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Earth-moving machinery — Collision warning and avoidance —

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

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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 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.

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.

Earth-moving machinery — Collision warning and avoidance —

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

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

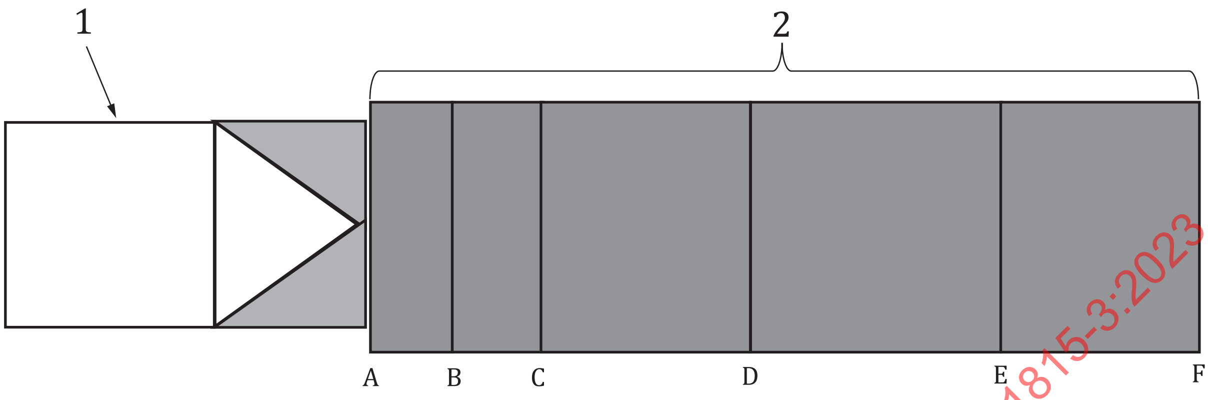
For the purposes of this document, the terms and definitions given in ISO 12100, ISO 21815-1, and the following apply.

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/

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.

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.

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

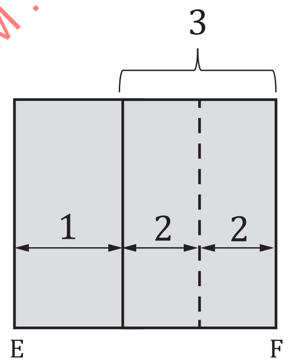
3.7
action
<CAS> performance of the interventional collision avoidance action by machine

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

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
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].

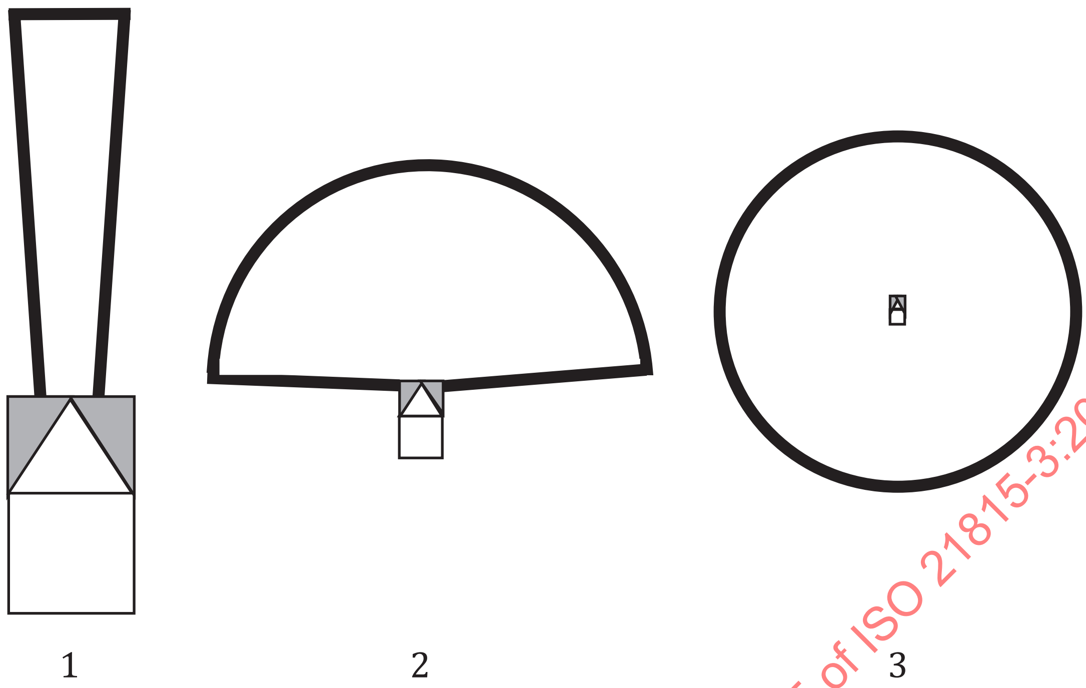
Note 2 to entry: Machine braking delay is included in the calculation or measurement of stopping distance.

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

3.16
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.



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.

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.

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

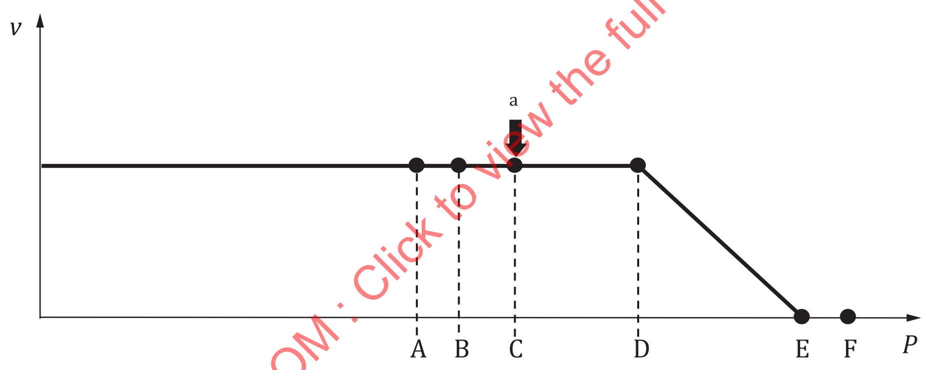
The CxS actions shall only occur for intended objects in the collision risk area.

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.

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.

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.

To prevent a possible rollaway condition, the CxS should require the operator to act (e.g., set parking brake) prior to allowing the CAS braking to discontinue.

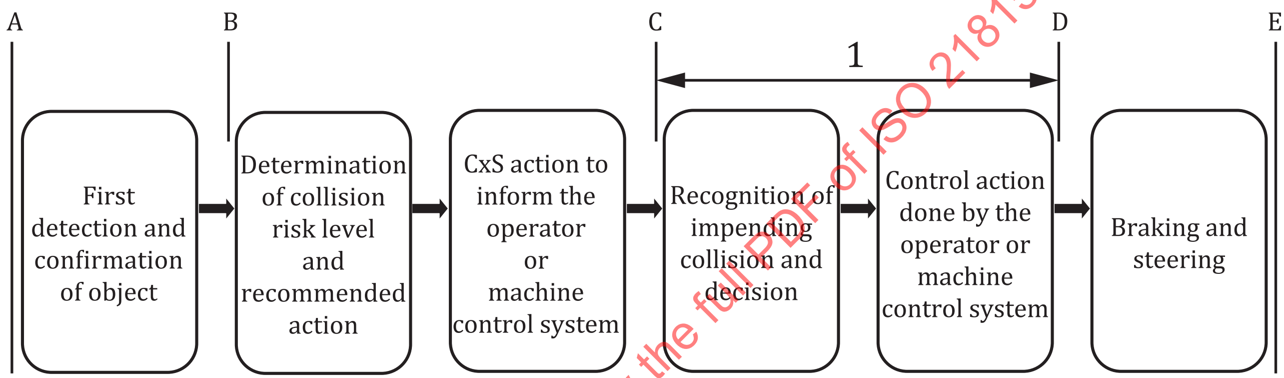
4.7.3 Intervention indicator

An intervention indicator shall be provided. The intervention indicator shall occur no later than the initiation of the interventional collision avoidance action (see Annex G).

5 Time and distance calculation guidance

5.1 General

The CxD distance may be subdivided into discrete parts based on CxS detection and determination (D_{AC}), action (D_{CD}), and machine stopping distance (D_{DE}) as shown in Figure 5.



Key

1 operator or machine control system action

Figure 5 — Subdivision of CxS distance into discrete parts

Annex C and Annex D show an example of the calculation.

5.2 CxS detection, determination and communication

The T_{AC} is the total time from initial detection of the intended object to communicating the action. It comprises the time to detect a potential object and confirm this as an intended object (T_{AB}) and time to analyse the collision risk, determine recommended action and communicate external to the CxS (T_{BC}).

$$D_{AC} = v_a * T_{AC} \quad (1)$$

NOTE 1 v_a units is in meters/seconds.

NOTE 2 T_{AC} units is in seconds.

NOTE 3 D_{AC} units is in meters.

5.3 Action time (T_{CD}) and action distance (D_{CD})

The action time T_{CD} is the time while the machine control system or the operator takes action.

$$D_{CD} = v_a * T_{CD} \quad (2)$$

NOTE 1 v_a units is in meters/seconds.

NOTE 2 T_{CD} units is in seconds.

NOTE 3 D_{CD} units is in meters.

5.4 CWS action time (T_{CD})

Depending on how the action is communicated, the decision by the operator requires time to recognize the impending collision, apply the controls (e.g. apply brake, steer around) or determine no action is necessary as shown in Table 4.

Table 4 shows example of calculating operator action time.

Table 4 — Example action times

Operator activity	Min. time [s]	Cumulative [s]
Recognition of impending collision and decision	1,5	1,5
Control action done by the operator	1,24	2,74

NOTE 1 Times in this table are defined in Table B.1 (Reference [10]).

NOTE 2 These times are indicative times and can vary based on several factors (e.g. age, health, complexity of control action)

6 Information for use

6.1 General

Information for use shall be provided in accordance with ISO 12100:2010, 6.4.

6.2 Operator's manual

Information for use shall be included in the operator's manual and shall use ISO 6750-1 for guidance. This information shall include the following as applicable:

— descriptions of symbols that are displayed to the operator and what action is required;

— descriptions of error messages that are displayed to the operator and what action is required;

— descriptions of warning messages that are displayed to the operator and what action is required;

— descriptions of calibration procedures that the operator is required to perform.

Annex A
(normative)

Determining of collision risk levels — forward/reverse motion

A.1 Collision risk levels

For forward/reverse motion there are multiple levels of risk. For all figures, the path shown is the expected path, but it could also be all types of paths as defined in Annex E.

A.1.1 Collision risk level – Not applicable

The CxS determines there is no risk of a collision as there is no intended object as shown in Figure A.1. The CRL is defined as (NA).

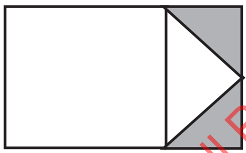
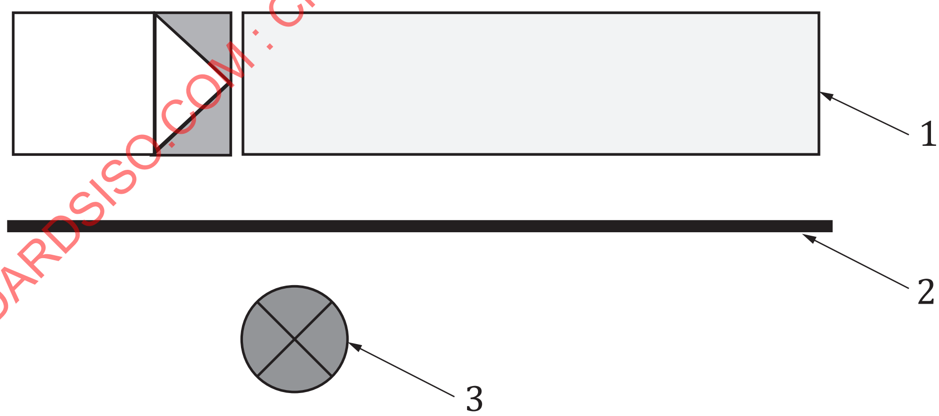


Figure A.1 — Risk level NA

A.1.2 Collision risk level 1

The risk of collision is not possible based on expected path of the machine and the location of the intended object (e.g. Figure A.2).



Key

1 expected path
2 barrier (e.g. berm, wall)
3 intended object

NOTE The example shows a barrier but it is not required to be a valid example.

Figure A.2 — Collision risk level 1

A.1.3 Collision risk level 2

The risk of collision is possible, if the movement is initiated or continues in the same expected path but no action is needed as shown in Figure A.3.

NOTE 1 CWS can make the operator aware of the intended object.

NOTE 2 CAS does not need to initiate interventional action, e.g. speed reduction.

Figure A.3 — Collision risk level 2

A.1.4 Collision risk level 3

The risk of collision is possible, if the movement is initiated or continues in the same expected path but the operator has time to take action as shown in Figure A.4. The operator shall be made aware of the intended object.

NOTE CAS could initiate interventional action, e.g. speed reduction.

Figure A.4 — Collision risk level 3

A.1.5 Collision risk level 4

The risk of collision is possible, if the movement is initiated or continues in the same expected path, but the CAS shall automatically take action as shown in Figure A.5.

NOTE 1 The CWS informing the operator does not have time to avoid the intended object by only braking.

NOTE 2 An alternative motion can be used to avoid the intended object (e.g. steer around, raise bucket).

NOTE 3 The CAS can react fast enough by applying interventional action control (e.g. brake, motion inhibition).

Figure A.5 — Collision risk level 4

A.1.6 Collision risk level 5

The risk of collision cannot be avoided, if the movement is initiated or continues in the same state (e.g. relative speed, direction, etc.) as shown in Figure A.6.

NOTE 1 An alternative motion can be used to avoid the intended object (e.g. steer around, raise bucket). However, the machine is not able to react fast enough by only applying interventional action control (e.g. brake, motion inhibition).

Figure A.6 — Collision risk level 5

A.2 Comparison of risk levels

Table A.1 compares the risk levels.

Table A.1 — Comparison of collision risk levels

Collision risk level	Existence of intended object	Possible risk of collision	Required collision avoidance action
NA	No	No	No
1	Yes	No	No
2	Yes	Yes	No
3	Yes	Yes	CWS, CAS (CSB, SDB)
4	Yes	Yes	CAS (ESB, TIC)
5	Yes	Yes	-

NOTE 1 CSB is controlled stop braking.

NOTE 2 SDB is slow down braking.

NOTE 3 ESB is emergency stop braking.

NOTE 4 See Annex G for more information.

NOTE 5 On risk level 5 a CAS that only does braking will not prevent the collision.

NOTE 6 TIC will occur at collision risk level 4.

Annex B
(normative)

Limitations of use of CxS

B.1 General

The following shall be considered in the development of the system and implementation.

Several challenges exist on assigning CRLs. These challenges can result in false positive CxS actions or false negative CxS actions. Too many CxS false positives create alarm fatigue and result in operators ignoring risk and create brake events that could create physical fatigue for the operators. False negatives CxS actions could result in collision.

B.2 Distance

The minimum distance at which an object would need to be detected could exceed the distance at which objects can be detected when the machines are traveling.

The CxS supplier shall provide information that describes the limits of detection and the configuration parameters that allow the CxS actions to be matched to the slow down and braking characteristics of a machine fitted with a CxD.

B.3 Environmental obscurants

Obscurants (e.g. rain, dust, EMI) can cause the object to be missed or cause the system to be non-functional which could result in false actions.

The CxS supplier shall provide information on the limitations of the system in the presence of environmental obscurants.

B.4 Terrain

The terrain of the collision risk area could degrade the performance of the system. Objects on uneven terrain (e.g. slopes, ruts), around blind curves (e.g. switchbacks) could result in false actions.

B.5 Close proximity

Machines frequently work in close proximity within the determined collision risk area to other objects on job-site to complete work tasks. Creating a system that can assign appropriate collision risk levels to the intended objects allowed in close proximity could be difficult (e.g. wheel loader and a truck).

The CxS supplier shall define the limitations for use of the CxD when working in close proximity to other objects.

B.6 Voids

Detecting a void requires the perception system to analyse the terrain and create a risk level based strictly on the terrain.

The CxS supplier shall define the capability for detection and assessment of the risk level for voids in the limitations for use.

B.7 Diverse objects

The types of objects are diverse. A technology that is sufficient for detecting one type of object could be insufficient for detecting a different type of object. A complex system could fuse multiple technologies together to address gaps.

The following are high level types of objects:

— earth-moving machinery;

— light vehicles;

— human;

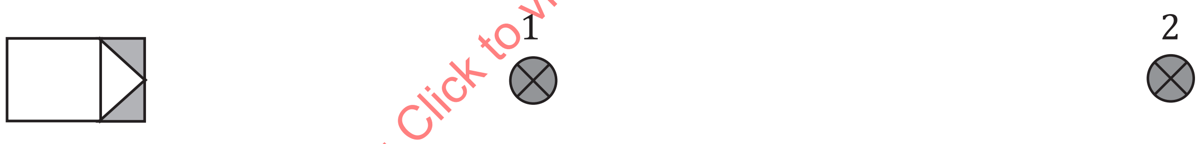
— others (e.g. infrastructures, environment, voids).

The CxS supplier shall define the capability for detection and assessment of supported object types in the limitations for use.

B.8 Multiple concurrent collision risk levels

There will be situations where there will be multiple objects that need be evaluated simultaneously as shown in Figure B.1. The system should analyse each object in the collision risk area, assign a risk level to each intended object and take appropriate action.

The system supplier shall communicate the limitations of concurrent risk levels.



Key

1 risk level 4

2 risk level 2

Figure B.1 — Multiple concurrent risk levels

B.9 Changing risk levels

Collision risk levels can change based on the movement of the machine and the object as shown in Figure B.2.

Key

1 risk level 1

2 risk level 5

Figure B.2 — Changing risk level

The CxS supplier shall define the limitations for use of the CxD when rapidly changing risk levels are present.

B.10 Instrumented vs non-instrumented objects

Some CxS can rely on the instrumentation of the objects to be detected to enable or improve the detection of those objects. Common examples of instrumentation include coverage with reflective material, addition of RFID tags and active reporting of GNSS position.

When CxS rely on the instrumentation of specific objects to meet a required detection rate, controls shall be put in place to detect and correct failures of the instrumentation.

Administrative controls should not be presumed infallible or having a success rate superior to reality.

The CxS supplier shall define the ability and/or limitations to detect instrumented or non-instrumented object.

B.11 Controlled vs uncontrolled site

On a controlled site, it is possible to ensure that objects (e.g. personnel and equipment) are restricted to authorized objects. In addition, it is possible to ensure that an authorized object is instrumented and the personnel are trained.

On an uncontrolled site, it should not be assumed that the objects are instrumented with a device to assist the CxS device or trained.

The CxS supplier shall define the limitations for use of the CxD for controlled or uncontrolled sites.

B.12 Variables that effect machine stopping distance

B.12.1 General

There are variables that affect the stopping distance. These variables are often either unknown or difficult to quantify in real time. A few of the variables are discussed below.

B.12.2 Tractive conditions

If the ground is slippery the coefficient of traction would be low, and this could limit the maximum deceleration rate of machine. The stopping distance would therefore be increased.

The CxS supplier shall provide information on configuration parameters that allow the CxS actions to be matched to the slow down and braking characteristics of a machine fitted with a CxD and limitations for use for the range of traction conditions on the operating site.

B.12.3 Brake capability

Brake capability is affected by a number of factors that vary during operation (e.g. brake temperature, maintenance, wear, mass, coefficient of friction between tyres and ground). For example, ISO 3450 defines the brake capability under a defined set of harsh test conditions but the actual braking distance in a specific instance will vary from the test results.

The CxS supplier shall provide information on configuration parameters that allow the CxS actions to be matched to the slow down and braking characteristics of a machine fitted with a CxD and limitations for use for the range of traction conditions on the operating site.

B.12.4 Terrain slope

The slope while braking will affect the stopping distance. The calculation of slope is complex as the value needed is the slope of the ground that will be travelled during braking rather than the current slope that the machine is currently travelling.

The CxS supplier shall provide information on configuration parameters that allow the CxS actions to be matched to the slow down and braking characteristics of a machine fitted with a CxD and limitations for use for the range of gradients experienced on the operating site.

B.12.5 Testing

The testing of the system under realistic scenarios without damaging equipment or personnel is challenging. Realistic test scenarios could lead personnel or equipment being placed at risk.

B.12.6 Human response times

The response time of the operator is critical in the calculation of CWS machine stopping distance. There can be significant variation between operators and for the same operator at different times of the day – for example at the start and end of a working shift. An example of one study that has characterised operator response time is shown in Table B.1.

Table B.1 — Mapping of human response times (example)

ISO 21815 - operator activity	Hopper-McGee chaining model		Time [s]	Cumulative [s]
Recognition of impending collision and decision	Perception	Latency	0,31	0,31
		Eye movement	0,09	0,4
		Fixation	0,2	0,6
		Recognition	0,5	1,1
Control action done by the operator	Initiating brake application		1,24	2,34

NOTE 1 Operator activities in column 1 are from Table 4. The component model values shown in the columns to the right are from Table 3.1 'Hopper-McGee Chaining Model of Perception-Response Time'; (Reference [10]).

NOTE 2 The above table is for reference only.

The CxS supplier shall provide information on configuration parameters that allow the CxS actions to be matched human response times and the slow down and braking characteristics of a machine fitted with a CxD in the limitations for use.

B.13 Braking performance for CxS

The system integrator shall configure the CxS taking into account the braking performance of the machine over the full range of operating speeds in the format defined in Table 3.

Stopping distances should not exceed the maximum allowed for specific machine types defined in ISO 3450 or ISO 19296 under the defined test conditions. Allowance should be made for actual operating conditions different to test conditions, including: roadway grades, initial speed, ground conditions, etc.

Refer to Annex F for an approach to determining the stopping distances used for configuration of the CxD based on actual stopping distance results (e.g. distance, velocity, retardation rate, time) or results derived from ISO 3450 or ISO 19296.

The braking performance during braking is highly dependent on the braking effort applied. Allowances should be made for variation in braking performance over the service life of the machine.

The configuration of the CxD shall take into account the delay between commencement of braking action and when the machine starts to decelerate due to application of retardation force between the machine and the roadway. In some cases, this delay can be appreciable and can result in a significant distance travelled by the machine before starting to slow down.

B.14 Compatibility

Information on the compatibility of the machine and the CxD shall be provided.

The CxS and machine shall be validated that they are compatible and were designed and configured to work together.

B.15 Override

A feature that allows the operator to override the system could create a hazard. Since there could be numerous objects each with a different risk level, the operator could be overwhelmed with information and believe that they understand risk for the object and mistakenly override the system.

The CxS supplier shall provide information on the mechanism that allows the operator to override CxS actions and limitations for use.

B.16 Detection and communication rate

For calculating the distance, the worst-case sample rate should be considered. A system will sample at a given frequency. The next opportunity for the system to evaluate the collision risk level is the next sample interval. A lower sample rate will increase the distance D_{AB}. The CxS supplier shall provide information on the latency of the CxS to detect new hazards as part of the limitations for use.

B.17 CxD installation challenges

There are several installation challenges such as:

— CxD installed in the cab should be mounted in such a way that it will not interfere with the operator's ergonomics, visibility or ability to operate the machine safely;

— the installation of CxD should not interfere with the other machine systems or negatively impact the machine's performance;

— if a dedicated CAN bus is provided for the CxS, then only the protocol for CxD to CxS should be communicated on this CAN bus;

— welding locations for the CxD should be submitted to the system integrator for approval. Welding on the ROPS and FOPS is prohibited;

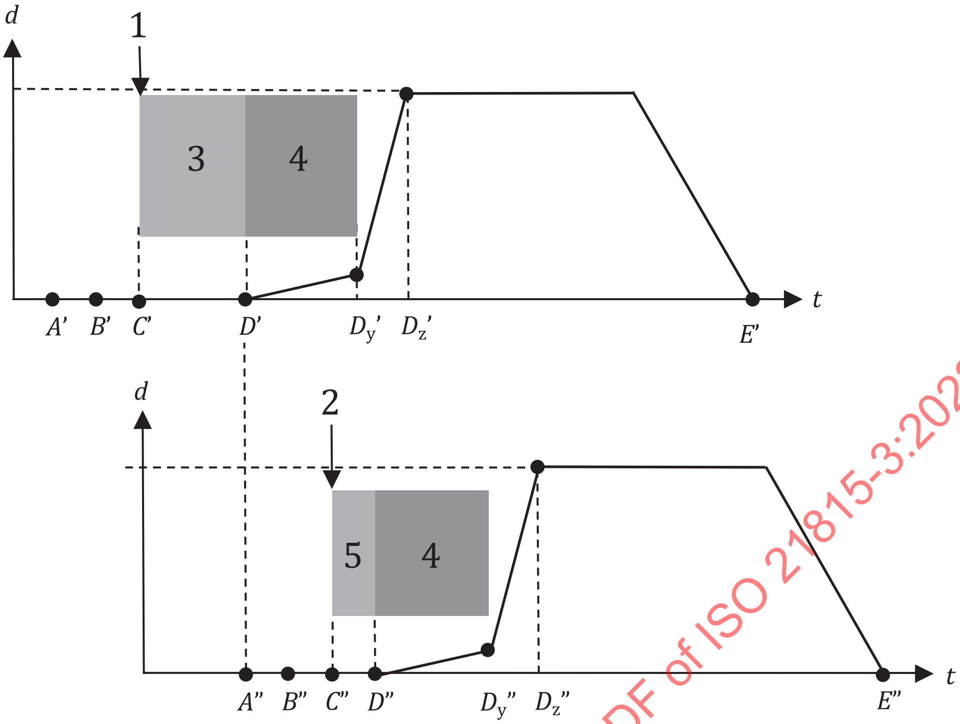
— different vintages of the same machine type can be configured differently so CxD may not be installed the same on all the machines;

— non-OEM installed options can cause CxD to be installed differently on different machine types.

B.18 CWS and CAS interaction

Where both CWS and CAS functions are implemented, the system integrator should configure the CWS to account for delay in the intervention action of CAS that would otherwise reduce the amount of time the operator has available for evasive action.

In the example shown in Figure B.3 the point *D*' (for CWS) should occur earlier than point *D*" (for CAS) to allow the operator sufficient time to take evasive action between points *C*' and *D*'.



Key

d fully developed deceleration
t time
1 CWS signal warn
2 CAS signal stop
3 operator
4 machine
5 controller

Figure B.3 — Example machine deceleration profiles for CxS braking action

Failure of the CWS to take into account CAS delays can result in less time available for an operator to take evasive action to avoid a potential collision.

The case where *D’* is aligned with *A”* provides the operator with the most time to take evasive action - coinciding with the point in time where the CAS has received the information needed to process the collision risk. In the next case, where *D’* is aligned with *B”*, the CAS has determined the risk level but has not yet communicated the intent to initiate an action. Subsequently, where *D’* is aligned with *C”* the signal to initiate the action has been sent by the CAS. Finally, when *D’* is aligned with *D”* the collision avoidance action has been decided by the machine and braking is initiated at the same time that the braking action is initiated by the operator. In this final case the CAS is overriding the operator action which could limit the options available to the operator to take evasive action.

In practice, the fully developed deceleration applied by the operator for CWS may be different to the fully developed deceleration applied by CAS resulting in unexpected override by the CAS if the operator is already responding to a CWS signal.

Annex C
(informative)

Example calculation CxS distance for surface vehicles

The example below is based on the ISO 3450 formulae which is for a slope of 10°.

Assumptions:

Vehicle type: rigid frame dumper with mass > 32,000 kg.

$$v_A = 50 v_A = 50\ \mathrm{km/h} \tag{C.1}$$

Object is stationary.

Calculate D_{AC} (detection distance)

Additional assumptions:

$$T_{AC} = 300\ \mathrm{ms} \tag{C.2}$$

$$D_{AC} = \frac{(v_A \times T_{AC})}{3{,}6} = \frac{(50\ \mathrm{km/h} \times 0{,}3\ \mathrm{s})}{3{,}6} = 4{,}17\ \mathrm{m} \tag{C.3}$$

Calculate D_{CD} (action distance)

Additional assumptions:

$$T'_{CD} = 2{,}5\ \mathrm{s} \tag{C.4}$$

$$T''_{CD} = 0{,}2\ \mathrm{s} \tag{C.5}$$

$$D_{CD} = v_A \times T_{CD} \tag{C.6}$$

Therefore

$$D'_{CD} = v_A \times T'_{CD} = 13{,}89\ \mathrm{m/s} \times 2{,}5\ \mathrm{s} = 34{,}73\ \mathrm{m} \tag{C.7}$$

or

$$D''_{CD} = v_A \times T''_{CD} = 13{,}89\ \mathrm{m/s} \times 0{,}2\ \mathrm{s} = 2{,}78\ \mathrm{m} \tag{C.8}$$

Calculate D_{DE} (braking distance)

Additional assumptions:

$$S_{grade(\%)} = 10\ \text{(down ramp)} \tag{C.9}$$

As shown in Figure C.1, the distance formula is from ISO 3450:2011, Table 3.

Scraper, rigid-frame dumpers and articulated-frame dumpers with machine test mass >32 000 kg	$\frac{v^2}{48-2,6\alpha}$

Key

v initial speed, in km/h

α test slope as a percentage between 8 % and 10 %

Figure C.1 — Distance formula

$$D_{DE} = \frac{(v_A)^2}{(48-2,6\alpha)} = \frac{(50\,\text{km}/\text{h})^2}{(48-(2,6\times 10))} = 113,64\,\text{m} \quad \text{(C.10)}$$

Total D_{AE} (collision stopping distance)

$$D_{AE} = D_{AC} + D_{CD} + D_{DE} \quad \text{(C.11)}$$

$$D'_{AE} = D_{AC} + D'_{CD} + D_{DE} = 4,17\,\text{m} + 34,73\,\text{m} + 113,64\,\text{m} = 152,53\,\text{m} \quad \text{(C.12)}$$

or

$$D''_{AE} = D_{AC} + D''_{CD} + D_{DE} = 4,17\,\text{m} + 2,78\,\text{m} + 113,64\,\text{m} = 120,59\,\text{m} \quad \text{(C.13)}$$

Total D_{AF} (CxS distance)

Additional assumptions:

Object position inaccuracy:

$$D_I = 0,5\,\text{m} \quad \text{(C.14)}$$

Safe offset distance. This is the minimum distance a machine is allowed to approach a human, as specified by the mine.

$$D_O = 1,0\,\text{m} \quad \text{(C.15)}$$

$$D_{EF} = (2\times D_I) + D_O \quad \text{(C.16)}$$

Therefore:

$$D_{AF} = D_{AE} + (2\times D_I) + D_O \quad \text{(C.17)}$$

$$D'_{AF} = D_{AE} + (2\times D_I) + D_O = 152,53\,\text{m} + 1,0\,\text{m} + 1,0\,\text{m} = 154,53\,\text{m} \quad \text{(C.18)}$$

or

$$D''_{AF} = D_{AE} + (2\times D_I) + D_O = 120,59\,\text{m} + 1,0\,\text{m} + 1,0\,\text{m} = 122,59\,\text{m} \quad \text{(C.19)}$$

Annex D
(informative)

Example calculations of CxS distance for underground mining machine

D.1 Example 1 – approaching stationary object

Assumptions:

Vehicle type: load haul dump

$$v_A = 20\ \mathrm{km/h} \quad \text{(D.1)}$$

Object is stationary.

Calculate D_{AC} (detection distance)

Additional assumptions:

$$T_{AC} = 0{,}620\ \mathrm{s} \quad \text{(D.2)}$$

$$D_{AC} = \frac{v_A \times T_{AC}}{3{,}6} \quad \text{(D.3)}$$

NOTE 3,6 is the conversion factor from km/h to m/s.

$$D_{AC} = \frac{(20\ \mathrm{km/h} \times 0{,}62\ \mathrm{s})}{3{,}6} = 3{,}44\ \mathrm{m} \quad \text{(D.4)}$$

Calculate D_{CD} (operator or machine action distance)

Additional assumptions:

$$T'_{CD} = 2{,}5\ \mathrm{s} \quad \text{(D.5)}$$

$$T''_{CD} = 0{,}2\ \mathrm{s} \quad \text{(D.6)}$$

$$D_{CD} = \frac{v_A \times T_{CD}}{3{,}6} \quad \text{(D.7)}$$

Therefore

$$D'_{CD} = \frac{v_A \times T'_{CD}}{3{,}6} \quad \text{(D.8)}$$

$$D'_{CD} = \frac{(20\ \mathrm{km/h} \times 2{,}5\ \mathrm{s})}{3{,}6} = 13{,}9\ \mathrm{m} \quad \text{(D.9)}$$

or

$$D''_{CD} = \frac{v_A \times T''_{CD}}{3{,}6} \quad \text{(D.10)}$$

$$D''_{CD} = \frac{(20\ \mathrm{km/h} \times 0{,}2\ \mathrm{s})}{3{,}6} = 1{,}11\ \mathrm{m} \quad \text{(D.11)}$$

Calculate D_{DE} (machine stopping distance)

ISO 19296:2018 specifies braking requirements for rubber tired underground mining machines. ISO 3450:2011, Annex A advises that regulations in many countries have specific braking requirements for underground vehicles. This example uses the requirements in ISO 19296:2018.

Additional assumptions:

Gradient: ≤ 20 %. ISO 19296 requires minimum retardation rate of 2,75 m/s^2 for gradients up to 20 %.

For CWS, operator applies braking to achieve a minimum retardation rate of 2,75 m/s^2.

Brake system response time:

$$T_{MBS} = 0{,}35\ \mathrm{s}\ \ [\text{ISO 19296}] \quad \text{(D.12)}$$

From ISO 19296, the service brake stopping distance, S, is given by

$$S = \frac{vt}{3{,}6} + \frac{v^2}{26\alpha} \quad \text{(D.13)}$$

where

S is the service brake stopping distance, in m;

v is the initial speed, in km/h;

t is the time, and has the value of 0,35 s;

α is the deceleration, in m/s^2 – use 0,28 g or 2,75 m/s^2.

$$D_{DE} = \frac{(v_A \times T_{MBS})}{3{,}6} + \frac{{v_A}^2}{26\alpha} \quad \text{(D.14)}$$

$$D_{DE} = \frac{(20\ \mathrm{km/h} \times 0{,}35\ \mathrm{s})}{3{,}6} + \frac{(20\ \mathrm{km/h})^2}{\left(26 \times 2{,}75\ \mathrm{m/s^2}\right)} = 7{,}54\ \mathrm{m} \quad \text{(D.15)}$$

Total D_{AE} (collision stopping distance)

$$D'_{AE} = D_{AC} + D'_{CD} + D_{DE} \quad \text{(D.16)}$$

$$D'_{AE} = 3{,}44\ \mathrm{m} + 13{,}9\ \mathrm{m} + 7{,}54\ \mathrm{m} = 24{,}88\ \mathrm{m} \quad \text{(D.17)}$$

or

$$D''_{AE} = D_{AC} + D''_{CD} + D_{DE} \quad \text{(D.18)}$$

$$D''_{\mathrm{AE}} = 3{,}44\ \mathrm{m} + 1{,}11\ \mathrm{m} + 7{,}54\ \mathrm{m} = 12{,}09\ \mathrm{m} \tag{D.19}$$

Total D_{AF} (CxS distance)

Additional assumptions:

Error value in the system in measuring the distance:

$$D_{\mathrm{I}} = 0{,}5\ \mathrm{m} \tag{D.20}$$

Safe offset value. This is determined by authorized person to provide additional clearance around the intended object.

$$D_{\mathrm{O}} = 1\ \mathrm{m} \tag{D.21}$$

Safe distance:

$$D_{\mathrm{EF}} = (2 \times D_I) + D_O \tag{D.22}$$

Therefore

$$D_{\mathrm{AF}} = D_{\mathrm{AE}} + (2 \times D_{\mathrm{I}}) + D_{\mathrm{O}} \tag{D.23}$$

$$D'_{\mathrm{AF}} = D'_{\mathrm{AE}} + (2 \times D_{\mathrm{I}}) + D_{\mathrm{O}} \tag{D.24}$$

$$D'_{\mathrm{AF}} = 24{,}88\ \mathrm{m} + 1\ \mathrm{m} + 1\ \mathrm{m} = 26{,}88\ \mathrm{m} \tag{D.25}$$

or

$$D''_{\mathrm{AF}} = D''_{\mathrm{AE}} + (2 \times D_{\mathrm{I}}) + D_{\mathrm{O}} \tag{D.26}$$

$$D''_{\mathrm{AF}} = 12{,}09\ \mathrm{m} + 1\ \mathrm{m} + 1\ \mathrm{m} = 14{,}09\ \mathrm{m} \tag{D.27}$$

D.2 Example 2 – approaching stationary object with slowdown

This example uses the same assumptions as D.1 (example 1), but adds in a ramp to reduce speed to a pre-determined slowdown speed prior to entering the stop zone.

Assumptions:

Vehicle type: load haul dump

$$v_{\mathrm{A}} = 20\ \mathrm{km/h} \tag{D.28}$$

$$v_{\mathrm{SD}} = 3\ \mathrm{km/h} \tag{D.29}$$

NOTE SD stands for slowdown.

Object is stationary.

No operator action, i.e. if the machine has CWS installed, assume the operator ignores the warning and does not initiate any braking.

Calculate D_{AC} (detection distance)

Additional assumptions:

$$T_{AC} = 0{,}62\,\text{s} \tag{D.30}$$

$$D_{AC} = \frac{v_A \times T_{AC}}{3{,}6} \tag{D.31}$$

$$D_{AC} = \frac{(20\,\text{km/h} \times 0{,}62\,\text{s})}{3{,}6} = 3{,}44\,\text{m} \tag{D.32}$$

Calculate D_{CD} (operator or machine action distance)

Additional assumptions:

$$T''_{CD} = 0{,}2\,\text{s} \tag{D.33}$$

$$D''_{CD} = \frac{v_A \times T''_{CD}}{3{,}6} \tag{D.34}$$

$$D''_{CD} = \frac{(20\,\text{km/h} \times 0{,}2\,\text{s})}{3{,}6} = 1{,}11\,\text{m} \tag{D.35}$$

Calculate $D_{DE(SD)}$ (braking distance) to slowdown speed

Additional assumptions:

Gradient: ≤ 20 %.

$$\alpha = 2{,}75\,\text{m/s}^2 \ \text{[ISO 19296]} \tag{D.36}$$

For slowdown 50 % of maximum braking is applied:

$$\alpha_{SD} = 0{,}5 \times \alpha = 0{,}5 \times 2{,}75\,\text{m/s}^2 = 1{,}38\,\text{m/s}^2 \tag{D.37}$$

Brake system response time (brakes released when slowdown speed reached):

$$T_{MBS} = 0{,}35\,\text{s} \ \text{[ISO 19296]} \tag{D.38}$$

The formula provided in ISO 19296 needs to be modified for a non-zero final speed:

$$S = \frac{vt}{3{,}6} + \frac{v^2 - u^2}{26\alpha} \tag{D.39}$$

where u is the final speed in km/h.

$$D_{DE(SD)} = \frac{(v_A \times T_{MBS})}{3{,}6} + \frac{{v_A}^2 - {v_{SD}}^2}{26\alpha_{SD}} \tag{D.40}$$

$$D_{DE(SD)} = \frac{(20\,\text{km/h} \times 0{,}35\,\text{s})}{3{,}6} + \frac{\left((20\,\text{km/h})^2 - (3\,\text{km/h})^2\right)}{\left(26 \times 1{,}38\,\text{m/s}^2\right)} = 12{,}84\,\text{m} \tag{D.41}$$

Calculate $D_{DE(STOP)}$ (braking distance) from slowdown speed to stationary

Additional assumptions:

$$T_{DE(STOP)} = 0{,}2\,\mathrm{s} \text{ (assumed to be the same as } T''_{CD}\text{)} \tag{D.42}$$

$$T_{MBS} = 0{,}35 \text{ s (brakes released when slowdown speed reached, so need to be applied again)} \tag{D.43}$$

Full braking applied

$$D_{DE(STOP)} = \frac{(v_{SD} \times T_{MBS})}{3{,}6} + \frac{v_{SD}^{\ 2}}{26\alpha} \tag{D.44}$$

$$D_{DE(STOP)} = \frac{(20\,\mathrm{km/h} \times 0{,}35\,\mathrm{s})}{3{,}6} + \frac{(3\,\mathrm{km/h})^2}{\left(26 \times 2{,}75\,\mathrm{m/s^2}\right)} = 2{,}07\,\mathrm{m} \tag{D.45}$$

Total D_{AE} (stopping distance)

Additional assumption: slowdown speed is reached at the start of the stop zone, i.e. no travel at slowdown speed

$$D_{AE(SD\&STOP)} = D_{AC} + D_{CD(CAS)} + D_{DE(SD)} + D_{DE(STOP)} \tag{D.46}$$

$$D_{AE(SD\&STOP)} = 3{,}44\,\mathrm{m} + 1{,}11\,\mathrm{m} + 12{,}84\,\mathrm{m} + 2{,}07\,\mathrm{m} = 19{,}46\,\mathrm{m} \tag{D.47}$$

Total D_{AF} (CxS distance)

Additional assumptions:

Object position inaccuracy:

$$D_I = 0{,}5\,\mathrm{m} \tag{D.48}$$

Safe offset distance is the minimum distance a machine is allowed to approach a human, as specified by the mine.

$$D_O = 1{,}0 \text{ m} \tag{D.49}$$

Since

$$D_{EF} = D_I + D_O \tag{D.50}$$

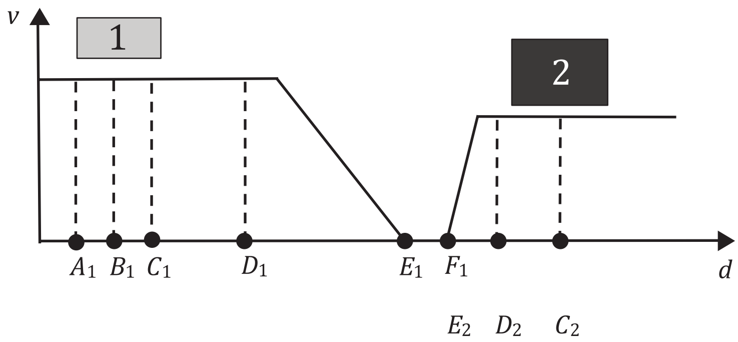
therefore

$$D_{AF(SD\&STOP)} = D_{AE(SC\&STOP)} + (2 \times D_I) + D_O \tag{D.51}$$

$$D_{AF(SD\&STOP)} = 19{,}46\,v + 1{,}0\,\mathrm{m} + 1{,}0\,\mathrm{m} = 21{,}46\,\mathrm{m} \tag{D.52}$$

D.3 Example 3 – two machines approaching head-on

Two machines approaching head-on as shown in Figure D.1 is an example of calculating the minimum detection distance for the CxS in order to prevent a collision between a truck travelling in one direction and a light vehicle travelling in the opposite direction, where there is insufficient roadway width to allow the two vehicles to pass each other.



Key

v machine speed

d distance

1 truck

2 light vehicle

Figure D.1 — Minimum distance for two machines

Assumptions:

First vehicle type: truck fitted with CxS

$$v_{A1} = 15\,\text{km}/\text{h} \quad (D.53)$$

Second vehicle type: light vehicle, not fitted with CxS

$$v_{A2} = 10\,\text{km}/\text{h} \quad (D.54)$$

$$S_{\text{grade}(\%)} = 0 \;\; (\text{level floor}) \quad (D.55)$$

Calculate D_{AC1} (detection distance)

Additional assumption:

$$T_{AC1} = 0{,}62\,\text{s} \quad (D.56)$$

$$D_{AC1} = \frac{v_{A1} \times T_{AC1}}{3{,}6} \quad (D.57)$$

$$D_{AC1} = \frac{(15\,\text{km}/\text{h} \times 0{,}62\,\text{s})}{3{,}6} = 2{,}58\,\text{m} \quad (D.58)$$

Calculate D_{CD1} (operator or machine action distance)

Additional assumptions:

$$T'_{CD1} = 2{,}5\ \text{s} \quad (D.59)$$

$$T''_{CD1} = 0{,}2\ \text{s} \quad (D.60)$$

$$D_{CD1} = \frac{v_{A1} \times T_{CD1}}{3,6} \tag{D.61}$$

Therefore

$$D'_{CD1} = \frac{v_{A1} \times T'_{CD1}}{3,6} \tag{D.62}$$

$$D'_{CD1} = \frac{(15\,\text{km}/\text{h} \times 2,5\,\text{s})}{3,6} = 10,42\,\text{m} \tag{D.63}$$

or

$$D"_{CD1} = \frac{v_{A1} \times T"_{CD1}}{3,6} \tag{D.64}$$

$$D_{CD(CAS)} = \frac{(15\,\text{km}/\text{h} \times 0,2\,\text{s})}{3,6} = 0,83\,\text{m} \tag{D.65}$$

Calculate D_{DE1} (machine stopping distance)

Additional assumptions:

For CWS, operator applies braking to achieve a minimum retardation rate of 2,75 m/s^2.

Brake system response time:

$$T_{MBS} = 0,35\ \text{s} \tag{D.66}$$

$$D_{DE1} = \frac{(v_{A1} \times T_{MBS})}{3,6} + \frac{{v_{A1}}^2}{26\alpha} \tag{D.67}$$

$$D_{DE1} = \left(\frac{15\,\text{km}/\text{h} \times 0,35\,\text{s}}{3,6}\right) + \frac{(15\,\text{km}/\text{h})^2}{\left(26 \times 2,75\,\text{m}/\text{s}^2\right)} = 4,61\,\text{m} \tag{D.68}$$

Total D_{AE1} (collision stopping distance)

$$D'_{AE1} = D_{AC1} + D'_{CD1} + D_{DE1} \tag{D.69}$$

$$D'_{AE1} = 2,58\,\text{m} + 10,42\,\text{m} + 4,61\,\text{m} = 17,61\,\text{m} \tag{D.70}$$

or

$$D"_{AE1} = D_{AC1} + D"_{CD1} + D_{DE1} \tag{D.71}$$

$$D"_{AE1} = 2,58\,\text{m} + 0,83\,\text{m} + 4,61\,\text{m} = 8,02\,\text{m} \tag{D.72}$$

Total D_{AF1} (CxS distance)

Additional assumptions:

Error value in the system in measuring the distance:

$$D_{I1} = 0{,}5\ \mathrm{m} \tag{D.73}$$

Safe offset value. This is determined by authorized person to provide additional clearance around the intended object.

$$D_{O1} = 1{,}0\ \mathrm{m} \tag{D.74}$$

Since

$$D_{EF} = (2 \times D_I) + D_O \tag{D.75}$$

therefore

$$D'_{AF1} = D'_{AE1} + (2 \times D_{I1}) + D_{O1} \tag{D.76}$$

$$D'_{AF1} = 17{,}61\ \mathrm{m} + 1{,}0\ \mathrm{m} + 1{,}0\ \mathrm{m} = 19{,}61\ \mathrm{m} \tag{D.77}$$

or

$$D''_{AF1} = D''_{AE1} + (2 \times D_{I1}) + D_{O1} \tag{D.78}$$

$$D''_{AF1} = 8{,}02\ \mathrm{m} + 1{,}0\ \mathrm{m} + 1{,}0\ \mathrm{m} = 10{,}02\ \mathrm{m} \tag{D.79}$$

Light vehicle

As the light vehicle has no CxS

$$D_{AC2} = 0{,}0\ \mathrm{m} \tag{D.80}$$

$$D_{DE2} = 0{,}0\ \mathrm{m} \tag{D.81}$$

Calculate D_{CD2} (operator action distance)

Additional assumptions:

$$T_{CD2} = 2{,}5\ \mathrm{s} \tag{D.82}$$

$$D_{CD2} = \frac{v_{A2} \times T_{CD2}}{3{,}6} \tag{D.83}$$

Therefore

$$D_{CD2} = \frac{v_{A2} \times T_{CD2}}{3{,}6} \tag{D.84}$$

$$D_{CD2} = \frac{(10\ \mathrm{km/h} \times 2{,}5\ \mathrm{s})}{3{,}6} = 6{,}94\ \mathrm{m} \tag{D.85}$$

Calculate D_{DE2} (machine stopping distance)

Additional assumptions:

Operator applies braking to achieve a minimum retardation rate of 5,0 m/s^2.

Brake system response time:

$$T_{LVBS} = 0{,}2\ \text{s} \quad \text{(D.86)}$$

$$D_{DE2} = \frac{(v_{A2} \times T_{LVBS})}{3{,}6} + \frac{{v_{A2}}^2}{26\alpha} \quad \text{(D.87)}$$

$$D_{DE2} = \left(\frac{10\ \text{km/h} \times 0{,}2\ \text{s}}{3{,}6}\right) + \frac{(10\ \text{km/hr})^2}{\left(26 \times 5{,}0\ \text{m/s}^2\right)} = 1{,}32\ \text{m} \quad \text{(D.88)}$$

Total D_{AE21} (stopping distance)

$$D_{AE2} = D_{CD2} + D_{DE2} \quad \text{(D.89)}$$

$$D_{AE2} = 6{,}94\ \text{m} + 1{,}32\ \text{m} = 8{,}26\ \text{m} \quad \text{(D.90)}$$

Truck and light vehicle

Total distance required for both vehicles to stop

$$D_{STOP} = D_{AE1} + D_{AE2} \quad \text{(D.91)}$$

Therefore

$$D'_{STOP} = D'_{AE1} + D_{AE2} \quad \text{(D.92)}$$

$$D'_{STOP} = 17{,}61\ \text{m} + 8{,}26\ \text{m} = 25{,}87\ \text{m} \quad \text{(D.93)}$$

or

$$D''_{STOP} = D''_{AE1} + D_{AE2} \quad \text{(D.94)}$$

$$D''_{STOP} = 8{,}02\ \text{m} + 8{,}26\ \text{m} = 16{,}28\ \text{m} \quad \text{(D.95)}$$

Total $D_{A1—C2}$ (CxS distance)

Additional assumptions:

Error value in the system in measuring the distance:

$$D_{I1} = 0{,}5\ \text{m} \quad \text{(D.96)}$$

Safe offset value. This is determined by the authorized person to provide additional clearance around the intended object.

$$D_{O1} = 1{,}0\ \text{m} \quad \text{(D.97)}$$

Since

$$D_{EF} = (2 \times D_I) + D_O \quad \text{(D.98)}$$

therefore

$$D'_{A1-C2} = D'_{STOP} + (2 \times D_{I1}) + D_{O1} \quad \text{(D.99)}$$

$$D'_{A1-C2} = 25,87\ m + 1,0\ m + 1,0\ m = 27,87\ m \tag{D.100}$$

or

$$D"_{A1-C2} = D"_{STOP} + (2 \times D_{I1}) + D_{O1} \tag{D.101}$$

$$D"_{A1-C2} = 16,28\ m + 1,0\ m + 1,0\ m = 18,28\ m \tag{D.102}$$

Annex E
(informative)

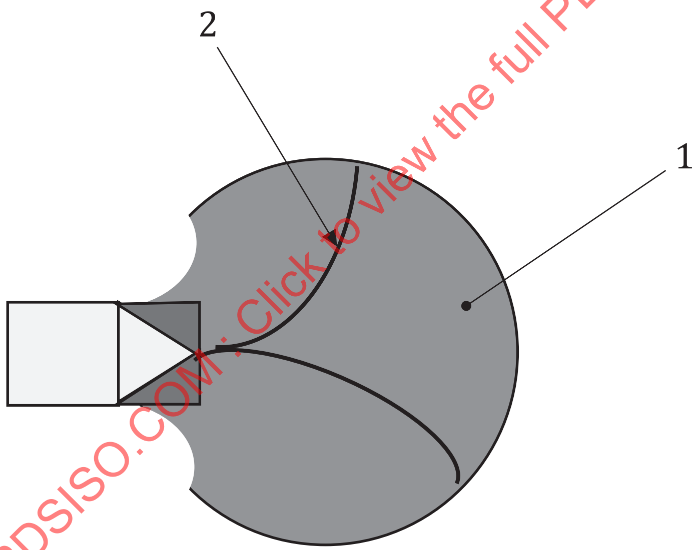
Estimating the path

E.1 General

On a relatively simple system, the projected, probable, or expected path would not be known so the collision risk area is very large, since the space would need to be the combined space of the possible stopping area of machine and object. On increasing complex systems, they have the ability to use machine and site information to make estimations on where the machine will be in the future. These estimations can be used to reduce the number of false CxS actions.

E.2 Possible path

The simplest system could rely on only object sensors. This type of system creates the largest number of possible paths and is only limited by the kinematics limitations of the machine as shown in Figure E.1.



Key

1 the grey area represents the entire area that the machine can travel

2 the black lines are examples of the possible paths a machine can travel

Figure E.1 — Possible path

E.3 Projected path

By using machine sensors (e.g. steering angle), the CxS system can estimate the future travel as shown in Figure E.2.

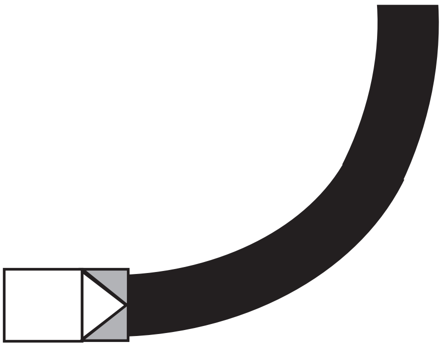
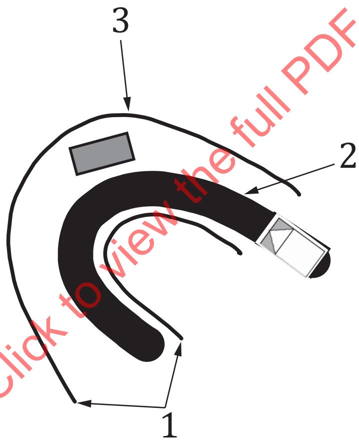


Figure E.2 — Projected path

E.4 Expected path

By using terrain information (e.g. terrain, barriers), the CxS system can estimate the future travel based on where the operator will navigate the terrain as shown in Figure E.3 and Figure E.4. There is only one expected path at a time.



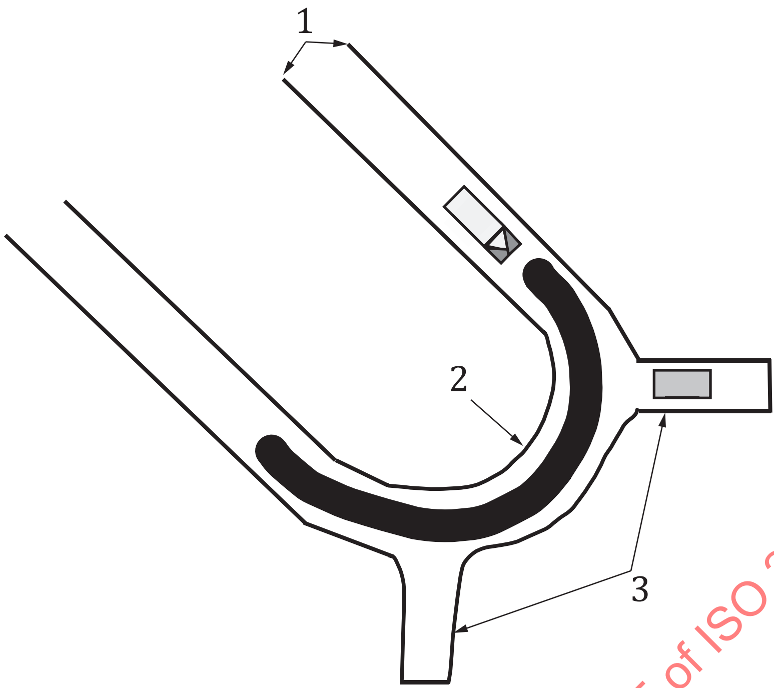
Key

1 the lines represent a bi-direction road with left-hand traffic

2 the shaded area represents the expected path and is constrained by the road and anticipated path to be driven

3 the road was designed such that the machine can travel exclusively in the shaded area

Figure E.3 — Expected path #1



Key

1 the lines represent road segment that only allows traffic in one direction at a time

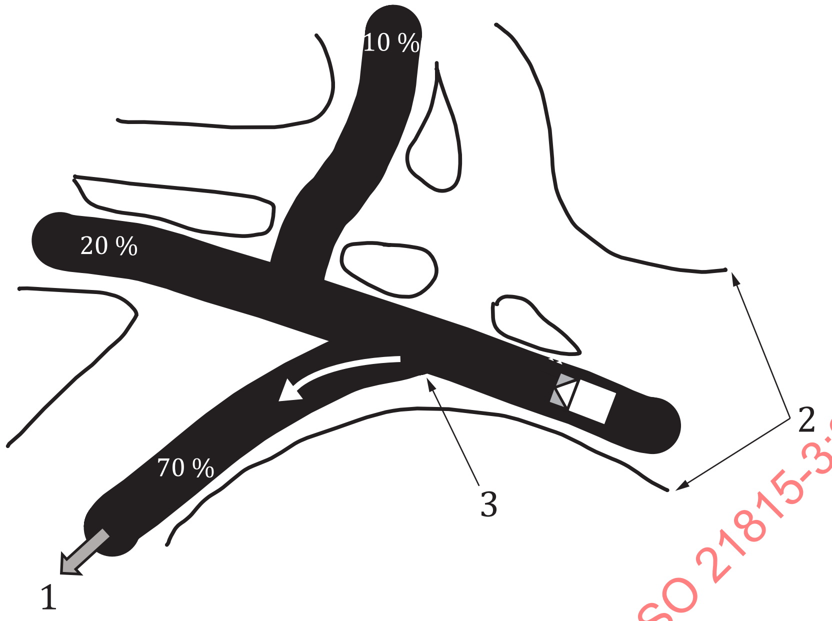
2 the shaded area represents the expected path of travel

3 the road has designated areas where traffic can pass each other

Figure E.4 — Expected path #2

E.5 Probable paths

In many situations, determining an expected path is not possible as there is more than one path that could be expected. A system can use machine and site information to create multiple paths and assign a probability to each path. The CxS could calculate the percentages based on such things as: (1) known travel route, (2) current activity, (3) type of area in which machine is traveling and (4) other traffic ahead or near the machine as shown in Figure E.4. Probable path could represent multiple distinct routes or areas. For example, at an intersection a machine can turn left but can actually go straight or turn right. The CxS can assign a likelihood to further improve the system (see Figure E.5).



Key

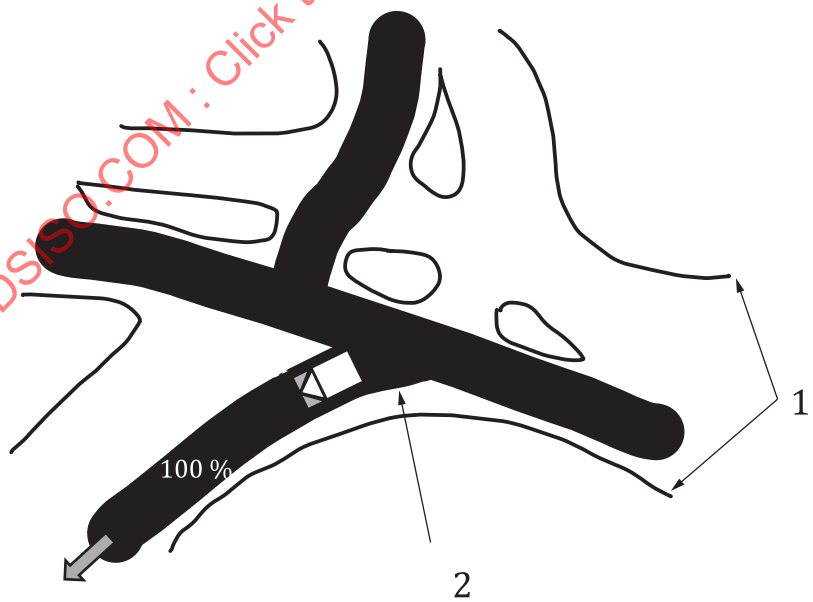
1 destination

2 the lines represent an intersection with bi-direction roads with left-hand traffic

3 the shaded area represents paths that could occur and a likelihood of the machine traveling each path

Figure E.5 — Probable path

When the CxS determines that the likelihood of the other paths is sufficiently low the probable path becomes the expected path as shown in Figure E.6.



Key

1 the lines represent an intersection with bi-direction roads with left-hand traffic

2 the shaded area with an 100 % is now the expected path as the previous probable paths are no longer probable

Figure E.6 — Expected path

Annex F
(informative)

An approach for determining CxS configuration

F.1 General

The CxS configuration table defined in 4.5.3 may be extended to indicate the assumptions made by the CxS designer or system integrator based on the stopping performance of the machine over the range of conditions that the machine will be operated.

NOTE 1 The following is one of many possible approaches.

The following parameters may be used to describe the basis of the resulting CxS configuration:

— machine delay – the time taken for the machine to commence to slow down after braking action is initiated by the operator (for CWS) or by intervention action (for CAS);

— average deceleration – the average value of deceleration commencing from when the machine starts to slow until the machine reaches a complete stop.

NOTE 2 Machine delay is the time from when the brake pedal is pressed (CWS) or when the machine receives a command from the interface (CAS) to when deceleration reaches a predefined value (m/s²).

NOTE 3 The machine delay response time varies over the life of the machine and contributes to the braking distance as calculated in ISO 3450 or ISO 19296 as appropriate.

These additional parameters can be inserted as shown in Table F.1 alongside the columns already defined in the CxS configuration table in 4.5.3.

Table F.1 — Example of extended CxS configuration table

Velocity [kph]	Slope [%]	T_{AC} [s]	T_{CD} [s]	Machine delay $D\text{-}D_Y$	Average deceleration $D_Y\text{-}E$	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 – Model 123 ☑ CWS ☑ CAS ☑ ESB ☑ CSB ☑						

The CxS manufacturer or the systems integrator may establish values for these two additional parameters, through suitable methods, including:

— measurement of the stopping performance of the machine under a range of actual site conditions with suitable instrumentation that can measure both machine delay and the average deceleration;

— use of the braking performance requirements defined in ISO 19296 or ISO 3450 as appropriate to determine default values extrapolated outside the narrow range of test conditions described in these standards.

The following subclauses provide examples of CxS configurations that match the braking performance for specific examples in ISO 3450 and ISO 19296.