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Earth-moving machinery — Functional safety —

Part 1: Methodology to determine safety-related parts of the control system and performance requirements

Engins de terrassement — Sécurité fonctionnelle —

Partie 1: Méthodologie pour la détermination des parties relatives à la sécurité des systèmes de commande et les exigences de performance

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

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Foreword

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

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

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

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

This first edition of ISO 19014-1, together with ISO 19014-2, ISO 19014-3, ISO 19014-4 and ISO/TS 19014-5, cancels and replaces ISO 15998 and ISO/TS 15998-2, which have been technically revised.

The main changes compared to the previous documents are as follows:

— method for determination of performance levels and machine control system safety analysis,

— additional requirements for mobile machines,

— environmental test requirements for components of safety controls systems, and

— requirements for software validation and verification of machine performance levels.

This corrected version of ISO 19014-1:2018 incorporates the following corrections:

— in 4.2 c) 2), 4.2 d) 1), 6.1 and Annex C, the cross-references to the steps defined in 4.2 have been corrected.

A list of all parts in the ISO 19014-series can be found on the ISO website. At the time of publication of this document, Part 2, *Design and evaluation of safety-related machine control systems*, Part 4, *Design and evaluation of software and transmission for safety related parts of the control system*, and Part 5, *Tables of performance levels*, are under development.

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

This document addresses systems of all energy types used for functional safety in earth-moving machinery.

The structure of safety standards in the field of machinery is as follows.

Type-A standards (basis standards) give basic concepts, principles for design and general aspects that can be applied to machinery.

Type-B standards (generic safety standards) deal with one or more safety aspects, or one or more types of safeguards that can be used across a wide range of machinery:

— type-B1 standards on particular safety aspects (e.g. safety distances, surface temperature, noise);

— type-B2 standards on safeguards (e.g. two-hands controls, interlocking devices, pressure sensitive devices, guards).

Type-C standards (machinery safety standards) deal with detailed safety requirements for a particular machine or group of machines.

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);

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.

Earth-moving machinery — Functional safety —

Part 1: Methodology to determine safety-related parts of the control system and performance requirements

1 Scope

This document provides a methodology for the determination of performance levels required for earth moving machinery (EMM) as defined in ISO 6165.

A Machine Control System Safety Analysis (MCSSA) determines the amount of risk reduction of hazards associated with control systems, required for Safety Control Systems (SCS). This reduction is quantified by the Machine Performance Level (MPL), the hazards are identified using the risk assessment principles as defined in ISO 12100 or by other means.

NOTE 1 Step 2 as shown in Annex A demonstrates the relationship between ISO 12100 and ISO 19014 as a complementary protective measure.

NOTE 2 ISO 19014 can also be used to assess the functional safety requirements of other off-road mobile machinery.

For those controls determined to be safety-related, the characteristics for architecture, hardware, software environmental requirements and performance are covered by other parts in ISO 19014.

ISO 19014 covers the hazards caused by the failure of a safety control system and excludes hazards arising from the equipment itself (for example, electric shock, fire, etc.).

Other controls that are not safety control systems (SCS), that do not mitigate a hazard or perform a control function and where the operator would be aware of a failure, are excluded from this standard (e.g. windscreen wipers, head lights, cab light, etc.).

NOTE 3 A list of safety control systems is included in Annex D.

NOTE 4 Audible warnings are excluded from the requirements of diagnostic coverage.

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 6165, *Earth-moving machinery — Basic types — Identification and terms and definitions*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 6165 and ISO 12100 and the following apply.

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

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

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

3.1
Machine Performance Level
MPL
discrete level to specify the ability of *safety-related parts of control systems* (3.3.2) to perform a safety function under reasonably foreseeable conditions

Note 1 to entry: The term MPL is used to describe the performance level required from a safety-related part of a control system. The 'M' refers to machine and denotes Earth Moving Machinery covered by the scope of this document and is used to differentiate from other functional safety standards (e.g. PL, AgPL, ASIL, etc.).

3.1.1
Machine Performance Level required
MPL_r
discrete level required as determined by processes in this document

3.1.2
Machine Performance Level achieved
MPL_a
discrete level achieved by the *safety control systems* (3.3.1) hardware, architecture and software

Note 1 to entry: Process for determination of MPLa will be covered in ISO 19014-2 and ISO 19014-4, under development.

3.2
functional safety
part of the overall safety relating to the equipment under control and its control system that depends on the correct functioning of the *safety control system (SCS)* (3.3.1) and other risk reduction measures

[SOURCE: IEC 61508-4:2010, 3.1.12, modified]

3.3
machine control system
MCS
system which responds to input signals from parts of machine elements, *operators* (3.4.1), external control equipment or any combination of these and generates output signals causing the machine to behave in the intended manner

[SOURCE: ISO 13849-1:2015, 3.1.32]

3.3.1
safety control system
SCS
sub-system or system used by a *MCS* (3.3) to achieve *functional safety* (3.2) by affecting machine behaviour or mitigating a hazard

Note 1 to entry: A system which can fail in a way that creates a hazard is considered a SCS.

Note 2 to entry: For example, SCS for propulsion may include throttle, gear shift, start/stop, etc.

3.3.2
safety-related part of the control system
SRP/CS
part of a *SCS* (3.3.1) that responds to safety-related input signals and generates safety-related output signals

Note 1 to entry: The combined safety-related parts of a control system start at the point where the safety-related input signals are initiated (including, for example, the actuating cam and the roller of the position switch) and end at the output of the power control elements (including, for example, the main contacts of a contactor).

Note 2 to entry: If monitoring systems are used for diagnostic coverage, they are also considered as SRP/CS.

Note 3 to entry: SRP/CS is a part or component within the specific MCS.

[SOURCE: ISO 13849-1:2015, 3.1.1, modified - Note 3 to entry has been added.]

3.4
person group
groups of people analyzed in the *MCSSA* (3.14)

3.4.1
operator
person operating the EMM and aware of associated risks or hazards

3.4.2
co-worker
person working in the vicinity of a machine and aware of associated hazards

3.4.3
bystander
person including non-employee, child, or member of the public with little or no awareness of machine hazards and no training

3.4.4
maintainer
person whose function is to perform maintenance tasks on the machine

Note 1 to entry: A maintainer is trained and familiar with the machine.

3.5
controllability
ability to avoid harm to the *person group* (3.4) at risk through the timely reactions of the *operator* (3.4.1), possibly with the support of alternative controls

3.6
exposure
percentage of time a *person group* (3.4) is exposed to the hazard

Note 1 to entry: The exposure is the product of the following dependent probabilities: *application use case* (3.11), *hazard time* (3.12), and *person group exposure* (3.15).

3.7
severity
estimate of the extent of harm to one or more individuals that can occur in a potentially hazardous situation

[SOURCE: ISO 26262-1:2011, 1.120]

3.8
operation indicator
means by which the state of the equipment or machinery is represented to an observer

[SOURCE: ISO 22555:2007, 3.2]

3.8.1
warning indicator
visual, sensory or audible indications where an action from the *operator* (3.4.1) or control system is required

3.8.2
immediate action warning indicator
warning indicator (3.8.1) requiring immediate action from the *operator* (3.4.1) to mitigate hazard or system failure

3.9
application
different industries where a machine is used in, that can have different hazardous situations from one another

Note 1 to entry: Applications can include general construction, road construction, waste management, quarrying, etc.

3.10
use case
intended use of a machine within an *application* (3.9)

Note 1 to entry: For example, a dozer can have dozing, ripping, travel and maintenance use cases within an application.

3.11
application use case
highest percentage of time a machine is anticipated to be used in a *use case* (3.10) within a given *application* (3.9) during the intended use of the life cycle of the machine

Note 1 to entry: Because the application use case represents the highest percentage of time, and not the average, a machine in the population spends in a use case, the sum of application use cases across an application can be greater than 100 %.

3.12
hazard time
percentage of time within the work cycle of the application use where it is reasonably foreseeable that a hazard may exist should the control system being assessed fail

Note 1 to entry: For example, a dozer pushing material off a high wall is only exposed to the hazard of going over the high wall for the time where the machine is traveling towards the high wall within the stopping distance of the machine.

3.13
hazard zone
any space within or around machinery in which a person can be exposed to a hazard from the *SCS* (3.3.1) under analysis

[SOURCE: ISO 12100:2010 3.11, modified - "from the SCS under analysis" has been added.]

3.14
machine control system safety analysis
MCSSA
risk assessment used to determine the *MPLr* (3.1.1) for the *SCS* (3.3.1) on a machine as outlined in this document

3.15
person group exposure
highest percentage of *hazard time* (3.12) that someone from the *person group* (3.4) being assessed is present in the *hazard zone* (3.13)

Note 1 to entry: The analysis is a sum of all the persons exposed from the person group, not a single individual within that group i.e. not a single car driving by, but the flow of traffic.

3.16
failure type
description of the type of failure that can occur in a *SCS* (3.3.1)

Note 1 to entry: Failure types to consider include failure to apply, failure to release, uncommanded apply, uncommanded release, incorrect apply rate, incorrect release rate or incorrect direction, etc.

3.17
worst credible
estimation of *severity* (3.7) of the most severe harm that can realistically occur from a single hazardous event

Note 1 to entry: Worst credible is not always the worst conceivable or the most likely but it is based on consideration of incident history and potential outcome of a hazardous events.

4 Method to determine MPLr for SRP/CS of earth moving machinery

4.1 General

Functional safety is achieved by one or more SCS which rely on many technologies (e.g. mechanical, hydraulic, pneumatic, electrical, electronic, programmable electronic). Any safety strategy shall consider all of the elements within a SCS, such as sensors, controlling devices and actuators.

Parts of the SCS which provide safety functions are called safety-related parts of control systems (SRP/CS). These can consist of hardware or software, can be separate or integrated parts of a control system, that shall be included in the MCSSA process.

The objective is to reduce the risk associated with a given hazard (or hazardous situation) during intended use of the machine. This shall be achieved by applying various protective measures (both SRP/CS and non-SRP/CS) with the end-result of achieving a safe condition.

An examination of risk for safety functions is focused on the origin of injuries to people. If in the analysis of potential harm it can be established that damage is clearly limited to property and does not involve injury to people, this would not require a MCS to be classified as a SCS. In addition, it is the responsibility of the user (owner) to perform a specific job site risk assessment and these assessments are not part of the MCSSA process.

4.2 Machine Control System Safety Analysis (MCSSA) method

a) Identify all MCS or functions for the machine being evaluated.

b) Identify possible failure types for each MCS or functions.

c) Identify risks presented for each failure type of each MCS or functions.

   1) If no risks are identified, the MCS or functions is not a SCS but may still be covered by the requirements for Quality Measure (QM) (see 6.6).

   2) If risks are identified, the MCS or functions is a SCS. Continue MCSSA with step d).

d) Evaluate risks

   1) Determined above using severity, exposure and controllability assessments using the method as defined in Clause 6, and continue to step e).

   NOTE ISO/TS 19014-5, on Machine Control System Safety Analysis (MCSSA) and performance levels, is being developed; this document will detail an alternative method to use when determining the appropriate MPLr for some common MCS's.

e) Determine MPLr using a risk graph (see Figure 2 in 6.6) for each failure type of each SCS, following the process in 6.3, 6.4 and 6.5.

   1) Select the highest MPLr to assign to that SCS as per 6.6.

f) If MCSSA was completed by function, not system, then assign MPLr to relevant SCS.

g) Use the other parts in the ISO 19014 series to determine the MPLa of the SCS.

h) Ensure MPLa ≥ MPLr.

If additional protective measures are added, they shall meet the MPLr for the SCS to which they relate.

NOTE Annex C provides a worked example of the MCSSA process

5 Requirements for immediate action warning indicators

5.1 General

The principles of this standard should also be applied to immediate action warning indicator intended to warn the operator of a possible hazard and requiring immediate action from the operator to correct and prevent such a hazard.

These indicators shall not be designated as meeting a performance level as the output/diagnostic coverage is reliant on human reaction; indicators provide no control of the system and therefore cannot be labelled as safety-related parts of the control system.

A review of immediate action warning indicators should be undertaken to ensure the designer understands the reactions required by the operator to mitigate a hazard.

Annex B provides a non-exhaustive list of warning indicators.

6 Performance level determination procedures

6.1 General

This Clause shall be applied when step d) 1) in 4.2 is applicable and a SCS is required.

The architecture (e.g. redundant channels, additional protective devices, interlocks that share common components with the SCS, etc.) of the SCS being reviewed shall not be considered during the MCSSA. Additional protective devices and interlocks can be a SCS, if so, an analysis is required.

Decisions made later in the life cycle that change the basis on which earlier decisions were made shall initiate a new MCSSA and assessment of the systems in accordance with all parts of the ISO 19014 series.

6.2 Participants in the risk assessment

The MCSSA should involve a cross functional team, for example, electronic or electrical development, testing or validation, machine or hydraulics design, operator, service, sales and marketing.

6.3 Assessment and classification of a potential harm

Worst credible severity of harm can be determined by using both past incident history and the potential outcome of malfunctions of the SCS being analyzed. The potential severity of harm or injury shall be described for each relevant scenario in the MCSSA.

NOTE Worst credible severity of harm to be considered is not always easy. The most severe can be very improbable and the most probable can be inconsequential, so that using either could lead to an inappropriate estimation of risk.

Categorization shall be used in classifying the severity of harm in four categories: S0, S1, S2, and S3 (see Table 1).

The operator of the involved machine and other parties (e.g. people lending assistance, other operators of machinery, bystander, co-worker, etc.) shall be used in a detailed description of the harm.

Table 1 — Examples of the descriptions of injuries

S0	S1	S2	S3
No significant injuries, requires only first aid	Injuries, requires medical attention, total recovery, reversible injury with no loss in work capacity after recovery	Severe injury, permanent loss in work capacity.	Fatality

6.4 Assessment of exposure in the situation observed

The following reflects the effects of possible failures in specific working and operating conditions.

The calculated exposure, E, shall be used to categorize the different frequencies or duration of exposure. It is calculated using the following formula:

$$E = A \times H \times P$$

where

A is the Application Use Case;

H is the Hazard time;

P is the Person Group Exposure.

An example of the MCSSA can be found in Annex C.

Where an application use case has a cycle with variable H and P values, H × P can be calculated for each step and summed for the cycle to obtain a total H × P for the cycle.

Machines shall be designed to mitigate risks of all intended uses, even if the worst case intended usage is a small percentage of the total field population. Applications with different hazards than a typical machine, for example derivative machine, designed with control systems specifically for that application can be treated as specialized applications and removed from the analysis and be considered in a separate MCSSA.

Three categories, designated E0, E1, and E2, are used (see Table 2), where E serves as an estimation of how often and how long an operator or bystander is exposed to a hazard which could result in an injury to the person group that is exposed. When carrying out a MCSSA, the risk from the highest exposure shall be used. Lower exposures that have higher severities shall also be reviewed in the assessment to verify whether a higher performance level is generated.

Exposure for maintainers should reflect the time spent maintaining the machine, consideration shall be given in the MCSSA when SRP/CS is muted for maintenance purposes.

NOTE A hazard can be a combination of conditions (e.g. environmental and operational) of the machine.

Table 2 — Exposure to the hazardous event based on application profile

E0	E1	E2
$E < 1\ \%$	$1\ \% \leq E < 10\ \%$	$E \geq 10\ \%$

6.5 Assessment of a possibility to avoid harm

The controllability of a given hazard shall be assessed, taking into consideration human reaction (e.g. panic, repeated command of function, etc.) and the capacity for the operator to react to the hazard and provide a means to enter a safe state. Alternative controls cannot be considered when they share a common cause failure with the system being analysed.

When considering multiple alternative actions, each of these actions shall be independent from each other.

The following factors are used to determine controllability and calculated using Figure 1.

Alternative controls

— **AC0 –** no alternative controls or possible action

— **AC1 –** 1 or more alternative control or possible action

Awareness of hazard

— **AW3 – High:** Known before action of function

— **AW2 – Medium:** Known at action of function, all the time

— **AW1 – Low:** Known at action of function, some of the time

— **AW0 – None:** Not known at action of the function e.g a system one cannot see or one is not aware of, operating with an uncommand action

Warning indicators shall only be considered in the assessment of awareness of hazard when they are defined as an immediate action warning indicator that has no common components with the SRP/CS of the system being analysed.

Ability to react

— **AR 3 –** Operator can react in time, natural response, operator has hand or foot on control e.g operator can steer around hazard when brakes fail

— **AR 2 –** Operator can react in time, natural response, operator has to move hand or foot to operate e.g. operator applies park brake when brake fails

— **AR 1 –** Operator can react in time, unnatural response e.g operator grounds implement when brakes fail

— **AR 0 –** Regardless of if there is another system to respond with, the operator or system is unable to respond in time to avoid the hazard

Multiple actions include expected, intended and/or intuitive actions and shall be documented. For example, moving from accelerator to brake pedals or for a brake failure on a dozer, it is expected and intuitive that the operator lowers the blade or ripper.

Examples for other safety control systems are included in Annex D.

Classification of controllability

— **C0** – High controllability

— **C1** – Medium controllability

— **C2** – Low controllability

— **C3** – No controllability

		AR0	AR1	AR2	AR3
AC0		C3	C3	C3	C3
AC1	AW0	C3	C3	C3	C3
	AW1	C3	C3	C3	C2
	AW2	C3	C3	C2	C1
	AW3	C3	C2	C1	C0

Key

AC Alternative Controls

AW Awareness of hazard

AR Ability to react

Figure 1 — Controllability classification

6.6 Determining the required MPL

The required MPLr is determined in Figure 2 by combining the severity, exposure, and controllability values for each identified hazard on the risk assessment. SCS used in multiple scenarios where the severity, controllability or exposure can vary, each scenario shall be considered. The highest performance level determined by the MCSSA shall be used for that SCS.

In addition to these levels, there is a quality measure (QM) whose implicit requirement is to carry out system development in accordance with quality management tools, relevant technical requirements and standards as applicable.

		C0	C1	C2	C3
S0		QM	QM	QM	QM
S1	E0	QM	QM	QM	a
	E1	QM	QM	a	b
	E2	QM	a	b	c
S2	E0	QM	QM	a	b
	E1	QM	a	b	c
	E2	a	b	c	d
S3	E0	a	a	b	c
	E1	a	b	c	d
	E2	b	c	d	e

Key

S severity

E exposure to hazardous event

C controllability

QM Quality Measure

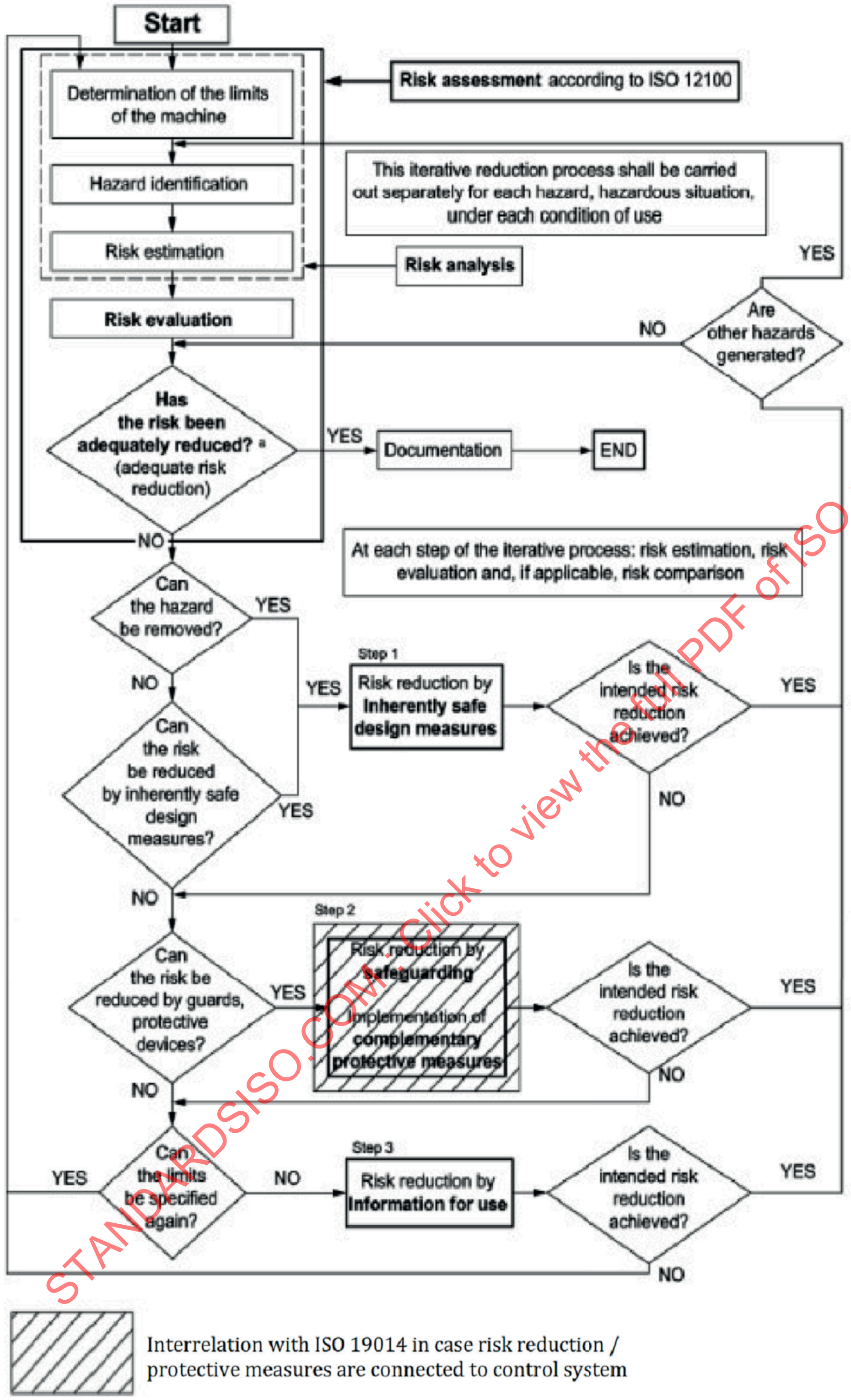
a, b, c, d, e Machine Performance Level required, MPLr

Figure 2 — Determination of MPLr

Annex A
(informative)

Process flow chart for machinery risk assessment

See Figure A.1.



a ISO 12100:2010, Clause 6, further defines what can be considered adequate risk reduction; inherently safe design measures, safeguarding and/or complementary protective measures, information for use.

Figure A.1 — Relationship between ISO 12100 and ISO 19014

Annex B
(informative)

Table of warning/operation indicators

The principles of this standard for risk assessment, architecture, hardware, software, environmental requirements and reliability should apply to immediate action warning indicators intended to warn the operator of a possible hazard that requires immediate action from the operator to correct and prevent such a hazard.

The following table is a list of general indicators used on EMM. This is not an exhaustive list or applicable to all types of EMM. Other EMM type specific indicators may also follow the principles of ISO 19014 as determined by the manufacturer.

NOTE Guidance can be found in ISO 6011:2003.

Table B.1 — EMM indicators

Indicator	Immediate Action Warning Indicator	
	Yes	No
Engine rotational speed		X
Engine oil pressure		X
Engine coolant temperature		X
Charging system voltage/amperage	X	
Torque converter oil pressure		X
Torque converter oil temperature	X	
Transmission oil pressure		X
Transmission oil temperature		X
Brake stored energy pressure	X	
Hydraulic oil pressure	X[a]	
Hydraulic oil temperature		X
Operating hours		X
Multi-function control [ISO 20474-1:2017, 4.5.1]	X	
Fuel Level gauge [ISO 20474-1:2017, 4.18.1]		X
Capacity indicator	X	
Proximity detection systems		X
Vision systems		X

[a] When required for clamping, maintaining attachment or load in position.

Annex C
(informative)

Example of MCSSA Process

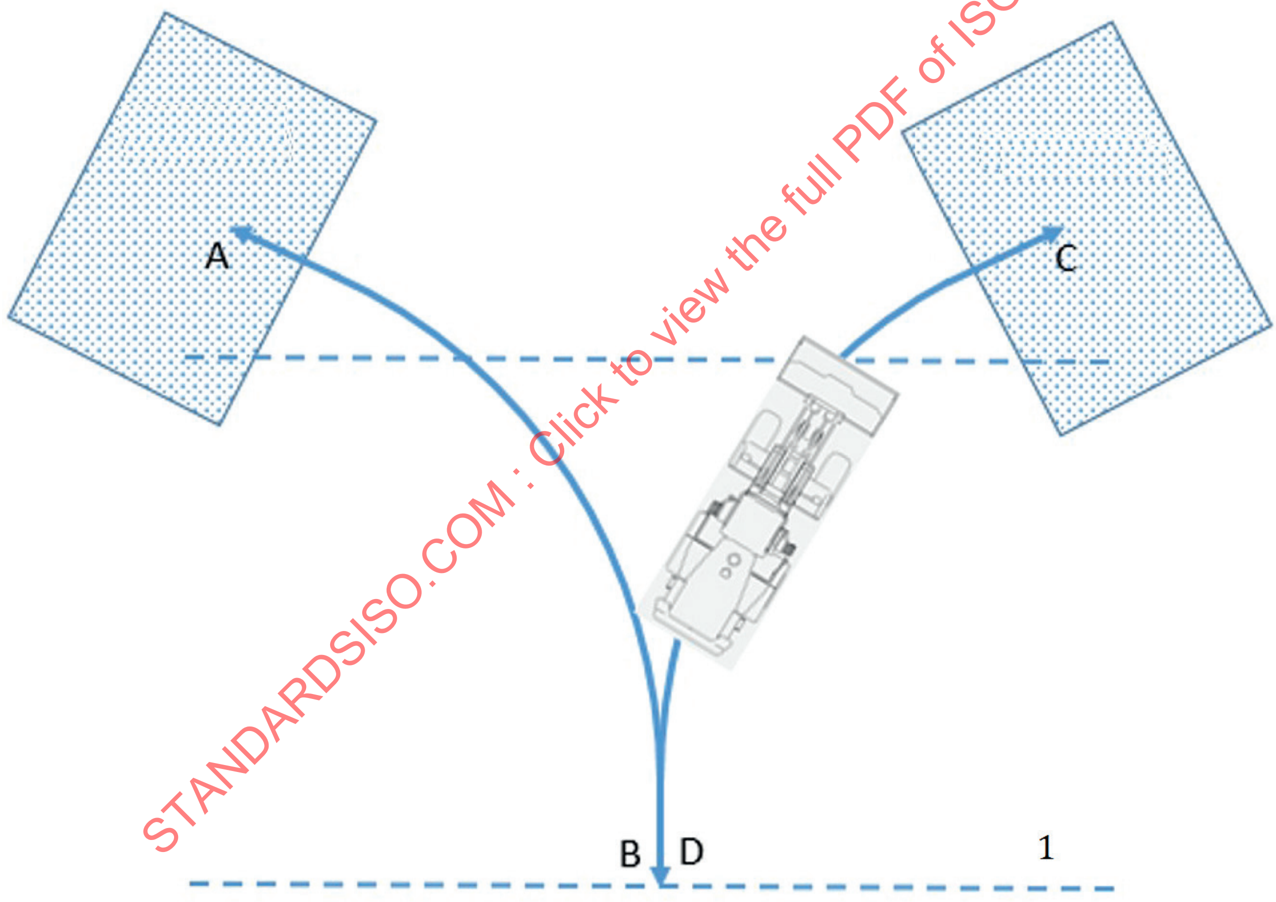
This annex provides a worked example of the MCSSA process, when following the procedure in 4.2 and with the manufacturer using 4.2 d) 1) rather than option 4.2 d) Note. See Figure C.1.

Subclause 4.2 Step a)

SCS – Braking

Application: General Outdoor Use (Quarry)

Use Case: Truck Loading



Key

A loading

C unloading

1 jobsite road

$P_{co\text{-}worker}$ = 10 %; $P_{bystander}$ = 5 %

Machine moves rapidly through this area, access for people to this area of the site is usually more restricted when operating machines of this size. It is considered poor jobsite organisation when people are in the path of the machine.

Figure C.1 — Application use case

Subclause 4.2 Step b)

Failure Type – Failure to apply on demand

Subclause 4.2 Step c)

Hazardous Outcome

Operator: Collision with Truck being loaded

Bystander: Run over (Pedestrian)

Co-worker: Collision (Light vehicle. Worse than co-worker sitting in truck for collision with truck)

Subclause 4.2 Step d) 1)

Severity

Operator: S1 – minor jolt

Bystander: S3 – run over

Co-worker: S3 – based on incident history

Exposure

A: 90 %

Table C.1 — Cycle time expressed as %

Application	Loading/Unloading (Forks, Hyd tools)	Bucket V-cycle (including Truck /train Loading, hopper)	Travel Mode (loaded / unloaded)	Low Speed Man./ Start up/ Parking	Low to Ground tool/ Dozing	Maintenance (Machine running) Service Repair
W Loader Open - Surface	90 %	**90 %**	80 %	6 %	90 %	6 %
W Loader Confined	90 %	90 %	80 %	6 %	90 %	6 %

H:

Idle: Truck is present up to 90 % of the time, therefore machine can be idle no more than 10 %. Will multiply H by (100 % – 10 %) = 90 %.

Operator

Table C.2 — Operators exposure to hazard expressed as a % of time

Stage of Work Cycle (see diagram)	Time (%)	Percentage of Stage Hazard Present (%)	H_{Stage} = Time (%) × (Percentage of Stage Hazard Present)
A	25 %	0 %	0 %
B	25 %	0 %	0 %
C	25 %	10 % - Hazard present only when approaching truck. Machine slows down in last 10 % of stage C	2,5 %
D	25 %	0 %	0 %
		Total	2,5 %

$H_{Operator} = H_{Stage} \times (100\ \% - \text{idle time}) = 2,5\ \% \times 90\ \% = 2,25\ \%$

Bystander/Co-worker

In this case, bystander and co-worker H are the same because the hazard zone for those people groups are in the same area.

Table C.3 — Bystander and co-worker exposure to hazard expressed as a % of time

Stage of Work Cycle (see diagram)	Time (%)	Percentage of Stage Hazard Present (%)	H(stage) = Time (%) × (Percentage of Stage Hazard Present)
A	25 %	0 %	0 %
B	25 %	10 % - Hazard present only when approaching the area behind work area. Machine slows down in last 10 % of stage B	2,5 %
C	25 %	0 %	0 %
D	25 %	10 % - Hazard present only when approaching the area behind work area. Machine slows down in last 10 % of stage C	2,5 %
		Total	5 %

$H_{(Bystander/Co\text{-}worker)} = H_{Stage} \times (100\ \% - \text{idle time}) = 5\% \times 90\ \% = 4,5\ \%$

P:

$P_{(Operator)}$: 100 % (always in wheel loader)

$P_{(Bystander)}$: 5 % (see diagram – data obtained from application experts)

$P_{(Co\text{-}worker)}$: 10 % (see diagram– data obtained from application experts)

E:

A × H × P

$E_{(Operator)} = A \times H_{(Operator)} \times P_{(Operator)} = 90\ \% \times 2,25\ \% \times 100\ \% = 2\ \%$, exposure is E1

$E_{(Bystander)} = A \times H_{(Bystander)} \times P_{(Bystander)} = 90\ \% \times 4,5\ \% \times 5\ \% = 0,2\ \%$, exposure is E0

$E_{(Co\text{-}worker)} = A \times H_{(Co\text{-}worker)} \times P_{(Co\text{-}worker)} = 90\ \% \times 2,25,5\ \% \times 4,5\ \% = 0,4\ \%$, exposure is E0

