing traffic fatalities, injuries and property damage caused by driver carelessness or unexpected events is a global challenge.

To address this situation, automatic emergency braking (AEB) systems were introduced to mitigate crash consequences through automatic deceleration by braking of the vehicle.

NOTE ISO 22839 and ISO 19237 are examples of related International Standards defining the minimum performance requirements of such systems. The ISO 22733 series defines test procedures to evaluate the performance level of such systems.

These AEB systems work effectively when there is a high probability of a collision, but their operation can be limited, or they can potentially not work at all, when there is a low probability of a collision (e.g. when the degree of overlap to the object is small). However, even in such scenarios, there are cases where a collision can be avoided by system support, i.e. by a small amount of lateral movement.

This document defines functional requirements, minimum performance requirements and test procedures to verify these requirements for collision avoidance systems using lateral movement of the vehicle. The aim of this system is to avoid collisions occurring in the subject vehicle’s travelling direction.

Intelligent transport systems — Collision evasive lateral manoeuvre systems (CELM) — Requirements and test procedures

1 Scope

This document specifies basic control strategies, minimum functional requirements, basic driver interface elements, and test procedures for verifying the system requirements for collision evasive lateral manoeuvre systems (CELM).

A CELM is a safety system aimed at supporting the driver's vehicle operation by avoiding collisions with objects in the forward path of the vehicle. When a collision is predicted, the CELM controls lateral movement of the vehicle by generating yaw moment.

The lateral control manoeuvres can be performed automatically by CELM or can be initiated by the driver and supported by CELM.

Specific methods for object detection and other environmental perception technologies are not described in this document.

This document applies to light vehicles[1] and heavy trucks.[1] Vehicles equipped with trailers are not within the scope of this document.

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.

FMVSS 105, *Hydraulic and Electric Brake Systems*

ISO 19206-2, *Road vehicles — Test devices for target vehicles, vulnerable road users and other objects, for assessment of active safety functions — Part 2: Requirements for pedestrian targets*

ISO 19206-3, *Road vehicles — Test devices for target vehicles, vulnerable road users and other objects, for assessment of active safety functions — Part 3: Requirements for passenger vehicle 3D targets*

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
subject vehicle
SV
vehicle equipped with a collision evasive lateral manoeuvre system (CELM)

3.2
object
obstacle that could represent a hazard if hit by the subject vehicle

3.3
lane marking
delineator, marking or Botts' dot intentionally placed on the borderline of the lane

3.4
lane boundary
outer edge of the lane marking

Note 1 to entry: See 3.3.

3.5
system failure
inability of a system or system component to perform a required function within specified limits, which is caused by mechanical or electronic malfunction

3.6
SV direction
direction of travel of SV used to predict a collision

3.7
time to collision
TTC
time that it will take a subject vehicle to collide with an object assuming constant relative velocity

3.8
critical approach
driving situation which leads to an imminent collision if no driver or system prevention reaction occurs

4 Symbols and abbreviated terms

4.1 Symbols

Symbols used in this document and their meanings are described in Table 1.

Table 1 — Symbols and meanings

Symbol	Meaning	Unit
V_{SV}	Speed of the SV.	m/s
V_{min}	Minimum SV speed for CELM operation.	m/s
V_{max}	Maximum SV speed for CELM operation.	m/s
V_{svL}	The mean of lateral speed of the SV orthogonal to the lane markings, i.e. the y-axis component of vehicle motion when traveling parallel to the lane markings (see 9.3.3.3 for details).	m/s

Table 1 *(continued)*

Symbol	Meaning	Unit
L_d	Lateral distance between the outermost edge of the object and the extension of the side of the SV closest to the object when measured parallel to the SV (i.e. point at which the distance becomes minimum). A positive value refers to a situation where an overlap exists between the SV and object. A negative value refers to a situation where an overlap does not exist between the SV and object. See 7.2.2 for details.	m
L_{d_inner}	Distance between the edge of an object and the inner edge of lane marking, when the object is located inside the ego lane of the SV.	m
L_{d_outer}	Distance between the edge of an object and the outer edge of lane marking, when the object is located outside the ego lane of the SV.	m
L_{ofst_min}	Minimum amount of lateral offset to which the system is designed to respond.	m
L_{ofst_max}	Maximum amount of lateral offset to which the system is designed to respond.	m
x_{c_min}	Minimum longitudinal distance for which the angle between the SV and an object must be constant when the SV approaches a test target.	m

4.2 Abbreviated terms

AEB automatic emergency braking

CELM collision evasive lateral manoeuvre system

LDP lane departure prevention

TTC time to collision

GNSS Global Navigation Satellite System

5 System overview

5.1 General

The CELM detects objects in the front area in the current SV direction of travel.

The CELM determines objects as hazardous if they are predicted to be in the driving path of the SV and a collision with the object is imminent.

The CELM activates actuators (e.g. steering, brake) to generate yaw moment in an attempt to avoid a collision.

The CELM controls or supports the lateral movement of the SV in the direction which avoids the collision in the best manner or which has been chosen by the driver.

The CELM may operate under conditions where AEB systems are activated.

5.2 Classification

CELMs are classified into two types as shown in Table 2.

Table 2 — Type classification

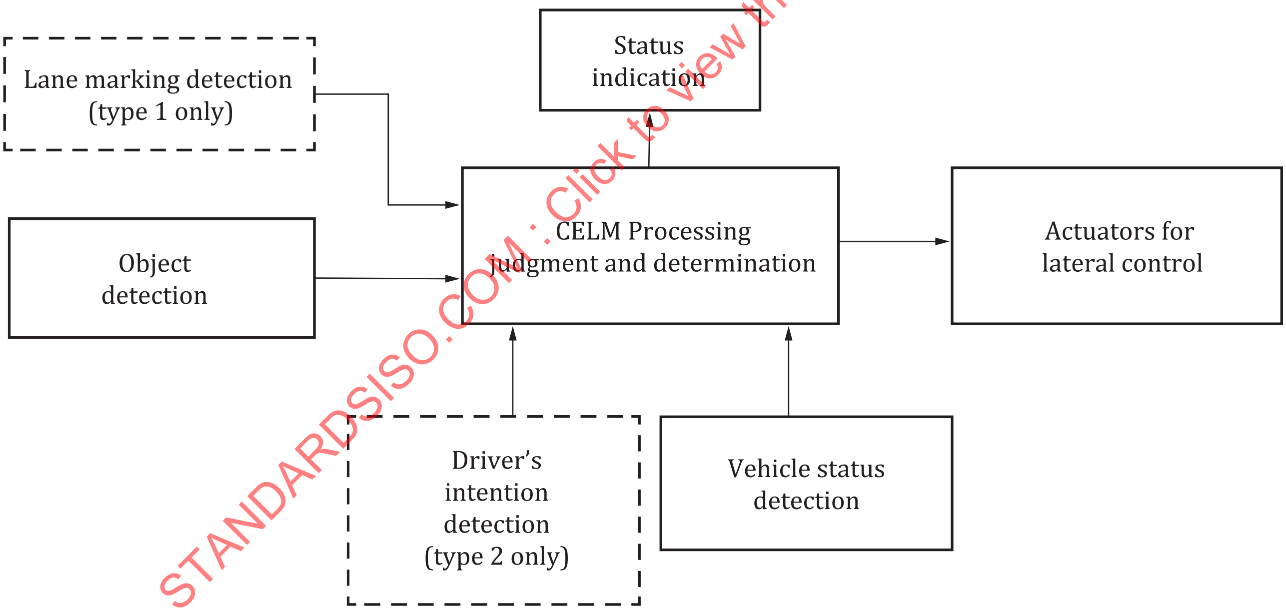
Types	Initiation	Description
Type 1	Automatic	— The evasive manoeuvre is performed automatically by the system (See Clause 7 for details). — Amount of lateral movement is restricted.
Type 2	Driver trigger	— The driver performs the evasive manoeuvre. The system supports the driver (See Clause 8 for details). — No restriction on the amount of lateral movement.

6 General functional requirements

6.1 Functional elements

The CELM shall be designed taking into consideration the functional elements shown in Figure 1.

Output to the brake actuator (e.g. activation of AEB systems) can potentially improve avoidance performance. However, the implementation methods for such a combination are not described in this document.



Key

——— common elements for both types

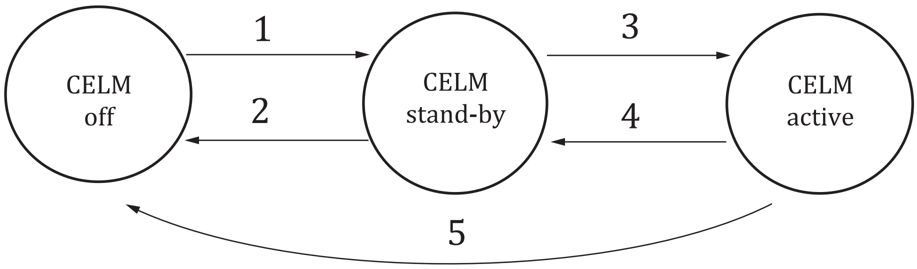
– – – – type specific elements

Figure 1 — Functional elements

6.2 State transition

A CELM shall operate according to the state transition diagram shown in Figure 2. Specific implementation beyond what is illustrated in Figure 2 is left up to the manufacturer.

The transition diagram in Figure 2 is applicable to both Type 1 and 2 systems. However, conditions for transition 3 and 4 are different.



Key

1 Ignition on
and no system failure
and CELM is switched on (optionally)

2 System failure
or ignition off
or CELM is switched off (optionally)

3 Type 1
— critical approach is predicted
— and $V_{min} \leq V_{sv} \leq V_{max}$
— and other criteria specified by manufacturer (optionally)
Type 2
— system predicts a critical approach to an object
— and the driver initiates an evasive manoeuvre
— and $V_{min} \leq V_{sv} \leq V_{max}$
— and other criteria specified by manufacturer (optionally)

4 Driver override condition satisfied
or evasive manoeuvre is completed

5 System failure
or ignition off
or CELM is switched off (optionally)

Figure 2 — State transition diagram

6.2.1 Definition of states

6.2.1.1 CELM off state

State in which the CELM is not ready for activation.

6.2.1.2 CELM stand-by state

State in which the system is ready for activation.

6.2.1.3 CELM active state

State in which the system is activated. Operating conditions and requirements defined in Clause 7 (for Type 1) or Clause 8 (for Type 2) and manufacturer-defined collision prediction conditions and minimum functional requirements shall be satisfied.

6.2.2 Transition conditions

6.2.2.1 Transition from CELM off to CELM stand-by (key element 1 of Figure 2)

The system shall transition from CELM off state to CELM stand-by state with the conditions of ignition on and no system failure. If the system is equipped with a CELM on/off switch, it shall transition from

CELM off state to CELM stand-by state with the conditions of ignition on, no system failure, and the system has not been deactivated by the driver.

6.2.2.2 Transition from CELM stand-by to CELM off (key element 2 of Figure 2)

The system shall transition from CELM stand-by state to CELM off state with the conditions of system failure or ignition off. If the system is equipped with a CELM on/off switch, it shall transition from CELM stand-by state to CELM off state when the driver deactivates CELM with the switch.

6.2.2.3 Transition from CELM stand-by to CELM active (key element 3 of Figure 2)

6.2.2.3.1 Type 1 systems

The system shall transition from CELM stand-by to CELM active state when the system predicts a collision, no driver avoidance operation is detected, and operating conditions and requirements defined in Clause 7 are satisfied.

NOTE See Annex A for examples of use cases of Type 1 systems.

6.2.2.3.2 Type 2 systems

The system shall transition from CELM stand-by to CELM active state when the system predicts a critical approach, the driver initiates an evasive manoeuvre, and operating conditions and requirements defined in Clause 8 are satisfied.

6.2.2.4 Transition from CELM active to CELM stand-by state (key element 4 of Figure 2)

The system shall transition from CELM active state to CELM stand-by state when the evasive manoeuvre is completed, or the driver overrides the system.

6.2.2.5 Transition from CELM active to CELM off (key element 5 of Figure 2)

The system shall transition from CELM active state to CELM off state with the conditions of system failure or ignition off. If the system is equipped with a CELM on/off switch, it shall transition from CELM active state to CELM off state. It is recommended for the transition to result in a gradual change of the yaw moment control.

6.3 Response to failure during CELM active state

Occurrence of a system failure during CELM active state should not result in conditions uncontrollable by the driver. Yaw moment control should fade out gradually.

6.4 Status indication

6.4.1 Active state

The system shall provide information to the driver when the system is in active state.

If the vehicle is equipped with AEB and/or lane departure prevention (LDP) systems, the display device may be commonly used to indicate the active state of multiple systems.

The driver shall be provided with an indication of active state. Specific implementation of the indication is left to the manufacturer.

6.4.2 Optional warning

When the system has detected probability of a collision exceeding the defined threshold, the CELM may provide a driver with a warning to suggest evasive manoeuvres. If the vehicle is equipped with AEB and/or LDP systems, the display device may be shared to provide this optional warning.

6.4.3 Failure

The driver shall be provided with an indication of system failure. Specific implementation of the indication is left to the manufacturer.

6.4.4 CELM switch on/off status

If the system is equipped with a CELM on/off switch, it shall be possible for the driver to determine the status of the switch (i.e. on or off) whenever needed.

6.5 Status symbols

Status symbols to indicate CELM function or malfunction may be specified by the manufacturer. Standardized symbols in accordance with ISO 2575 may be used.

6.6 Minimization of vehicle lateral movement by CELM

Lateral movement should be limited so that the SV passes the object as close as possible while still maintaining a sufficient clearance to reliably avoid a collision.

6.7 Driver override

The driver shall be provided with the means to override the system operation at any time. Such means shall include steering wheel operation (e.g. towards the direction opposite to the evasive manoeuvre), and optionally may include CELM off-switch operation if the vehicle is equipped with a CELM on/off switch. When the system is either initiating, performing or terminating an evasive manoeuvre, the vehicle shall remain controllable by the driver.

Brake intervention by the driver during the CELM active state shall not be considered as an override.

6.8 User-adjustable intervention thresholds

CELM may be equipped with a user-adjustable switch to change intervention thresholds, such as the point in time to issue a warning, the point in time to transition to CELM active state, or the degree of yaw moment control during CELM active state.

6.9 Information to the user in the manual

Manufacturers shall provide the user with a general description of the system functionalities and limitations in the user's manual.

7 Operating conditions and requirements for Type 1 systems

7.1 General

Type 1 systems support the driver in an approach situation where a collision with an object is imminent. If the driver does not react, the system shall perform an automatic evasive manoeuvre when physical conditions (e.g. road friction, geometry) allow. CELM determines the evasive driving direction (left/right) and, when the physical conditions allow, calculates a path to avoid a collision with the object. The evasive manoeuvre shall be performed within the lane of the subject vehicle.

The system shall control the SV position and orientation with respect to the lane so that the heading angle is as parallel as possible to the direction of the lane when an evasive manoeuvre is complete. However, the heading angle requirement does not apply if the SV comes to a stop during the evasive manoeuvre.

If there are no lane markings, the maximum allowable lateral movement is limited.

7.2 Object condition

7.2.1 Object type

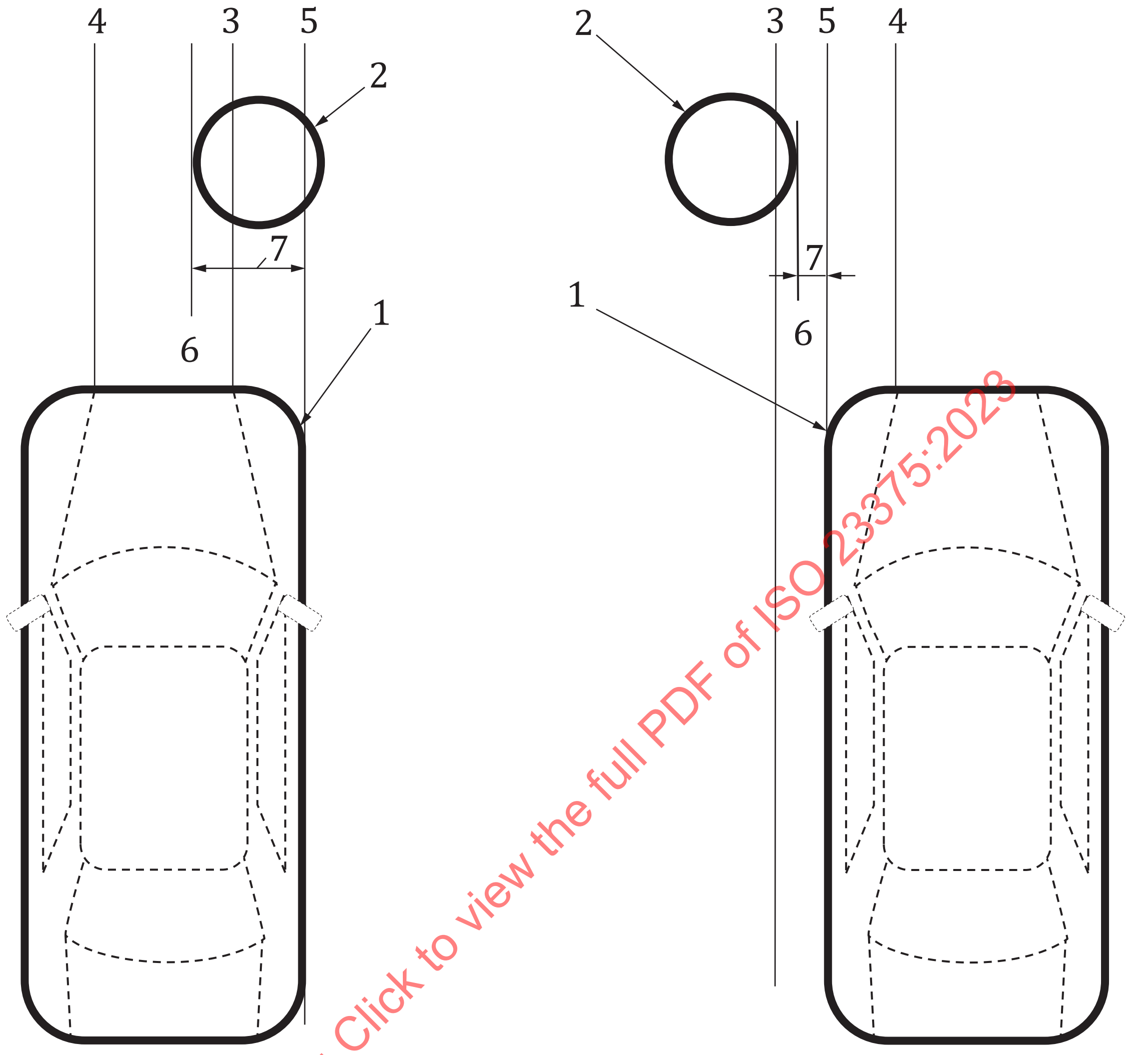
The manufacturer shall define the type of objects to which the system shall respond. At a minimum, Type 1 systems shall respond to a stationary pedestrian or a stationary vehicle. Further augmentation of the system to respond to moving objects or other types of stationary objects is up to the manufacturer. However, this document does not specify performance requirements for such augmented systems with enhanced performance.

7.2.2 Amount of lateral offset

Type 1 systems shall operate, at a minimum, under conditions where an overlap exists between the object and SV. The relative lateral positions between the SV and object where CELM activates (i.e. values of L_{ofst_min} and L_{ofst_max}) shall be defined by the manufacturer.

Figure 3 illustrates the relative lateral positions between the SV and object where the object is within the range for system operation.

Depending on the system design, L_{ofst_min} may be a negative value, meaning that the object is outside of the extension of the vehicle width, but can still be determined by CELM that a collision is imminent. This condition is illustrated in Figure 3 b).



a) Overlap exist

b) Overlap does not exist

Key

1 outermost edge of SV

2 outermost edge of object

3 L_{ofst_min}

4 L_{ofst_max}

5 extension of SV width (object side)

6 extension of outermost edge of object

7 L_d

Figure 3 — Amount of lateral offset

7.3 Activation speed of subject vehicle

Type 1 systems can be further classified by activation speed as shown in Table 3.

For example, systems primarily intended to be used on urban/city roads are in the low-speed category and systems primarily intended to be used on highway/motorways are in the high-speed category.

V_{min} and V_{max} shall be defined by the manufacturer.

The difference between V_{min} and V_{max} of each CELM shall be greater than 5,5 m/s, and include at least the range shown in Table 3.

Table 3 — Minimum activation speed range of SV

Categories	Minimum required ranges	Examples of possible activation speed ranges		
		V_{min}	V_{max}	Difference
Low speed	$V_{min} \leq 12$ m/s $V_{max} \geq 13$ m/s	7,5 m/s	13 m/s	5,5 m/s
		12 m/s	17,5 m/s	5,5 m/s
		5 m/s	15 m/s	10 m/s
High speed	$V_{min} \leq 17$ m/s $V_{max} \geq 20$ m/s	17 m/s	22,5 m/s	5,5 m/s
		14,5 m/s	20 m/s	5,5 m/s
		15 m/s	25 m/s	10 m/s

7.4 Road condition

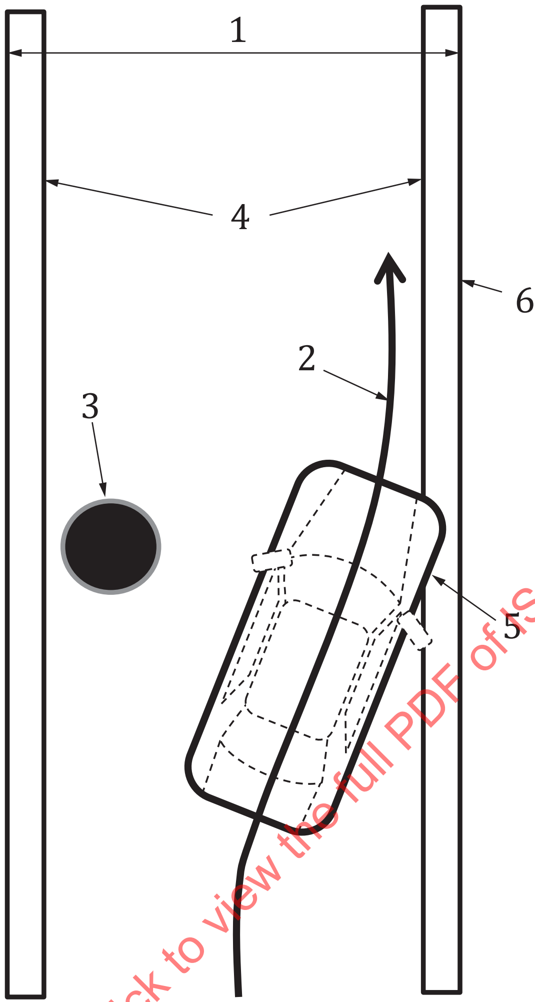
As a minimum requirement, Type 1 systems shall operate on roads with visible lane markings.

Optionally, Type 1 systems may also operate on roads without lane markings.

7.5 Operational limit

7.5.1 Operation on roads with lane markings

In situations where the system operates on roads with lane markings, its lateral control shall be performed within the SV's own lane. Therefore, allowable lateral movement for evasive manoeuvre is limited to the lane boundary on the avoidance side, which means that the body of the SV (excluding side view mirrors) shall not cross over the lane boundary (outer edge of the lane marking). Figure 4 illustrates the lane boundary and the allowable lateral movement of SV.



Key

1 allowable range of lateral movement

2 vehicle trajectory

3 object

4 lane markings

5 outermost edge of SV excluding side view mirrors

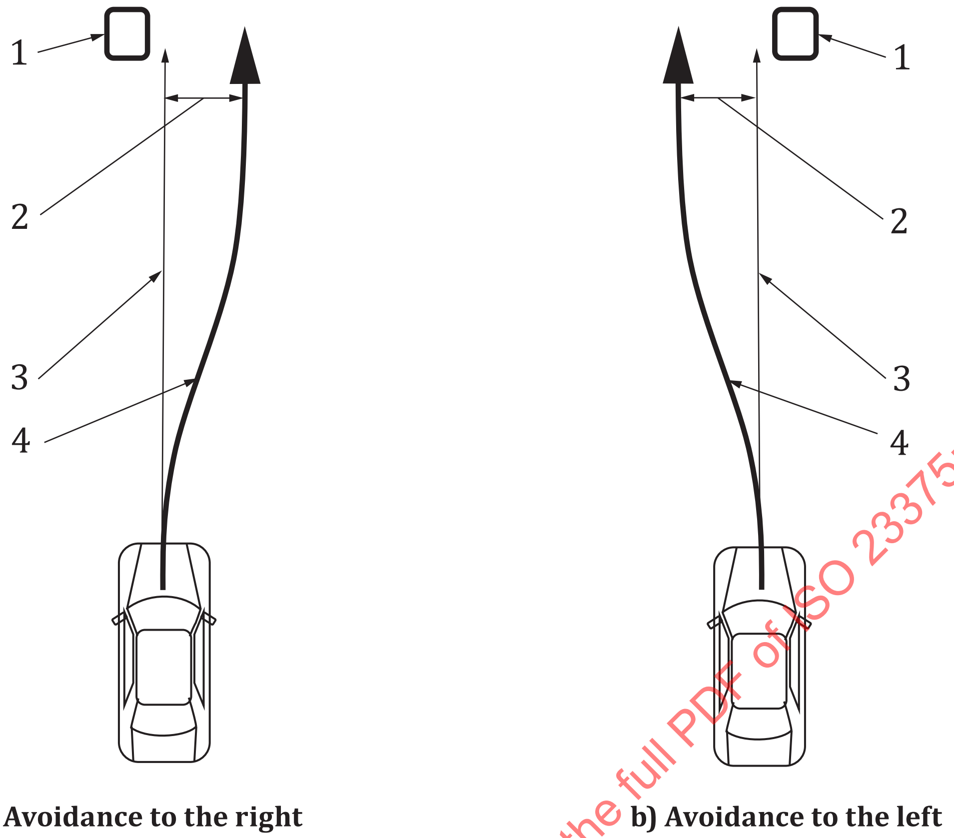
6 lane boundary (outer edge of the lane marking)

NOTE This figure shows an example of collision avoidance to the right. However, it can be applied to collision avoidance in both directions (right and left).

Figure 4 — Lane boundary and allowable lateral movement of SV

7.5.2 Operation on roads without lane markings

In situations where the system operates without lane markings, the permissible range of lateral movement of the SV should not exceed 0,75 m with respect to the extension of the path of the SV. Figure 5 illustrates the recommended permissible lateral movement.



Key

1 object

2 recommended allowable lateral movement

3 extension of the path of the SV

4 travelling path with CELM

Figure 5 — Recommended allowable lateral movement

8 Operating conditions and requirements for Type 2 systems

8.1 General

Type 2 systems support the driver in steering around an object when the system detects a critical approach.

As soon as the driver initiates an evasive manoeuvre, the system calculates a path that allows the SV to pass the object without colliding with it. However, when the physical conditions [(e.g. road friction, geometry, time to collision (TTC)] do not allow such a manoeuvre, the system will not necessarily activate, or the assisted evasive manoeuvre will not necessarily result in object avoidance. The evasive direction (left/right) is determined by the driver's input on the steering wheel. If the steering torque applied by the driver is not sufficient to avoid a collision with the object, the system supports the driver action by adjusting the yaw moment. The driver is expected to continuously steer the vehicle during the evasive manoeuvre since the system can only provide support (i.e. does not perform automatic collision avoidance). There are no lateral restrictions to the trajectory. Therefore, the SV can potentially depart from its own lane of travel as a result of assisting the driver's evasive manoeuvre. However, it should be noted that Type 2 systems are not aimed at supporting a normal lane change manoeuvre in the absence of a critical approach.

8.2 Object condition

As a minimum, Type 2 systems shall respond to a stationary vehicle and may respond to a moving vehicle.

Further augmentation of the system to respond to other types of moving or stationary objects is up to the manufacturer. However, this document does not specify requirements for augmented systems with such enhanced performance.

8.3 Activation speed of subject vehicle

The manufacturer shall specify the upper and lower limits, V_{min} and V_{max}. These limits shall satisfy the following conditions.

— $V_{min} \leq 17$ m/s

— $V_{max} \geq 20$ m/s

— There shall be a range of 5,5 m/s or more between V_{min} and V_{max}

8.4 Additional considerations for support beyond collision avoidance

It is recommended that after avoiding a collision, Type 2 systems provide support in controlling the heading angle of the SV in an appropriate direction (e.g. based on lane markings, relative to the test target, relative to the original heading angle). However, this document does not require such appropriate control due to the variety of possible situations, and instead focuses on the minimum requirement in providing support to avoid a collision. This document therefore does not include verification of such aspects in the test procedure and pass criteria.

9 Performance evaluation test methods

9.1 General

In order to confirm conformance with the requirements specified in this document, CELM shall be tested according to the procedures defined in the following subclauses. The typical conditions that satisfy the minimum requirements defined in Clause 7 and 8 are provided.

For both Type 1 and 2 systems, testing shall be performed under the conditions specified in 9.2. Test procedures and pass criteria for Type 1 systems are specified in 9.3. Test procedures and pass criteria for Type 2 systems are specified in 9.4.

9.2 Test conditions

9.2.1 Environmental conditions

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

— The ambient temperature range shall be between −20 °C and +40 °C.

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

— The horizontal visibility range shall be greater than 1 km.

— For the lane markings at the test location, ISO 11270:2014, Annex B may be referenced.

9.2.2 Test course conditions

The course shall be of sufficient length to maintain the maximum vehicle speed required by a specific test. The testing shall be performed on a straight road. For a system using lane information, the width of the lane marking shall be in the range of 0,1 to 0,3 m and the width of the lane shall be in the range of 3,0 to 4,0 m in accordance with applicable regulations for highway-like or city roads.

However, to verify the minimum requirements for Type 1 systems aimed at avoiding objects within the current lane of travel [see Figure 7 a) for details], the width of the lane shall be greater than the sum of the vehicle width, plus 0,75 m, plus L_{d_inner}.

Curvature of the segment of the road shall be less than 1/5,0 m. The road superelevation (i.e. lateral inclination or road camber) shall be less than either 3 % or 1,7 °.

9.2.3 Test vehicle conditions

The test vehicle mass shall be between complete vehicle curb mass (see ISO 1176), and complete vehicle curb mass plus test operator(s) and test equipment loaded to the test vehicle (combined mass of test operator(s) and test equipment shall not exceed 200 kg). No alterations shall be made once the test procedure has begun.

The vehicle used for testing shall be adequately conditioned. If requested by the vehicle manufacturer, drive a maximum of 100 km on a mixture of urban and rural roads with other traffic and roadside objects to calibrate the sensor system. Avoid harsh acceleration and braking. The conditions for adequately warming up brake systems/tyres for the test vehicle shall be equivalent to FMVSS 105 S7.4.1.1.

9.2.4 Test system installation and configuration

The CELM shall be installed and configured in accordance with the instructions provided by the manufacturer to ensure its intended functionalities.

In case of a system which allows user-adjustable intervention thresholds, each test shall be performed with the earliest possible intervention threshold. No alterations shall be made to the system once the test procedure has begun.

9.2.5 Data recording

The vehicle speed (m/s) shall be recorded.

In addition, lateral acceleration (m/s^2) or yaw-rate (rad/s) shall be recorded when testing type 1 systems.

The data above shall be obtained for all evasive manoeuvres performed by CELM during the test. The data shall be measured by a device other than the system. The precision of the test device shall be noted in the test report.

Data sampling frequency shall be determined in accordance with the digital sampling theorem to ensure replication of the signals.

9.2.6 Test target

Test targets used for verifying the minimum requirements shall conform to the specifications provided in the reference documents in Table 4.

Table 4 — Test target reference documents

Object type	Reference document
Pedestrian	ISO 19206-2
Vehicle	ISO 19206-3

Test targets for other object types may be used for verifying systems with enhanced performance. It is recommended to refer to ISO 19206-4 for testing with bicyclists. Real objects (such as guardrails) may also be used.

Test objects will be stationary for verification of the minimum requirements in this document.

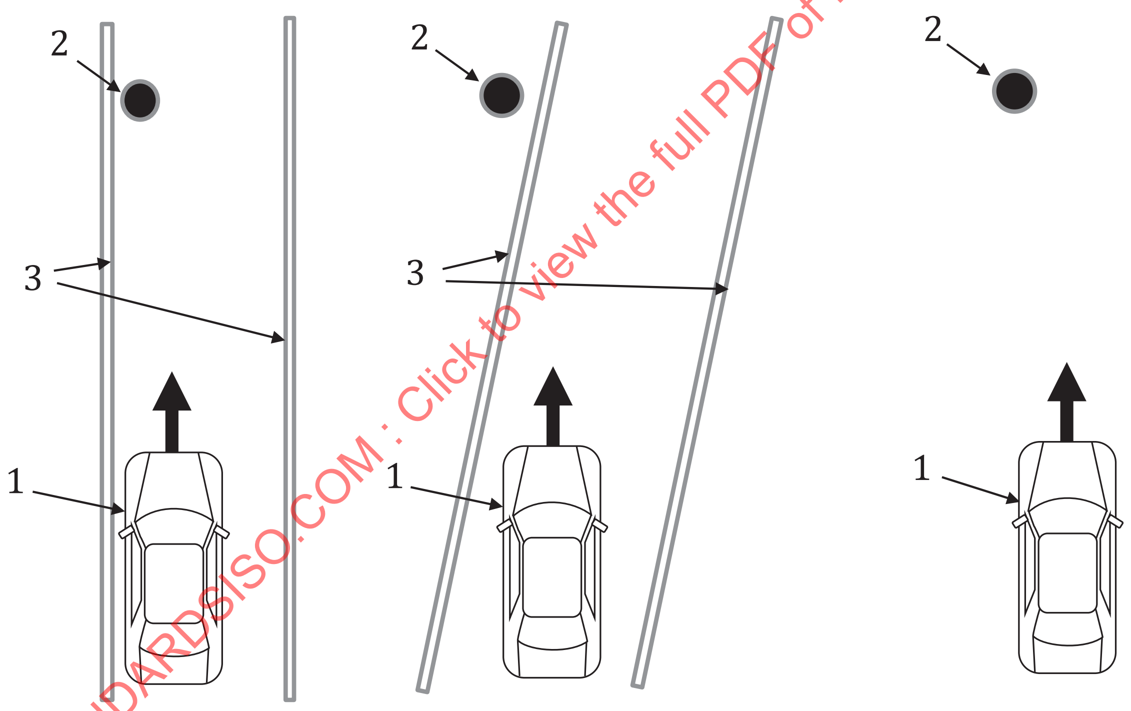
9.3 Type 1 test procedures

9.3.1 Test case selection

Type 1 systems have three test cases (shown in Table 5) based on relative positional relationships between the SV, the object and the lane markings. All of the test case(s) for which the system under test is designed to respond shall be chosen.

Table 5 — Test cases for Type 1systems

Test case	Object condition	Reference figure
Case I	Avoidance of in-lane object	Figure 6 a)
Case II	Avoidance of object outside of the lane	Figure 6 b)
Case III	Avoidance of object without lane information	Figure 6 c)



a) Case I b) Case II c) Case III

Key

1 SV

2 object

3 lane markings

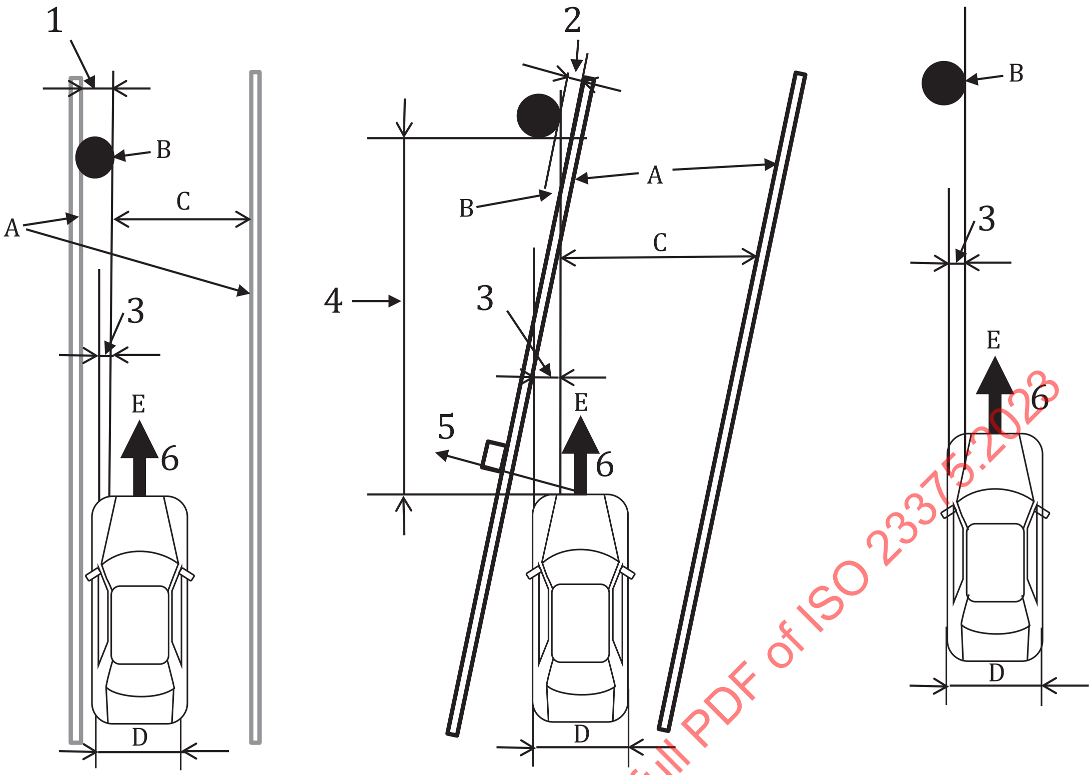
Figure 6 — Relative positional relationships between SV, object and lane

9.3.2 Test parameters

The values specified in Table 6 shall apply for testing (for Test case III, key reference 1 is not applicable). See Figure 7 for relationship between the items in Table 6 and each test case. See Figures 7 to 10 for example test setups.

Table 6 — Test parameters

Key of Figure 7	Item	Units	Value
1 or 2	[Test case I] L_{d_inner}	m	Value which satisfies the following two conditions: — 0,50 m ≤ L_{d_inner} ≤ 1,0 m — C > D + 0,75 m
	[Test case II] L_{d_outer}	m	0,3 m
	[Test case III] No item	—	
3	[Test case I] L_d	m	Either one of the values from the following options shall be chosen where an overlap exists (lateral offset is a positive value), based upon which one the system under test is designed to respond to: — 50 % of the SV width — 25 % of the SV width Tolerance of L_d shall be within 5 %
	[Test case II] L_d	m	At minimum, a portion of the object is within the following range where an overlap exists (lateral offset is a positive value): — from 25 % to 50 % of the SV width
	[Test case III] L_d	m	Either one of the values from the following options shall be chosen where an overlap exists (lateral offset is a positive value), based upon which one the system under test is designed to respond to: — 50 % of the SV width — 25 % of the SV width Tolerance of L_d shall be within 5 %
4	[Test case I] No item	—	
	[Test case II] x_{c_min}	m	$x_{c\_min} = V_{sv}$ × TTC threshold criterion TTC threshold criterion = 2 s
	[Test case III] No item	—	
5	[Test case I] No item	—	
	[Test case II] V_{svL}	m/s	Low speed system = 0,3 m/s High speed system = 0,5 m/s Tolerance of the V_{svL} shall be within ±0,05 m/s
	[Case III] No item	—	
6	[Common for all cases] V_{sv}	m/s	Low speed system = 12,5 m/s High speed system = 18,5 m/s Tolerance of the V_{sv} shall be within 3 %



a) Test case I

b) Test case II

c) Test case III

Key

1 L_{d_inner} [Figure 6 a)]
2 L_{d_outer} [Figure 6 b)]
3 L_d
4 x_{c_min}
5 V_{svL}
6 V_{sv}

A lane boundary
B outermost edge of object
C allowable range of lateral movement
D SV width
E SV direction

Figure 7 — Relationship between the items in Table 6 and each test case

9.3.3 Test target selection and positioning

9.3.3.1 General

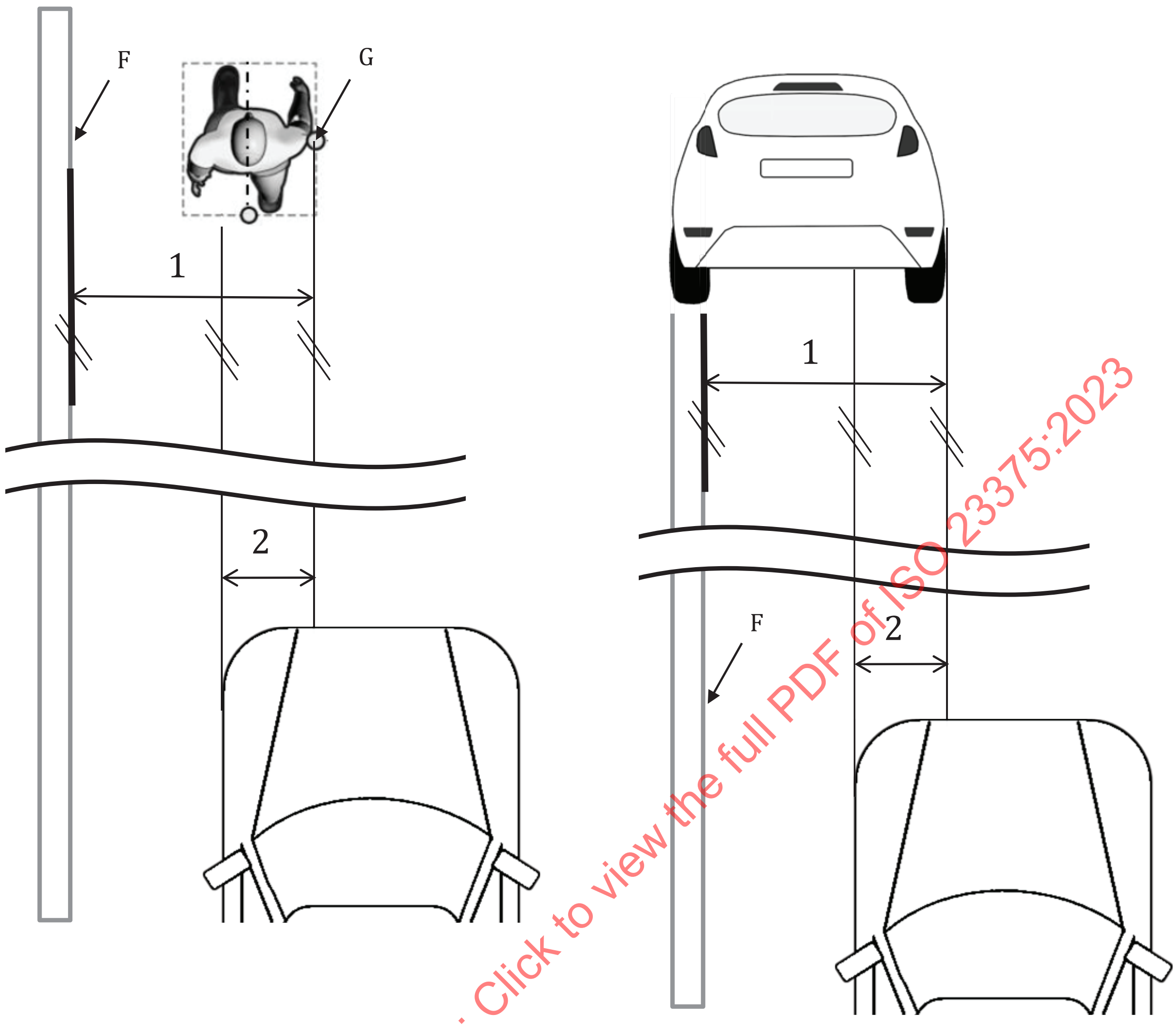
In order to verify the minimum requirement, either the adult pedestrian test target or the vehicle test target (See Table 4) shall be chosen depending on the type of object to which the system under test is designed to respond.

The test target shall be placed stationary at the position specified in the following subclauses and in accordance with the values defined in 9.3.2.

9.3.3.2 Test case I

Figure 8 specifies the positions of the vehicle and pedestrian test targets for Test case I. Both test targets shall be facing in the same direction of travel as that of the SV.

A virtual box is defined as the outer edge of the pedestrian test target. The shoulder shall be used as the reference point in determining L_{d_inner} and L_d.



a) Pedestrian test target

b) Vehicle test target

Key

1 L_{d_inner}

2 L_d

F inner edge of lane marking

G reference point

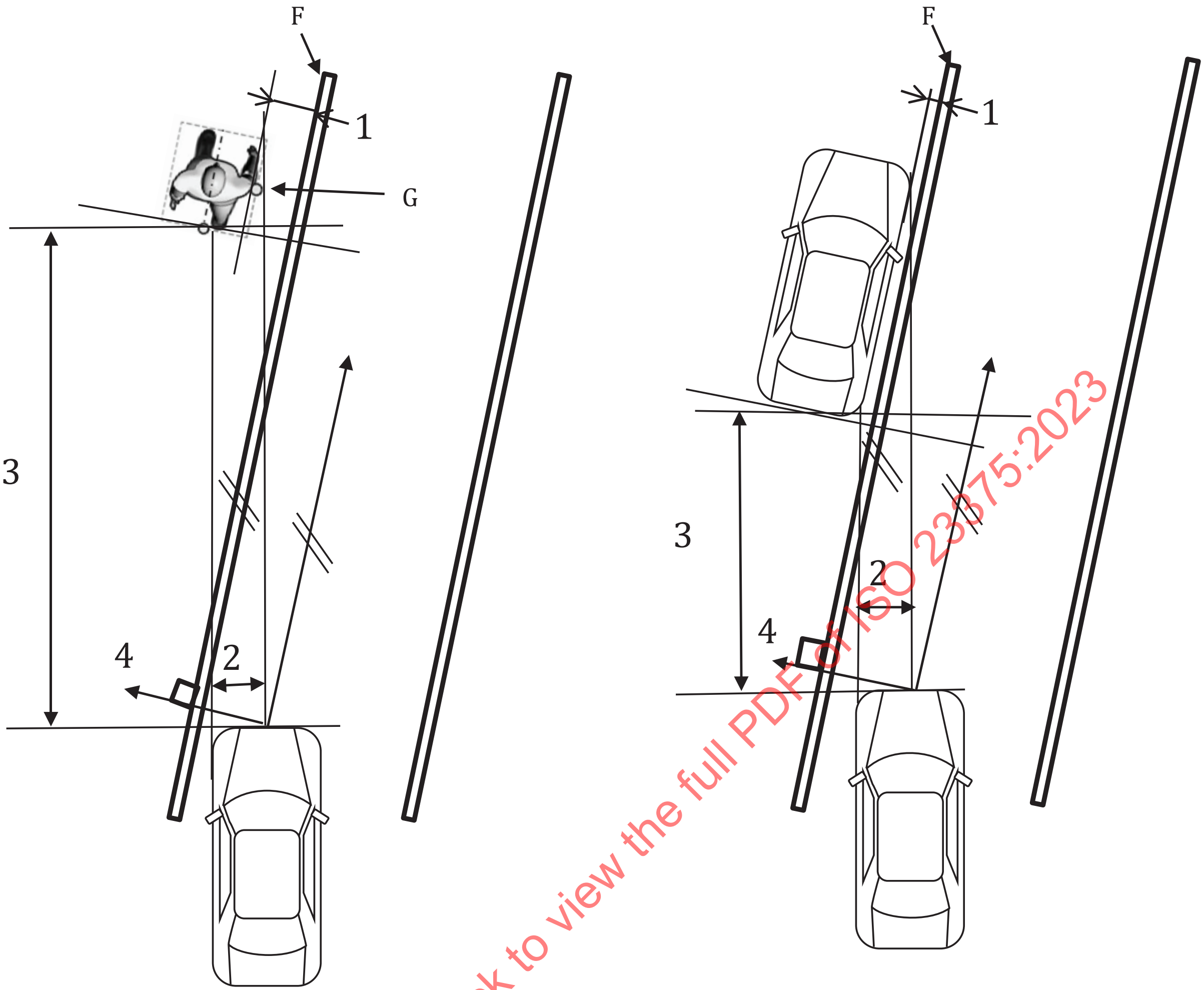
Figure 8 — Test case I test target position

9.3.3.3 Test case II

Figure 9 specifies the position of the test target for Test case II. Both test targets shall be placed parallel to the lane marking and facing in the same direction of travel as that of the SV.

For Test case II, it is assumed that the SV will travel within the lane during its approach, and the test target will not necessarily be in the forward path of the SV. In this case, the heading angle of the SV is adjusted to achieve the specified V_{svL} and L_d when satisfying x_{c_min} at the latest.

Note that V_{svL} is zero when travelling parallel with the lane marking, and that V_{svL} as defined in Figure 9 can be achieved when the heading angle of the SV is approximately 1,5° relative to the lane marking.



a) Pedestrian test target

b) Vehicle test target

Key

1 L_{d_outer}

2 L_d

3 x_{c_min}

4 V_{svL}

F outer edge of lane marking

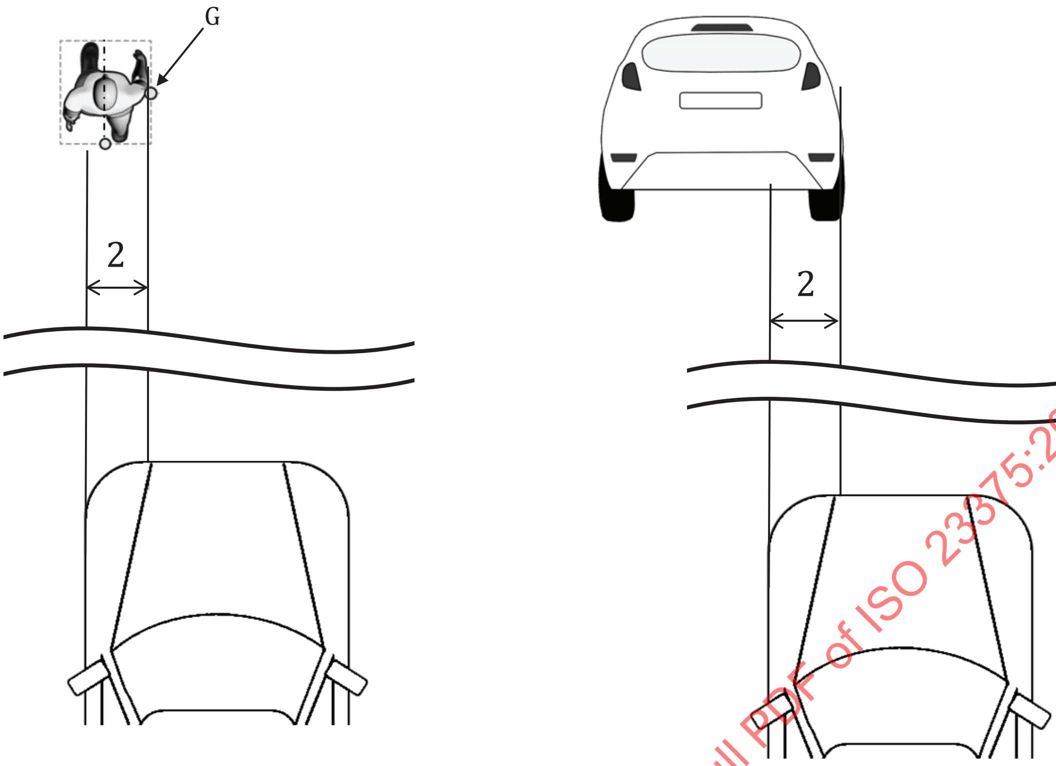
G reference point

Figure 9 — Test case II test target position

9.3.3.4 Test case III

Figure 10 specifies the positions of the vehicle and pedestrian test targets for Test case III. Both test targets shall be facing in the same direction of travel as that of the SV.

A virtual box is defined as the outer edge of the pedestrian test target. The shoulder shall be used as the reference point in determining L_d.



a) Pedestrian test target **b) Vehicle test target**

Key

2 L_d

G reference point

Figure 10 — Test case III test target position

9.3.4 Test procedures

9.3.4.1 Test case I

Testing shall be carried out as follows.

1) Place the test target in accordance with 9.3.3.2.

2) Set the SV direction in such a way that the L_d value is satisfied.

3) Drive the SV towards the object maintaining V_{sv} until either the evasive manoeuvre starts, or other safety systems (e.g. AEB) are activated.

4) To verify automatic collision avoidance, the steering wheel shall not be operated by the test driver while the CELM is performing the lateral evasive manoeuvre.

9.3.4.2 Test case II

Testing shall be carried out as follows.

1) Place the test target in accordance with 9.3.3.3.

2) Drive the SV towards the object in accordance with 9.3.3.3 while maintaining V_{sv}. When the actual longitudinal distance between the SV and the test target is closer than x_{c_min}, continue to drive whilst maintaining V_{svL} and L_d until either the evasive manoeuvre starts, or other safety systems (e.g. AEB) are activated.

3) To verify automatic collision avoidance, the steering wheel shall not be operated by the test driver while the CELM is performing the lateral evasive manoeuvre.

9.3.4.3 Test case III

Testing shall be carried out as follows.

1) Place the test target in accordance with 9.3.3.4.

2) Set the SV direction in such a way that the L_d value is satisfied.

3) Drive the SV towards the object maintaining V_{sv} until either the evasive manoeuvre starts, or other safety systems (e.g. AEB) are activated.

4) To verify automatic collision avoidance, the steering wheel shall not be operated by the test driver while the CELM is performing the lateral evasive manoeuvre.

9.3.5 Pass criteria

The pass criteria are determined by the combination of the type of test target used and the selected Test case as shown in Table 7.

In order to take into consideration any uncontrollable external disturbance (e.g. environmental conditions) that can occur during the test procedures, the test shall be performed five times and shall satisfy the pass criteria defined below four out of the five times.

If a collision was avoided only by longitudinal deceleration induced by an AEB system without a lateral evasive manoeuvre induced by a CELM, the test shall not be counted as a pass or a fail. In this case the test parameters shall be modified until the lateral evasive manoeuvre is observed.

Use of visual image or differential GNSS location data is recommended for verifying the criteria defined in Table 7.

Table 7 — Test pass criteria

	Test cases I and II	Test case III
Pedestrian test target	— There is no physical contact between the SV and the test target (including side view mirrors). — The tyre of the SV shall not cross the outer edge of the lane marking.[a]	— There is no physical contact between the SV and the test target (including side view mirrors).
Vehicle test target	— There is no physical contact between the SV's body (excluding side view mirrors) and the test target. — The tyre of the SV shall not cross the outer edge of the lane marking.[a]	— There is no physical contact between the SV's body (excluding side view mirrors) and the test target.

[a] Note that the requirements stated in 7.5.1 refer to the body of the SV against the outer edge of the lane markings. However, this criteria will focus on the tyre of the SV considering feasibility of measuring the test results.

9.4 Type 2 test procedures

9.4.1 Test equipment

9.4.1.1 Steering robot

Testing CELM Type 2 requires a steering robot capable of controlling the SV in two different modes: trajectory-based control (closed loop), and torque-based control (open loop). The steering robot shall also be capable of changing its mode from trajectory-based control to torque-based control during a single test run.

1) Trajectory-based control involves adjusting the position of the SV towards a sequence of way points defined in absolute position coordinates. Data used for trajectory-based control also contain speed information.

2) Torque-based control involves applying a series of predefined amounts of torque to the steering wheel at certain times and/or locations.

See Annex B for additional information.

9.4.1.2 Test target selection and positioning

To verify the minimum requirements, the vehicle shall be chosen as a test target based on Table 4.

The orientation of the vehicle target shall face the same direction as the SV's direction of travel.

9.4.1.3 Substitute test target

A substitute test target (e.g. image placed flat on the road surface) is to be used during the confirmation run to avoid unnecessary damage to the SV.

9.4.2 Trajectory and torque data

9.4.2.1 Creating trajectory data

Trajectory data which satisfies the following requirements and values specified in Table 8 shall be created. Key references in brackets correspond to those shown in Figure 11.

— The approaching trajectory data (key reference F) between the SV starting point (key reference C) and the triggering point (key reference D) shall maintain a constant lateral offset with the test target.

— A waypoint (key reference B) shall be defined which satisfies the crash overlap when the SV is projected over the position of the test target at the same angle as the test target. The longitudinal position of this way point shall be aligned with the rearmost edge of the test target. The lateral position of this waypoint shall be determined in accordance with the distance of the reference point of the SV to the outermost edge of the SV.

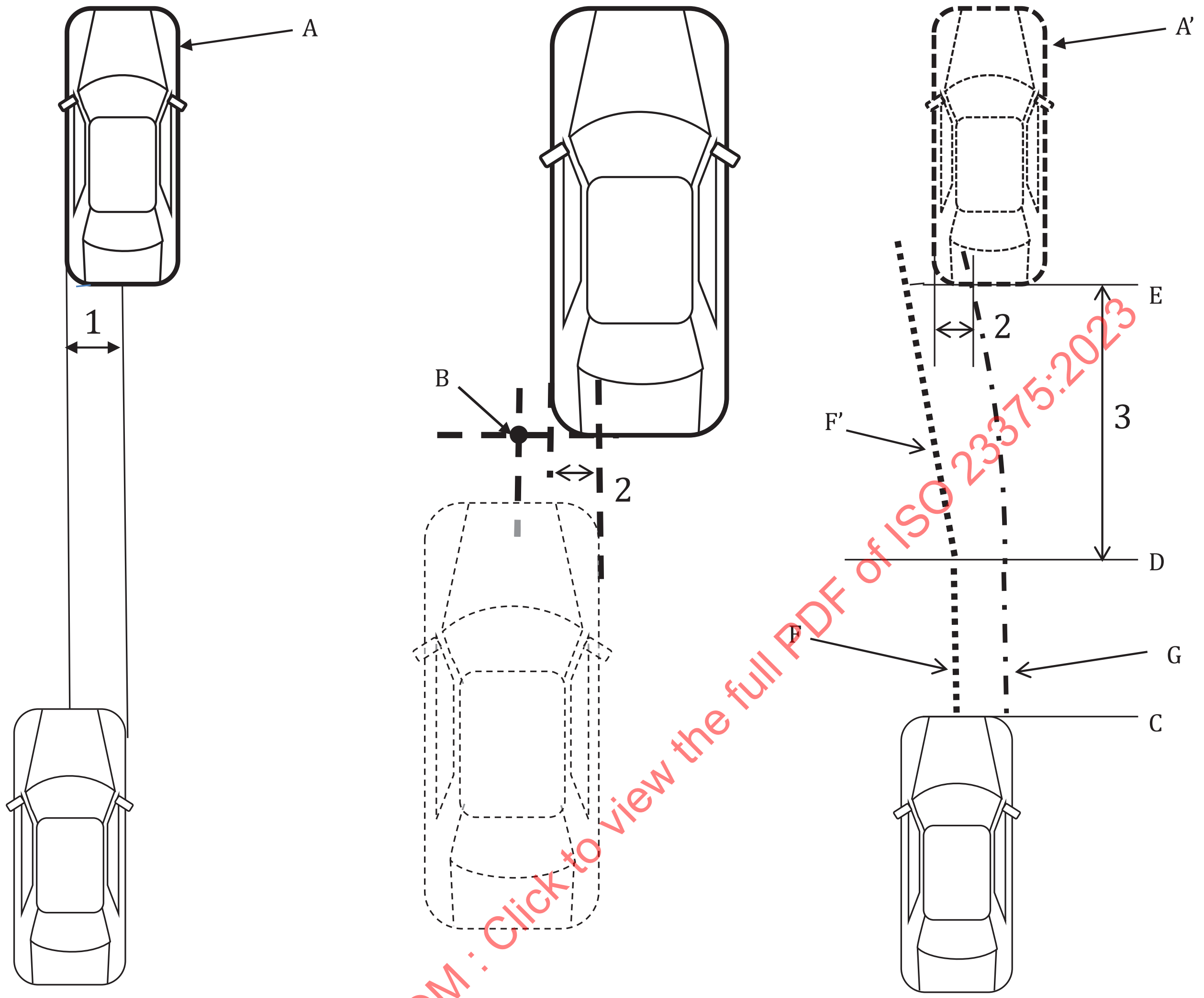
— In most cases, the centre of the forward axle of the SV is used as the reference point for trajectory-based control.

— The evasive trajectory data (key reference F') shall connect the triggering point (key reference C) and the waypoint (key reference B) to replicate an evasive manoeuvre towards the intended avoidance direction. The evasive trajectory may either end at the waypoint (key reference B) or be extend in an appropriate direction as needed.

Table 8 — Trajectory data requirements

Key in Figure 11	Item	Value	Acceptable tolerance
—	V_{sv}	18,5 m/s	3 % [a]
1	Initial L_d	One of the values from the following options shall be chosen where an overlap exists (lateral offset is a positive value), based on the conditions in which the system under test is designed to respond: — 100 % of vehicle width — 50 % of vehicle width — 25 % of vehicle width	5 %
2	Crash overlap	12,5 % of the width of the SV	2,5 %
3	TTC	A value below 2,5 s shall be chosen, based on the conditions in which the system under test is designed to respond.	

[a] The value shall be determined, at a minimum, 2 s before the triggering point or before an AEB system activates, whichever is earlier. Refer to 9.4.2.3 for testing CELM coupled with AEB systems.



a) Initial overlap b) Crash overlap c) Trajectory data

Key

1 initial L_d
2 crash overlap
3 TTC

A test target
A' test target (substitute)
B waypoint which satisfies initial L_d
C SV starting point
D triggering point
E rearmost edge of test target
F approaching trajectory data
F' evasive trajectory data
G sequence of locations where the outermost edge of the SV passes

Figure 11 — Trajectory data creation

