BS ISO 21815-3:2023

BSI Standards Publication

Earth-moving machinery — Collision warning and avoidance

Part 3: Risk area and risk level for forward/reverse motion

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National foreword

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The UK participation in its preparation was entrusted to Technical Committee B/513/1, Earth moving machinery (International).

A list of organizations represented on this committee can be obtained on request to its committee manager.

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Part 3: Risk area and risk level for forward/reverse motion

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CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
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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 document 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).

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This document was prepared by Technical Committee ISO/TC 127, *Earth moving machinery*, Subcommittee SC 2, *Safety, ergonomics and general requirements*.

A list of all parts in the ISO 21815 series can be found on the ISO website.

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.

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Introduction

The increasing use of detection systems and avoidance technology has been supporting operators to safely operate machines in the field of mining and construction.

At the same time, there are demands to set standards for machines and systems detecting, alerting and intervening to mitigate collision risk. This document addresses collision risk areas and collision risk levels for machines utilizing detection systems and avoidance technology in the area of earth-moving machinery that exhibit forward and reverse motion.

This document is a type-C standard as stated in ISO 12100.

This document is of relevance, in particular, for the following stakeholder groups representing the market players with regard to machinery safety:

— machine manufacturers (small, medium, and large enterprises);

— health and safety bodies (regulators, accident prevention organisations, market surveillance etc.).

Others can be affected by the level of machinery safety achieved with the means of the document by the above-mentioned stakeholder groups:

— machine users/employers (small, medium, and large enterprises);

— machine users/employees (e.g. trade unions, organizations for people with special needs);

— service providers, e. g. for maintenance (small, medium, and large enterprises);

— consumers (in case of machinery intended for use by consumers);

— providers of collision warning and avoidance technology;

— system integrators.

The above-mentioned stakeholder groups have been given the possibility to participate at the drafting process of this document.

The machinery concerned and the extent to which hazards, hazardous situations, or hazardous events are covered are indicated in the Scope of this document.

When requirements of this type-C standard are different from those which are stated in type-A or type-B standards, the requirements of this type-C standard take precedence over the requirements of the other standards for machines that have been designed and built according to the requirements of this type-C standard.

This document addresses requirements for detecting, alerting and intervention in mitigating collision risk.

There are currently two existing standards in the field: ISO 16001 and ISO 17757. These standards provide guidance for visibility aids and object detection system and for autonomous and semi-autonomous machines, however, there is currently no standard that describes collision risk awareness, warning signals and collision avoidance actions of manually operated machinery when there is a risk of collision.

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Earth-moving machinery — Collision warning and avoidance —

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1 Scope

This document defines requirements for collision warning systems (CWS) and collision avoidance systems (CAS) that address forward and reverse motion for:

— earth-moving machinery as defined in ISO 6165,

— mobile underground mining machinery as defined in ISO 19296, and

— road construction machinery as defined in ISO 22242.

This document does not consider machine height beyond that of height in travel position (e.g. dump body on dumper in lowered position) as established by machine manufacturer.

This document covers collision avoidance by reducing speed, stopping, or inhibiting motion; it does not cover avoidance by automatic manoeuvring (e.g. steering) away from the intended object. Specific requirements for other types of machine motion are defined in the other parts of the ISO 21815 series.

The system described in this document is intended to assist the operator of the machine. The responsibility for safe operation of the machine remains with the machine operator.

This document is not applicable to collision warning and collision avoidance systems installed/manufactured before the date of its publication.

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 6750-1, *Earth-moving machinery — Operator's manual — Part 1: Contents and format*

ISO 12100:2010, *Safety of machinery — General principles for design — Risk assessment and risk reduction*

ISO 21815-1, *Earth-moving machinery — Collision warning and avoidance — Part 1: General requirements*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12100, ISO 21815-1, and the following 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/

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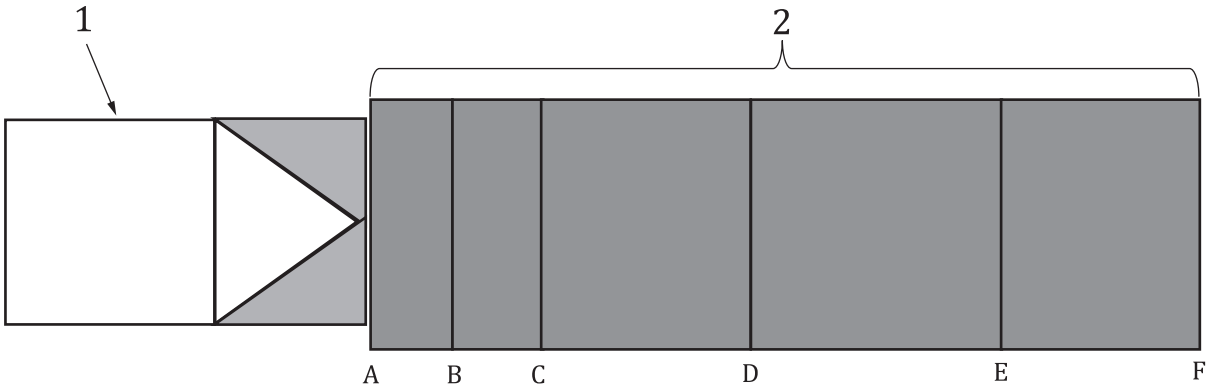
3.1
CxS distance
minimum distance for the CxS to complete *detection* (3.2), *determination* (3.3), *action* (3.6, 3.7), and *machine stopping distance* (3.15), plus *safe distance* (3.10)



Key

1 machine

2 CxS distance

A – F see Table 1 and Table 2

Figure 1 — Graphical representation of CxS distance

Table 1 — CxS distance points

Point	Description[a]
A	The point of the initial detection of the intended object by CxD
B	The point where the intended object is confirmed by the CxS (including debounce time) NOTE For some systems this point cannot be quantified. There are no requirements for this point.
C	The point where the CxS completes an assessment of risk level and the course of action is communicated to the operator (for CWS) or to the machine interface (for CAS)
D	The point where the operator has been provided sufficient time to react to the warning communicated by the CWS or for the interventional collision avoidance action to be initiated on the machine (for CAS)
E	The point where the machine has fully stopped
F	The position of the intended object

[a] CWS specific notations are indicated with a single prime (’) and CAS specific are indicated with double prime (”) throughout the document. No prime indicates CxS.

EXAMPLE A indicates CxS.
A’ specifies a CWS.
A” specifies a CAS.

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Table 2 — CxS intervals

CxS distance interval[a]	CxS time interval[a]	Description[a]
D_{AB}	T_{AB}	*detection* (3.2)
D_{BC}	T_{BC}	*determination* (3.3)
D_{CD}	T_{CD}	*action* (3.6, 3.7)
D_{DE}	T_{DE}	*machine stopping distance* (3.15)
D_{EF}	T_{EF}	*safe distance* (3.10)

[a] CWS specific notations are indicated with single prime (') and CAS specific indicated with double prime (") throughout the document. No prime indicated CxS.

EXAMPLE A-B indicates CxS

A'-B' specifies a CWS

A"-B" specifies a CAS

Note 1 to entry: See Figure 1 for a graphical representation.

Note 2 to entry: The motion can be either forward or reverse (measured in meters).

Note 3 to entry: The values for D_{CD} are typically larger for CWS than a CAS due to the slower action time of the operator.

Note 4 to entry: The first observable output of the CxS can be point C due to difficulty in measuring points A or B without specialized equipment.

Note 5 to entry: Table 1 are points within the CxS distance.

Note 6 to entry: Table 2 are the intervals with the CxS distance.

Note 7 to entry: For a CWS, can be referred to as collision warning distance.

Note 8 to entry: For a CAS, can be referred to as collision avoidance distance.

Note 9 to entry: D_{AB} is the period where the sensor algorithm is determining if the intended object is present. This interval can be important for the designer of the CxS but could be difficult for the system integrator to measure or interpret.

3.2
detection
acknowledgement of intended object

[SOURCE: ISO 21815-1:2022, 3.11, modified — The phrase "by a CxS" was removed from the end of the definition.]

3.3
determination
analysis of collision risk level of the intended object(s) by CxS

Note 1 to entry: Determination also includes the transmission of warning/interventional collision avoidance action as appropriate for the collision risk level.

3.4
decision
<CWS> acceptance of warning and selection of action by operator

Note 1 to entry: See Figure 5.

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3.5
decision
<CAS> acceptance of recommended interventional collision avoidance action by machine control system

Note 1 to entry: Acceptance does not imply providing feedback to the CxS.

Note 2 to entry: See Figure 5.

3.6
action
<CWS> performance of the evasive action by operator

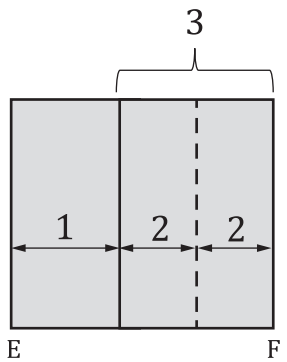
3.7
action
<CAS> performance of the interventional collision avoidance action by machine

3.8
safe offset distance
D_O
distance value that is determined by the authorized person to provide additional clearance around intended object

3.9
error distance
D_I
error value in the system in measuring the distance D_{AE}

3.10
safe distance
D_{EF}
distance comprising the *safe offset distance* (3.8) plus the possible error in the CxS measurements position variance

Note 1 to entry: Figure 2 illustrates safe distance.



Key

1 D_O (3.8)
2 D_I (3.9)
3 D_I (3.9) × 2

Figure 2 — Safe distance

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3.11
possible path
space that the machine could occupy based on machine state, potential paths of motion, and machine stopping distance

Note 1 to entry: Machine state includes velocity, current direction, etc.

Note 2 to entry: See Annex E for more information.

3.12
projected path
space that the machine movement will occupy if there is no change in machine motion inputs and limited by machine stopping distance

Note 1 to entry: See Annex E for more information.

3.13
probable path
space where the machine is permitted to move based on site operation rules and limited by machine stopping distance

Note 1 to entry: Multiple probable paths can have estimates of future likelihood.

Note 2 to entry: See Annex E for more information.

Note 3 to entry: It is assumed that the machine is under control of the operator.

3.14
expected path
space where the machine is anticipated and permitted to move based on the site operation rules and machine operating context (e.g. lanes, loaded) and limited by machine stopping distance

Note 1 to entry: There is only one expected path.

Note 2 to entry: See Annex E for more information.

Note 3 to entry: It is assumed that the machine is under control of the operator.

3.15
machine stopping distance
$\boldsymbol{D}_{\mathbf{DE}}$
distance travelled by the machine from the point which the machine brake control actuation begins (e.g. operator actuates the brakes for CWS or when intervention action commences for CAS) to the point where the machine is fully stopped

Note 1 to entry: It is expressed in meters [m].

Note 2 to entry: Machine braking delay is included in the calculation or measurement of stopping distance.

Note 3 to entry: Operator action time is excluded from the calculation or measurement of stopping distance.

3.16
detection zone
space where intended objects are expected to be detected by the CxS with a specified reliability

Note 1 to entry: CxS device technology or detection methods impact the bounds of the space.

Note 2 to entry: Examples of typical detection zones shown in Figure 3.

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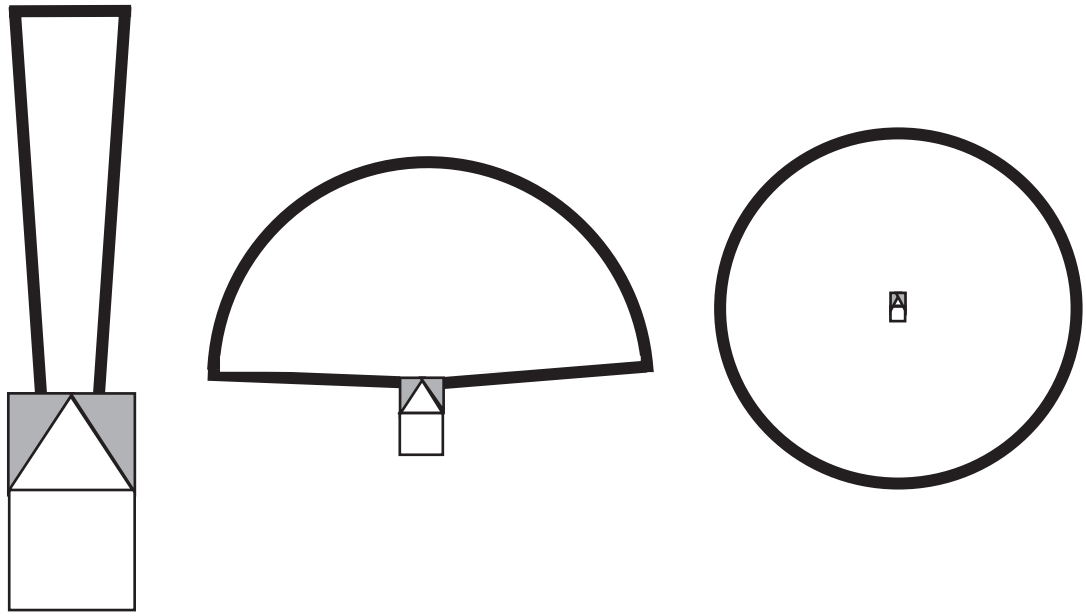

1 2 3

Key

1 trapezoidal example

2 semi-circular example

3 complete circular example

Figure 3 — Examples of detection zones

3.17
intervention indicator
signal that the automatic interventional collision avoidance action is engaged

3.18
bi-directional traffic
traffic that flows in opposite directions on established travel routes

Note 1 to entry: Often described as right-hand traffic or left-hand traffic.

Note 2 to entry: Right-hand traffic keeps to the right of established travel routes. Opposing traffic passes along the left side.

Note 3 to entry: Left-hand traffic keeps to the left of established travel routes. Opposing traffic passes along the right side.

3.19
alarm fatigue
state when a person is overloaded with excessive number of notifications and starts to ignore these notifications including potentially important ones

3.20
debounce time
period where the sensor algorithm is determining if the intended object is present

Note 1 to entry: This time could be inapplicable for certain types of systems.

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3.21
collision risk level
CRL
value that is assigned to each intended object to determine if a collision is foreseeable based on the current motion of the machine and the intended object

Note 1 to entry: See A.1.4 for additional information on collision risk levels.

Note 2 to entry: Adapted from ISO 21815-1:2022, 3.6.

4 Performance requirements

4.1 General requirements

Machinery shall conform with the safety requirements and/or protective/risk reduction measures of this clause. In addition, the machine shall be designed according to the principles of ISO 12100:2010 for relevant but not significant hazards which are not dealt with by this document.

CxS shall comply with the requirements of ISO 21815-1, in as far as those are not modified or added to by the requirements in this document.

The CxS shall determine a collision risk level of each intended object and communicate the appropriate action.

NOTE For multiple intended objects, see B.8.

The detection zone of CxD should be the same or larger than the collision risk area. However, due to limits of the system, the detection zone may be smaller than the collision risk area. In that case, the limits of the system shall be defined in the operator's manual as a system limitation.

Annex B shall be used to provide information on the limitations of use of the CxS.

4.2 Calculating CxS distance

4.2.1 Forward/reverse motion

The CxS distance shall be long enough to allow a machine to stop to avoid a collision with an intended object where earth-moving machinery (EMM) movement can occur.

NOTE 1 Examples of calculating CxS distances are provided in Annex C (surface machines) and Annex D (underground machines).

NOTE 2 An example of an approach to determining CxD configuration parameters based on stopping performance is provided in Annex F.

4.2.2 Collision risk area reduction

The collision risk area is determined by the limitations of physical kinematics (e.g. speed, turning radius, angle, dimensions) of the machine. The size of the collision risk area may be reduced by knowing the real-time value of kinematics (e.g. speed, turning angle).

Physical or virtual barriers can reduce the collision risk area, if the CxS is capable of considering them.

A CxS which has the ability to utilize information regarding projected path and expected path and their interactions may be able to reduce the size of the collision risk area.

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4.3 Determination of collision risk level

The CxS shall determine a collision risk level upon detection of each intended object within the detection zone or collision risk area. The collision risk level is based on analysis of the current motion of machine and possibility of a collision. For forward and reverse travel, Annex A shall be used to determine the collision risk level.

NOTE 1 For other types of machine movement other parts of the ISO 21815 series can be used.

NOTE 2 For multiple intended objects, see B.8.

4.4 Collision warning and collision avoidance action

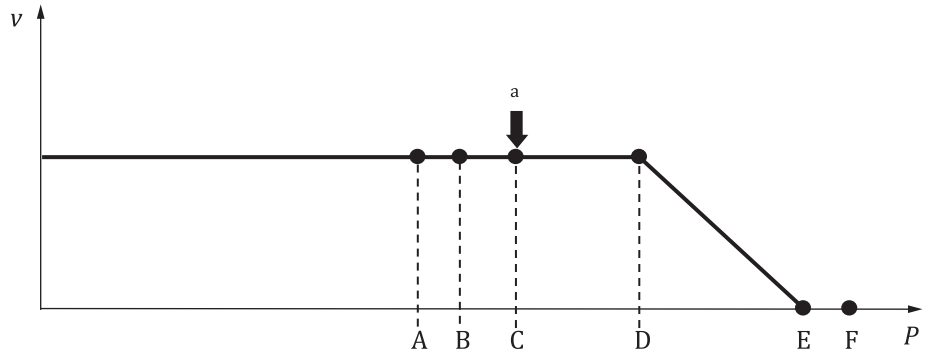
The CxS actions shall only occur for intended objects in the collision risk area.

NOTE There are several challenges (see Annex B) that can result in false positive detections (detecting objects that do not have a high risk of collision) or false negative detections – missing real risks. False positives could create alarm fatigue and result in operators ignoring real collision risks.

4.5 CxS action and expected machine speed behaviour

4.5.1 General

Figure 4 shows CxS device output in relation to distance travelled.



Key

v machine speed

P point (see Table 1)

a CxS action.

Figure 4 — Expected machine speed

4.5.2 Requirement of D_0

The CxS may allow the means for the value to change in accordance with the worksite situation and environment. This should be done by an authorized person.

4.5.3 CxS configuration

The CxS manufacturer shall communicate the typical delays in their system. If the CxS allows for configurable parameters, the CxS manufacturer shall communicate the default values and how a system integrator can change the default values.

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If the system integrator changes the default values, the system integrator shall communicate the configuration and assumptions. The following values shall be communicated:

— velocity,

— slope,

— T_{AC},

— T_{CD},

— and D_{DE}.

Table 3 is an example of the information.

Table 3 — Example of configuration and assumptions

Velocity [kph]	Slope [%]	T_{AC} [s]	T_{CD} [s]	D_{DE} [m]
40	-10	0,300	2,5	130
10	-10	0,300	2,5	30
Ground conditions – dry and hard packed Model of machine – truck model 123 Model of CxS – CwS model ☑ CWS ☑ CAS ☑ ESB ☑ SDB ☑				
NOTE For additional information, see Annex F, G.2 (ESB) and G.3 (CSB).				

4.6 Collision warning system

4.6.1 System functionality

CWS shall provide warning(s) to assist operator in avoiding collision. The warning from the CWS shall be initiated if the collision risk level with the intended object is at least equal to the threshold value of collision risk level 3.

4.6.2 Discontinuation of warning signal and reactivation

Warning signals shall discontinue when the collision risk level of intended object has been reduced below CRL-3. After the collision risk level of the intended object has become lower than CRL-3 but returns to CRL-3 and above the threshold again, a warning signal shall be applied.

4.6.3 Human interface requirements

4.6.3.1 General

All visual, audible and haptic warnings shall be perceptible by the operator.

For devices that provide CWS functions, the operator action time shall be used in determining the collision warning distance (see 5.3 and 5.4 for additional details).

A CWS shall provide warnings to the operator and may provide warnings to workers and other persons present at the work site. If warnings are provided on levels, each warning signal shall be clearly distinguishable from the others by the operator and correspond to the risk level.

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The CWS shall notify for a period for time to allow the operator's senses to recognize the CWS Action (e.g. visual, audio).

4.6.3.2 Audible signals

Audible signals shall be set at and maintained, or should automatically adjust to, a level at least 3 dB higher to the operator than the expected ambient noise level. Audible signals shall be selected so that they are clearly audible to the operator.

The warning signal should align with the frequency range as defined ISO 16001:2017, 4.3.2.1.

Audible signals shall be distinguishable from other sounds (for example, warnings or machinery noise). A voice message or melody type signal may be used for the warning signal. The voice message shall be in the language understood by the operator. If multiple languages are available, then the system should allow language selection.

Voice and melody signals can take an appreciable length of time to annunciate and for the operator to comprehend the message, therefore, additional time shall be allowed for the operator action delay when using voice or melody.

NOTE Distinctiveness of the alarm can be achieved by varying the spectral characteristics and the temporal distribution of the signals (see ISO 9533).

4.6.3.3 Warning lights and visual devices

The warning lights and visual devices in the cab shall be located such that it is in the 120° arc centred in front of the operator and shall be bright enough to be viewed under sunlight operating conditions. Appropriate shielding may be used to reduce the effect of direct sunlight onto the visual devices.

The warning lights shall be distinguishable from other instrument panel warnings.

Visual devices may indicate recommended collision avoiding actions either by symbols and/or using words such as "Emergency braking", "Slow down". If words are used, then the text or audible words shall be in a language understood by the operator.

Visual devices may indicate direction of the other intended objects in surrounding area.

4.7 Collision avoidance system

4.7.1 System functionality

The collision avoidance system shall provide an interventional collision avoidance action (e.g. braking, inhibiting motion, slowing down) to help the operator to avoid or mitigate risk of collision. An appropriate level of intelligence should be provided in the system for determination of the collision risk levels and the decision of the appropriate automatic actions.

The system may allow operator's intentional control to override automatic interventional action if appropriate. If the CAS is also equipped with CWS, the CWS may warn before the automatic interventional action is initiated. The action from the CAS shall be initiated if the collision risk level with the intended object is at least equal to the threshold value of collision risk level 4.

The system shall not override the operator control if braking by the operator is greater than that of the system. For additional information on types of braking see Annex G.

4.7.2 Discontinuation of collision avoidance action and reactivation

The detail of discontinuation and reactivation of collision avoidance or mitigation action shall be defined by the system integrator, based on the information provided by the CxS manufacturer and the machine manufacturer, and shall be documented in the information for use.

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