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Intelligent transport systems — Minimal risk manoeuvre (MRM) for automated driving —

Part 1: Framework, straight-stop and in-lane stop

Systèmes de transport intelligents — Manœuvre à risque minimal pour la conduite automatisée (MRM) —

Partie 1: Cadre général, arrêt en ligne droite et arrêt dans la voie

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Foreword

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

A list of all parts in the ISO 23793 series can be found on the ISO website.

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Introduction

A minimal risk manoeuvre (MRM) is the fallback function of an automated driving system (ADS) used to achieve a minimal risk condition (MRC) which is a stable, stopped state (see ISO/SAE PAS 22736).

In a scenario where the dynamic driving task is being performed by the ISO/SAE Level 3-5 ADS, an event which prevents the ADS from continuing the dynamic driving task can occur. Examples of such events include:

a) for ISO/SAE Level 3-5 ADS, the failure of the ADS, automated driving component(s) or other vehicle component(s);

b) for ISO/SAE Level 3 or 4 ADS, the risk that the ADS exits its operational design domain (ODD);

c) for ISO/SAE Level 3 ADS, the failure of the fallback ready user (FRU) or passenger to take over the dynamic driving task when the ADS issues a request to intervene.

In response, the ADS initiates an MRM function to provide enhanced safety for all passengers and other road users. The MRM function selects the most appropriate MRM type to reduce the risk (taking into account the subject vehicle state and traffic conditions) and eventually stops the vehicle through vehicle control. In addition to longitudinal control, lateral control can be added for certain MRM types.

The MRM is not a system, but rather a functionality within an ADS. "MRM" and "failure mitigation strategy" appear similar in that both functions stop the vehicle in response to an adverse event for ADS operating at Level 3 to 5 automation. However, they differ in that the MRM is a function of an ADS, whereas failure mitigation strategy is a vehicle function designed to automatically bring a vehicle to a stop when it has been incapacitated.

"MRM" and "object and event detection and response" (OEDR) based collision mitigation and avoidance systems such as a "forward vehicle collision mitigation system" (FVCMS) sometimes behave similarly, as they try to minimize the collision risk. However, they also differ in their purposes: collision mitigation and avoidance systems consider impacts with external objects during normal operations, whereas an MRM tries to stop the vehicle in order to limit risk under abnormal conditions (such as ADS system failures or violations of ODD conditions) by decelerating the vehicle. OEDR-based collision mitigation and avoidance will be executed independently of and in parallel to MRM.

This document can be used to define the MRM function of ADSs such as motorway chauffeur systems (MCS) (ISO/TS 23792-1) or low speed automated driving (LSAD) systems (ISO 22737).

Intelligent transport systems — Minimal risk manoeuvre (MRM) for automated driving —

Part 1: Framework, straight-stop and in-lane stop

1 Scope

This document addresses the minimum requirements for minimal risk manoeuvres (MRM), which are the response of an ADS to perform automated fallback to reach a minimal risk condition (MRC).

This document specifies the classification framework for MRMs. The classification framework establishes the concept of MRM operation, classification of different MRM types, and basic principles of the decision-making process to decide which MRM type can be performed based on the situation.

This document also specifies the minimum requirements of the control strategy and test procedures for the two simplest types of MRM: straight stop for type 1 and in-lane stop for type 2.

The scope of the MRM described in this document covers minimum requirements for ADS performance during MRM action, from initiation to termination, aimed at achieving an MRC. MRM action-specific safety requirements for robust system design, such as those specified in ISO 26262 and ISO 21448, are not within the scope of this document.

The MRM described in this document are intended to be used on light-duty vehicles equipped with Level 3-5 ADS.

The scope does not include methods for detecting ADS failures and the decision-making process to initiate an MRM. This is because there are numerous cases that can initiate MRMs, and there is no general agreement on classification of those cases in the industry.

2 Normative references

There are no normative references in this document.

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
minimal risk manoeuvre
MRM
manoeuvre by an automated driving system while performing the DDT fallback to attain the minimal risk condition

3.2
minimal risk condition
MRC
stable, stopped condition to which a user or an automated driving system may bring a vehicle after performing the dynamic driving task fallback in order to reduce the risk of a crash when a given trip cannot or should not be continued

[SOURCE: ISO/SAE PAS 22736:2021, 3.16, modified — Notes to entry and Examples have been removed.]

3.3
subject vehicle
SV
vehicle equipped with an automated driving system that is capable of performing minimal risk manoeuvres

3.4
standstill management
function that is implemented in actions taken to maintain the vehicle in minimal risk condition

3.5
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 detectable road features or other means such as localization relative to a digital map, magnetic markers, crash barriers, etc.

3.6
road shoulder
part of the road installed at the edge of the road, outside the lane boundary, to enable an emergency vehicle to bypass traffic congestion or to provide a place for a vehicle that encounters a problem to get out of the active traffic

3.7
acceleration control
control that generates positive acceleration using vehicle functions such as powertrain control

3.8
deceleration control
control that generates negative acceleration using vehicle functions such as brake

3.9
failure mitigation strategy
vehicle function [not an automated driving (ADS) function] designed to automatically bring an ADS-equipped vehicle to a controlled stop in path following either:

1) prolonged failure of the fallback-ready user of a Level 3 ADS feature to perform the fallback after the ADS has issued a request to intervene; or

2) occurrence of a system failure or external event so catastrophic that it incapacitates the ADS, which can no longer perform vehicle motion control in order to perform the fallback and achieve a minimal risk condition

[SOURCE: ISO/SAE PAS 22736:2021, 3.11]

3.10
collision mitigation and avoidance system
vehicle system that senses and monitors conditions inside and outside the vehicle for the purpose of identifying perceived present and potential dangers to the vehicle, occupants and/or other road users, and that automatically intervenes to help avoid or mitigate potential collisions via active control of the vehicle subsystems (brakes, throttle, suspension, etc.)

4 Abbreviated terms

ADS	automated driving system
CAN	control area network
DDT	dynamic driving task
ECU	electronic control unit
FRU	fallback-ready user
HMI	human-machine interface
MRC	minimal risk condition
MRM	minimal risk manoeuvre
ODD	operational design domain
OEDR	object and event detection and response
SV	subject vehicle
V2X	vehicle to everything

5 Function framework

5.1 MRM description

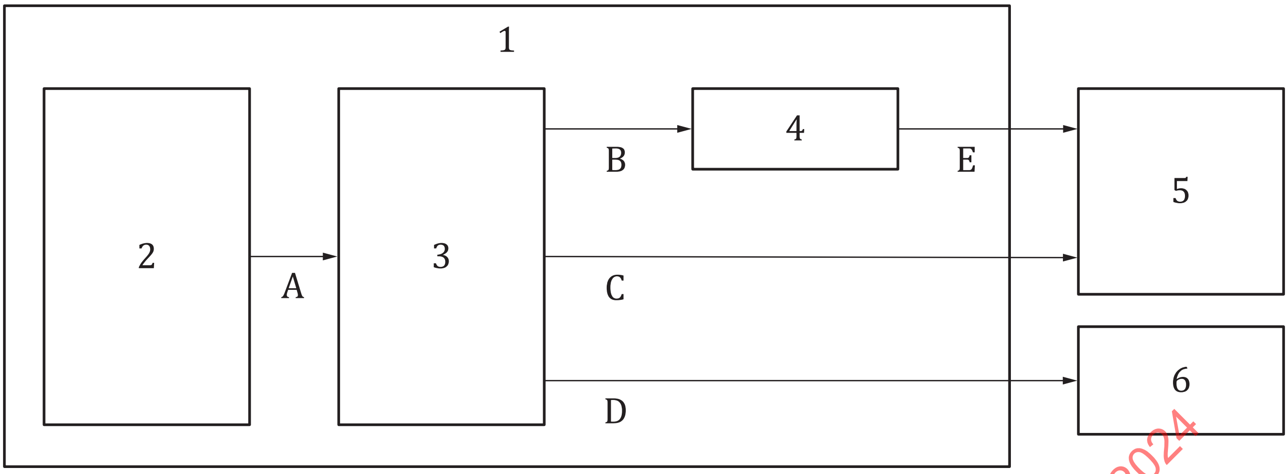
The MRM is a fallback action by ADS which entails stopping as the last countermeasure of an ADS in response to various risky situations such as failures and ODD constraint violations. Therefore, MRM is performed only when an ADS is not able to continue performing the DDT, and once an MRM starts, the ADS cannot automatically return to a normal state. MRM is not triggered in situations when ADS performance of the DDT can be maintained. Maintaining the DDT includes temporary stops (e.g. due to changes in environmental conditions) under the condition of remaining within the prescribed ODD.

The MRM is a function that aims to stop the SV in the safest achievable way, not to stop the SV as quickly as possible. Therefore, it is not a sudden hard braking control, but rather a longitudinal/lateral control according to the situation, which continuously seeks ways to minimize risks. The MRM is designed to minimize traffic hazards, but it can violate traffic regulations while performing the MRM to minimize the risk (e.g. stop in-lane).

5.2 State diagram

5.2.1 General

Figure 1 shows an example of an MRM state diagram to help illustrate the feature. Specific states of the MRM and transition conditions can be different for each ADS.



Key

1	ADS active	A	transition to MRM
2	ADS normal operation	B	transition to MRC
3	ADS MRM operation	C	transition to sustained standstill management
4	minimal risk condition	D	transition to manual driving
5	sustained standstill management	E	transition to sustained standstill management
6	manual driving		

Figure 1 — State diagram

5.2.2 ADS active (1)

5.2.2.1 ADS normal operation (2)

In the ADS normal operation state, the ADS performs the DDT as the system is intended to operate.

In the ADS normal operation state, the ADS determines whether an MRM is required. If it is determined that an MRM is required, the ADS transitions to MRM operation (A).

5.2.2.2 MRM operation (3)

In the MRM operation state, the ADS controls the SV to reach the MRC state.

In the MRM operation state:

— the ADS makes a decision on MRM type;

— the ADS controls the SV to execute the MRM;

— if a human user is on board, the ADS provides status information about the MRM;

— when the ADS is operated in the presence of other traffic, it displays an external indication that an MRM is occurring.

In the transition from the MRM operation to an MRC (B):

— the SV speed is zero (V_{SV} = 0 km/h) and the ADS activates standstill management, which is the ADS functionality.

In the transition from the MRM operation to sustained standstill management (C):

— the SV activates the failure mitigation strategy, either:

a) in response to the ADS request; or

b) on its own in case of a catastrophic failure of the ADS.

In the transition from the MRM operation to manual driving (D):

— the implemented conditions of the underlying ADS to complete DDT transition apply, but additional conditions can apply during an ongoing MRM to prevent the unintended MRM termination.

5.2.3 Minimal risk condition (4)

In the minimal risk condition (MRC) state, the ADS keeps the SV in a stable, stopped condition.

In the transition from the MRC to sustained standstill management (E):

— sustained standstill management is engaged by the SV.

5.2.4 Sustained standstill management (5)

In the sustained standstill management state:

— if the SV is moving, the SV performs failure mitigation strategy manoeuvres to stop the SV;

— the SV continues to perform standstill management to maintain the SV in a stable, stopped condition.

5.2.5 Manual driving (6)

In the manual driving state, the driver performs the whole DDT.

5.3 Functionality

Figure 2 shows one example of the MRM process to enhance understanding of the MRM. More detailed processes of the MRM could differ for each ADS.

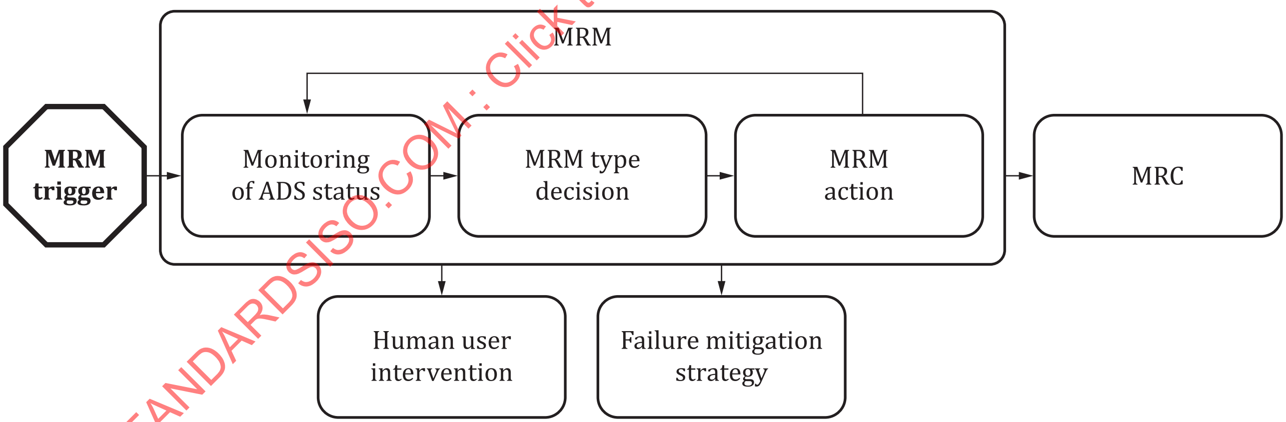


Figure 2 — Process of MRM

When the ADS requests MRM, it is performed through the following steps.

— Monitoring of ADS status: First, ADS checks the state of the system. It analyzes failure severity, identifies system impacts, and checks the status of relevant system components to determine the current DDT performance capabilities of the ADS.

— MRM type decision: Based on the internal (ADS and SV status) and external (e.g. traffic regulation, traffic density, ODD) conditions, the ADS then decides on the appropriate MRM type to be initiated. The initial MRM type selection should be maintained, but the type can be changed if a serious internal/external factor change occurs, or if the selected MRM is not executable due to changes in the traffic situation. If the MRM type is changed while the ADS is performing an MRM, the ADS shall ensure multiple MRM type changes do not delay the system from reaching an MRC in a reasonable and safe manner.

— MRM action: The ADS performing the DDT fallback executes the selected MRM type.

The above steps should be repeated until the vehicle reaches the MRC state.

During the MRM process, a human user can intervene to take over the DDT. If the ADS is not able to perform DDT fallback, the vehicle performs the failure mitigation strategy.

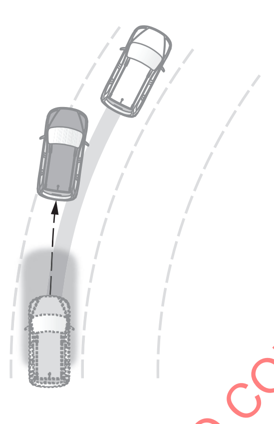
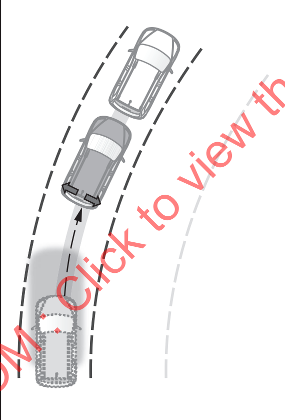
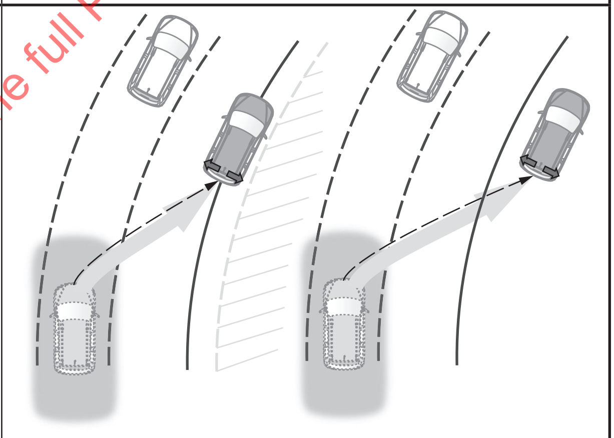
5.4 Classification

5.4.1 Overview

Depending on the internal and external conditions of an ADS equipped vehicle, the available MRM can differ. MRM cases are classified into 3 types, as shown in Table 1.

An MRM can be classified as "traffic lane stop" and "road shoulder stop", based on the stopping locations. Through future innovation and technological development, additional classes can be added.

Table 1 — Classification of MRMs

Category	**Traffic lane stop**		**Road shoulder stop**
MRM types	**Type 1**	**Type 2**	**Type 3**
	Straight stop	**In-lane stop**	**Road shoulder stop**
Description			
Lateral control	Not available	Use	Use
Acceleration control	Prohibited	Prohibited	May be used to keep current speed temporarily
Deceleration control	Use	Use	Use
Lane change	Prohibited	Prohibited	Use
Detection of potential stopping locations out of traffic lanes	Unnecessary	Unnecessary	Use

5.4.2 Traffic lane stop

5.4.2.1 General

Traffic lane stop occurs in response to severe failures of the subject vehicle or its ADS. Traffic lane stop includes: straight stop and in-lane stop. Traffic lane stop can affect the traffic flow and potentially create a hazard that can potentially contribute to secondary crashes, depending on the area of operation.

5.4.2.2 Straight stop

Straight stop uses longitudinal deceleration control to stop the vehicle when lateral control is not available. Straight stops shall apply only when lateral control is not available (e.g. lane detection failures, steering actuator failures) or there are no lane references available to follow (e.g. valet parking system).

During a straight stop MRM, the vehicle can potentially cross the lane boundary (due to the lack of lateral control) and stop outside of the lane. A straight stop MRC can therefore potentially be attained anywhere, where the intention is to try to avoid leaving the current lane of travel. This functional limitation of straight stop does not necessarily prevent the risk of collision with infrastructure elements such as road barriers.

Straight stops only use deceleration control.

5.4.2.3 In-lane stop

An in-lane stop is a way of stopping the vehicle within the boundary of the lane in which the vehicle was travelling when the MRM was initiated.

For in-lane stop, both longitudinal deceleration and lateral control are used with supporting environmental information about the travelling lane (sensors, map data, etc.). In-lane stops can be applied in situations when lane changes, or driving to reach a shoulder stop location, are not possible.

An in-lane stop MRC will be attained within the boundary of the current lane.

5.4.3 Road shoulder stop

In case of road shoulder stop, both lateral and longitudinal control are utilized in order to try to stop the SV in a suitable location away from the traffic flow. As a result of the road shoulder stop manoeuvre, as much of the vehicle as possible shall remain stationary outside of the traffic lane.

Road shoulder stops use both longitudinal and lateral control as well as driving environment information on all relevant lanes using sensors, map data or some other means to recognize the driving environment. For road shoulder stop, an ADS shall be capable of estimating the location to stop the vehicle and of determining whether the vehicle is able to reach that location. Some driving in-lane can be necessary to reach the locations. Acceleration control may be performed while driving to the potential stopping location.

Crossing the lane boundary can be determined by the ADS which is performing an MRM, and the number of lane boundary crossings is not limited. Lane changes shall only be made in the direction of the targeted shoulder where the MRC is intended.

A road shoulder stop MRC will be attained at the hard shoulder, preferably by removing the SV from the active traffic lanes.

5.4.4 MRM type change

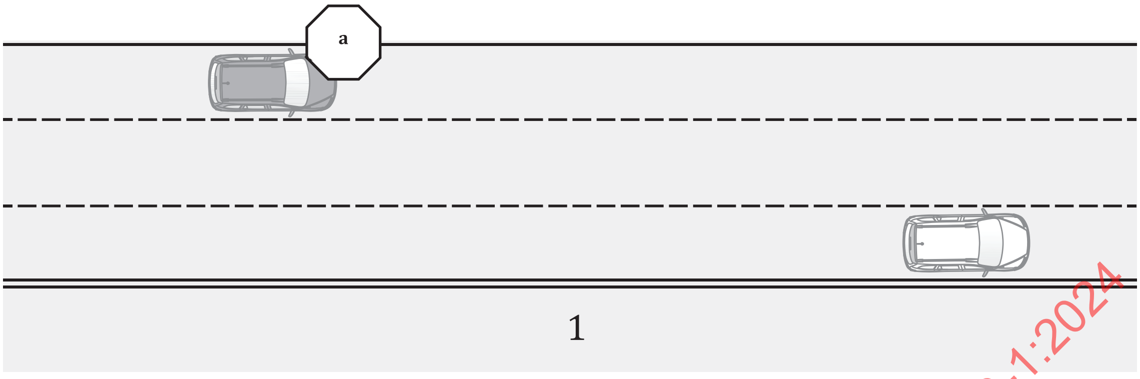
5.4.4.1 General

During an MRM action, further relevant events can potentially occur inside or outside the vehicle, or additional information can be perceived by the ADS. If the ADS decides it is appropriate to reach the MRC via a different MRM type, it may change the intended MRM into a lower MRM type. The MRM type can be changed in only one direction; from higher to lower level type. If the MRM type is changed while the ADS is performing an MRM, the ADS shall ensure multiple MRM type changes do not delay the system from reaching an MRC in a reasonable and safe manner.

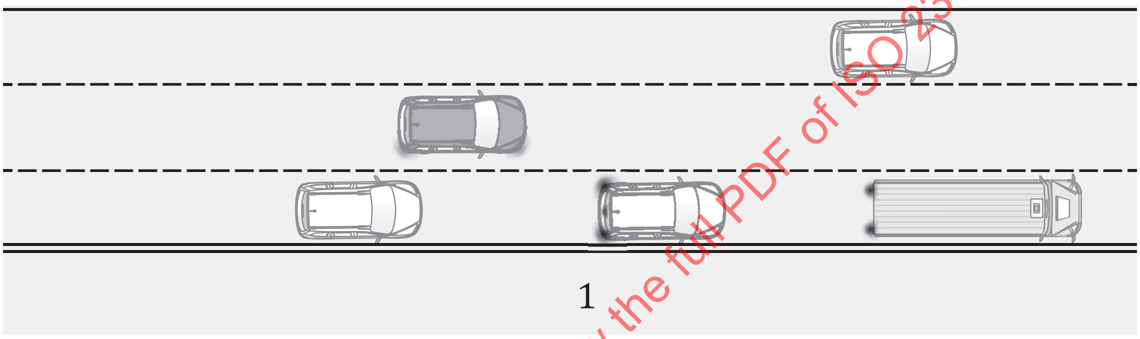
NOTE "Higher type" refers to the higher type number in Table 1.

5.4.4.2 Example of MRM type change

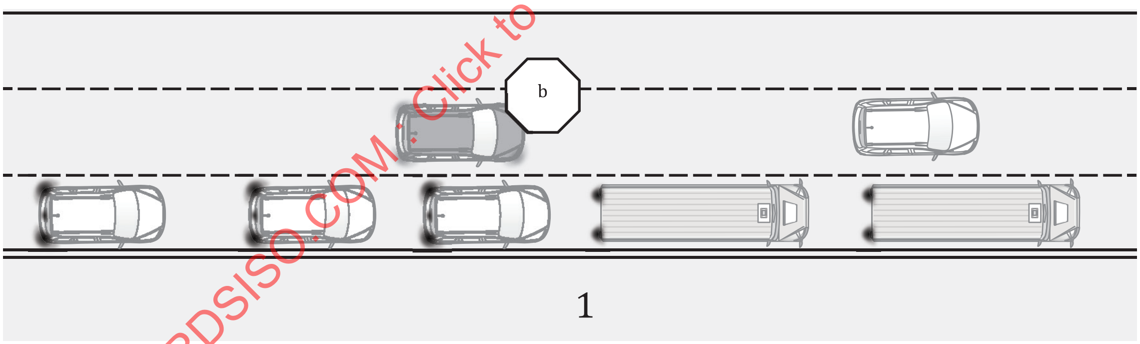
Figure 3 shows an example of a situation that requires an MRM type change. The ADS detects a failure and requests an MRM "full-shoulder stop" (Step 1). The ADS changes lane from the first lane to the second lane according to the manoeuvre and then continuously tries to change the lane again to reach the lane adjacent to the shoulder. If it is judged that it is no longer possible to change lanes due to traffic congestion or other factors, the ADS changes MRM type from shoulder stop to in-lane stop (Step 2). The ADS performs the "in-lane stop" and achieves the MRC state (Step 3).



a) Step 1



b) Step 2



c) Step 3

Key

1 road shoulder

a MRM.

b STOP.

Figure 3 — Example of MRM type change

6 Requirements

6.1 General requirements

6.1.1 Overview

The MRM is not performed by a dedicated system but is a functionality that is implemented within an ADS. Therefore, more detailed requirements that are related to MRM operation need to be fulfilled by the underlying ADS system.

The general requirements in this subclause are common requirements for all MRM types. Additional requirements for each MRM are contained in other parts of the ISO 23793 series.

6.1.2 Vehicle and ADS status monitoring

Based on current information about ADS and vehicle condition, ODD and environmental limitations, the ADS shall determine which MRM type is feasible under the given circumstances. For this purpose, the ADS shall check the vehicle conditions and driving environment that could limit its ability to perform an MRM. For example, the ADS shall check whether the vehicle has deviated from its ODD, whether there is a free space available at the target MRC location, whether any of the ADS subsystems have been impaired, and whether the propulsion energy of the subject vehicle is sufficient to get to the MRC location. These are examples of the vehicle conditions and driving environment that can affect the feasibility of executing different MRM types.

6.1.3 MRM triggering conditions

MRM triggering conditions are specific to each ADS, so they shall be defined by the ADS manufacturer. The ADS manufacturer should provide relevant examples of MRM triggering conditions in user documentation (e.g. handbook, manual).

The ADS manufacturer should develop MRM triggering logic to trigger only when absolutely necessary (the MRM is the last resort of the ADS).

6.1.4 Decision-making for MRM types

The ADS shall choose the preferred MRM type based on the ADS and vehicle condition and infrastructure, traffic and environmental conditions.

An ADS may switch the type of MRM while executing MRM. However, it shall prevent unnecessary or unsafe toggling between different MRM types. MRM type shall be changed only in one direction: from higher to lower type number.

6.1.5 Operational speed of an MRM

An MRM functionality shall be available to perform when the ADS is in active status. Therefore, at least one MRM type shall be achievable anywhere within the operation speed range of ADS.

6.1.6 Implementation of an MRM

After an MRM is activated, the ADS shall not automatically go back to ADS normal operation state without human intervention. Once triggered, it shall terminate in one of the following states:

— MRC;

— manual driving: human user (driver) takes over control;

— ADS is incapacitated leading to failure mitigation strategy.

6.1.7 Human user takeover of the DDT during an MRM

The ADS may permit human user takeover of the whole DDT (but not partial DDT) during an MRM. The means for takeover during an MRM shall be defined by the manufacturer.

6.1.8 Deceleration control

The ADS choose the time at which the deceleration to reach an MRC is initiated. In case of traffic lane stop, the ADS shall generate a deceleration of at least 1,0 m/s^2 within 1 s of the MRM activation until an MRC is achieved, unless it is necessary to delay the MRM deceleration by a few seconds to avoid decelerating the vehicle where it could create a potential traffic hazard. If the MRM action to reach an MRC is not time-critical, deceleration control should be used at least one second after the external information is displayed (e.g. hazard warning lights, external indicators) to reduce the impact on following traffic.

The MRM shall not apply deceleration greater than 4 m/s^2, unless it has been confirmed that there are no obstacles that pose an immediate risk of collision (e.g. approaching vehicles) behind the subject vehicle. The specific maximum deceleration achievable by each ADS is defined by the manufacturer.

If forward obstacle detection is not possible, or the detection range is insufficient, the system shall apply the maximum deceleration that the ADS is designed to use for the MRM to achieve an MRC.

6.1.9 Standstill management

After reaching MRC, the ADS shall either perform standstill management or request the SV to perform standstill management. The SV in the MRC state shall remain stationary, regardless of the longitudinal or lateral slope of the stopped location, until operations are resumed; see 6.1.10.

6.1.10 Resumption of operation after an MRC

Resumption of operation after an MRC shall always require human interaction with the system. The ADS shall convey information to the human user about how automated or manual operation can be resumed. For example, if the ADS is not available to resume the active state, it may provide the information to the human user through display such as "press brake and shift into Drive to cancel MRC and drive manually". For unoccupied vehicles, a remote support person shall confirm readiness to resume automated driving operations after achieving the MRC.

6.1.11 Collision mitigation and avoidance function

The collision mitigation and avoidance systems, or functions in the ADS that perform the same functionality as the collision mitigation and avoidance systems shall take priority over the MRM to respond to imminent danger. If the MRM has become incapable of performing collision avoidance, the collision mitigation and avoidance systems shall act. If the subject vehicle does not reach an MRC by use of the collision mitigation or avoidance function, the MRM shall be continued until an MRC is achieved.

6.1.12 Failure mitigation strategy

If an MRM cannot be performed by the ADS because of a catastrophic failure, a failure mitigation strategy of the subject vehicle shall be requested by the ADS. For example, if all major sensing capabilities of the ADS are lost because of a catastrophic power failure, it shall request a failure mitigation strategy from the subject vehicle.

6.1.13 Internal/external status information

If a human user is on board, the ADS shall have internal means to provide status information about an MRM. The internal status information shall be provided from initiation of the MRM. The internal status information that the vehicle is going to stop shall be provided through a visual means combined with an audible or haptic signal. When the MRM is terminated, the internal status information may be turned off automatically.

When an ADS is operated in the presence of other traffic, it shall have an external means to provide information about the MRM, such as hazard warning lights or other external indicators, or both. Vehicles equipped with V2X capabilities should transmit a notification that they have executed an MRM, including the location of the MRM. The external status information shall be provided from initiation of the MRM. When the MRM is terminated, the external status information shall be maintained until resumption of operation by a human user.

6.2 Straight stop requirements

6.2.1 Operational speed

The ADS that performs the straight stop shall be capable of performing the straight stop throughout the operating speed range of ADS.

6.2.2 Detection capability

Straight stop may use forward object detection capability.

6.2.3 Acceleration control

No positive acceleration shall be applied during the straight stop manoeuvre.

6.2.4 Lateral control

Straight stop does not include lateral control because it is only invoked when ADS has lost lateral control capability caused by steering actuator failure, lack of detectable lane markings or perception failure. If lateral perception and control are available, in-lane stop or other higher type MRM shall be applied.

In case the steering actuator has not failed, Straight Stop may include the function to turn the steering wheel to neutral. However, this is not considered a lateral control.

6.2.5 MRC location

After performing the straight stop, the subject vehicle shall stop the vehicle at a location that may be inside or outside its original lane.

6.3 In-lane stop requirements

6.3.1 Operational speed

The ADS that perform the in-lane stop shall be capable of performing the in-lane stop throughout the operating speed range of ADS.

6.3.2 Detection capability

In-lane stop shall have a means to detect the vehicle position and the alignment relative to the lane boundaries.

6.3.3 Acceleration control

No positive acceleration shall be applied during the in-lane stop manoeuvre.

6.3.4 Lateral control

During the in-lane stop, the ADS shall perform lateral control continuously to keep the subject vehicle within its lane. Lateral control for lane change shall not be performed.