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Earth-moving machinery — Collision warning and avoidance —

Part 3:
Risk area and risk level — Forward/reverse motion

ICS: 53.100

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Contents

Page

Foreword

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

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

For an explanation on 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 the following URL: www.iso.org/iso/foreword.html.

The committee responsible for this document is 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

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);

— 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 standard addresses requirements for detecting, alerting and intervention in mitigating collision risk.

There are currently two existing standards in the field: ISO 16001:2017 Earth-moving machinery – Object detection systems and visibility aids – Performance requirements and tests, and ISO 17757:2017 Earth-moving machinery – Autonomous machinery system safety. 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.

Earth-moving machinery — Collision warning and avoidance —

Part 3:
Risk area and risk level — Forward/reverse motion

1 Scope

This document defines requirements for collision warning and collision avoidance systems 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.

Specific requirements for particular types of machines and use cases are defined in the other parts of this standard series.

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.

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

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

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

ISO 3450, *Earth-moving machinery — Wheeled or high-speed rubber-tracked machines — Performance requirements and test procedures for brake systems*

ISO 19296, *Mining — Mobile machines working underground — Machine safety*

3 Terms and definitions

3.1 Terms and definitions

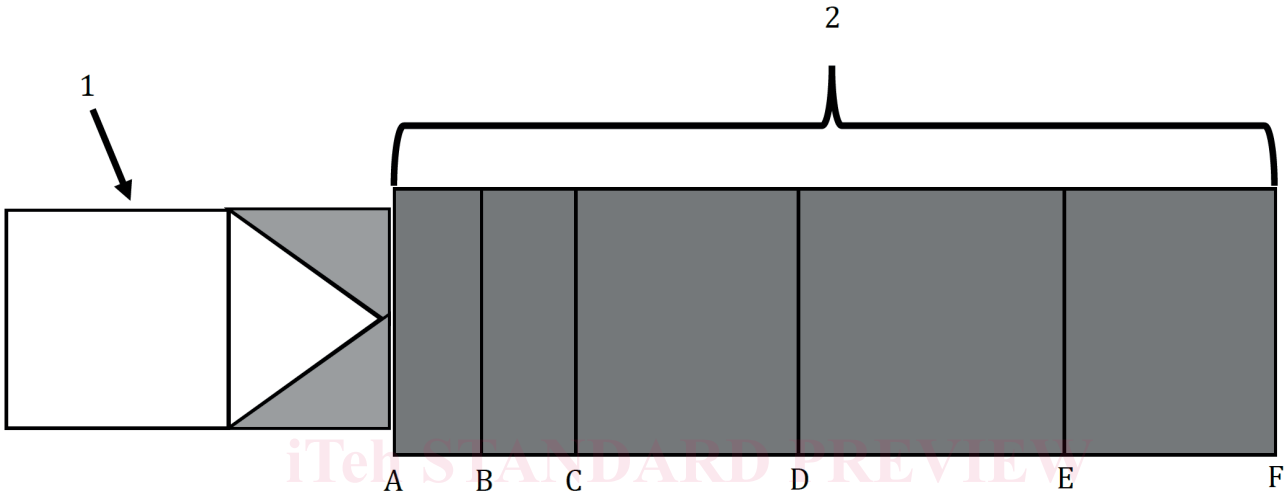
For the purposes of this document, the terms and definitions given in ISO 12100:2010, ISO 21815-1:2021, and the following apply.

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

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

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

3.1.1
CxS distance
minimum distance for the system to complete *detection* (3.1.2), *determination* (3.1.3), *action* (3.1.5), and machine stopping distance (3.1.15), plus *safe distance* (3.1.9)



Key

1 EMM

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 confirmed by CxS (including debounce time) Note: For some systems this Point can not 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 communicate 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 indicated with ’ and CAS specific indicated with ” throughout the document. No prime indicated CxS.

Examples: A indicates CxS

A’ specifies a CWS

A” specifies a CAS

Table 2 — CxS intervals

CxS Distance Interval[a]	CxS Time Interval[a]	Description[a]
D_{AB}	T_{AB}	detection (3.1.2)
D_{BC}	T_{BC}	determination (3.1.3)
D_{CD}	T_{CD}	action (3.1.5)
D_{DE}	T_{DE}	stopping distance (3.1.15)
D_{EF}	T_{EF}	safe distance (3.1.8)
[a] CWS specific indicated with ’ and CAS specific indicated with ” throughout the document. No prime indicated CxS. Examples: A-B indicates CxS A’-B’ specifies a CWS A”-B” specifies a CAS		

Note 1 to entry: See Figure 1 for 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: DAB 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.

3.1.2
detection
acknowledgement of intended object

[SOURCE: ISO 21815-1 3.11]

3.1.3
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.

3.1.4.1
decision
<CWS> acknowledgement of warning and selection of action by operator

3.1.4.2
decision
<CAS> acceptance of recommended interventional collision avoidance action by machine control system

Note 1 to entry: acknowledgement does not imply providing feedback to the CxD

3.1.5
action
<CWS> performance of the control by operator

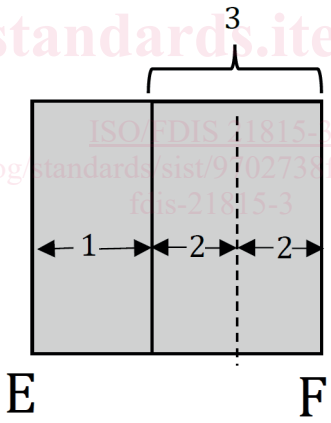
3.1.6
action
<CAS > performance of the interventional collision avoidance action by machine

3.1.7
safe offset distance
D_O
distance value that is determined by the authorized person to provide additional clearance around intended object

3.1.8
error distance
D_I
error value in the system in measuring the distance $\boldsymbol{D_{AE}}$

3.1.9
safe distance
D_{EF}
distance (Figure 2) comprising the safe offset distance plus the possible error in the CxS measurements position variance

Note 1 to entry: Figure 2 illustrates safe distance



Key
1 D_O (3.1.7)
2 D_I (3.1.8)
3 D_I (3.1.8) x 2

Figure 2 — Safe Distance

3.1.10
possible paths
all 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

3.1.11
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

3.1.12
probable paths
space where the machine is permitted to move based on site operation rules

Note 1 to entry: multiple future paths can have an estimate of likelihood

Note 2 to entry: See Annex E for more information

Note 3 to entry: Assumes that the machine is under control of the operator

3.1.13
expected path
space where the machine is anticipated and permitted to move based on the site operation rules and machine operating context (eg. 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: Assumes that the machine is under control of the operator

3.1.14
machine stopping distance
D_{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

3.1.15
detection zone
space where the CxS is intending to detect objects 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

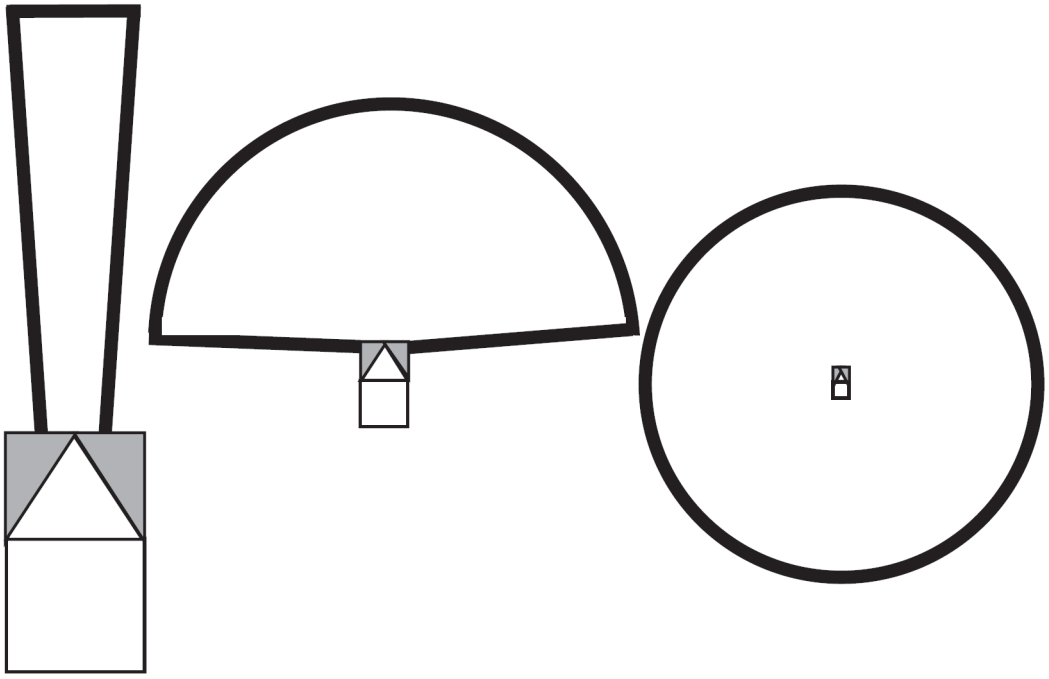


Figure 3 — Example of detection zones

3.1.16
preliminary collision warning
warning which informs the operator of the presence of a potential collision hazard in order for the operator to prepare to take the necessary action to avoid a potential collision

3.1.17
intervention indicator
indicator which provides a signal that automatic interventional collision avoidance action engaged

3.1.18
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.

3.1.19
alarm fatigue
when a person is overloaded with excessive number of notifications starts to ignore these notifications including potentially important ones

3.1.20
debounce time
period where the sensor algorithm is determining if the intended object is present

Note 1 to entry: this time could not be applicable for certain types of systems

4 Performance requirements

4.1 General requirements

Machinery shall comply 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.

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

The detection zone of CxS should be the same or larger than the collision risk area. However, due to limits of the system, the detection zone can 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.

The limitations of use of CxS are provided in Annex B.

4.2 Calculating CxS distance

4.2.1 Forward/reverse motion

The CxS distance shall be large enough to allow a machine to stop to avoid a collision with an intended object where 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 physical kinematics (e.g. speed, turning radius, angle, dimensions) limitations of the machine. The size of the collision risk area can 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.

The 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.

4.3 Collision risk level

The CxS shall determine a collision risk level (CRL) 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 & reverse travel, see Annex A to determine the collision risk level.

NOTE 1 For other types of machine movement other parts of this standard series can be used.

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

4.4 Collision warning and collision avoidance action

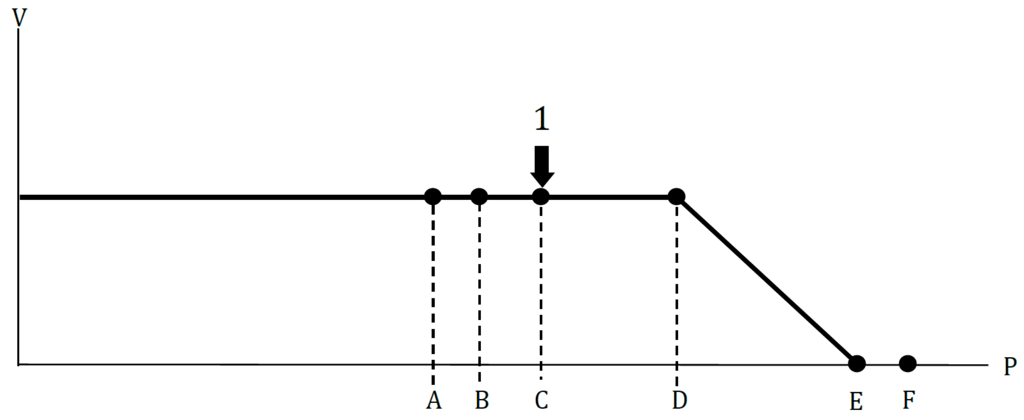
The CxS actions shall only occur for intended objects in the collision risk area.

NOTE There are several challenges (see Annex D) 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

1 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.

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 assumption

Velocity kph	Slope %	T_{AC} Seconds	T_{CD} Seconds	D_{DE} Meters
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 ☑ CSB ☑				
NOTE For additional information, see Annex F				

4.6 Collision Warning System

4.6.1 System functionality

CWS shall provide warning 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 Preliminary collision warning (optional)

CWS may provide preliminary collision warning(s).

NOTE 1 The purpose of the preliminary collision warning is to alert the operator to take action to avoid or reduce the severity of a possible evasive action.

NOTE 2 Although the system can provide this warning prior to the evasive warning, it is possible that rapidly changing conditions can occur which result in the evasive warning being issued without a preceding preliminary collision warning.

4.6.3 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 should be applied. The debounce time can be taken into consideration for discontinuation and reactivation.

4.6.4 Human interface requirements

4.6.4.1 Warning output specification

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).

4.6.4.2 Warning devices for CWS

4.6.4.2.1 General

A CWS shall provide indications to the operator and may provide indications 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.