TECHNICAL SPECIFICATION

# ISO/TS 19014-5

First edition
2021-12

# Earth-moving machinery — Functional safety —

## Part 5: Tables of performance levels

*Engins de terrassement — Sécurité fonctionnelle —*

*Partie 5: Tableaux des niveaux de performance*



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# Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO 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, together with ISO 19014-1, ISO 19014-2, ISO 19014-3 and ISO 19014-4, cancels and replaces the first editions (ISO 15998:2008 and ISO/TS 15998-2:2012), which have been technically revised.



The main changes are as follows:

— complete reassessment and associated rewriting of the document, following the process according to ISO 19014-1;

— added detail to assist users in determining if the assessments contained herein are applicable to their product;

— added detail to assist system designers in understanding what hazards and failure types apply to what machine performance level requirements.

A list of all parts in the ISO 19014 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

This document addresses functional safety of all types of energy systems utilized by 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 contains a list of Machine Performance Level requirements ($MPL_r$) by function and earth-moving machinery type, determined through the process outlined in ISO 19014-1.

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 organizations, 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).

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 5: Tables of performance levels

## 1 Scope

This document provides normative tables of machine performance levels required ($MPL_r$) by common function and type for earth-moving machinery (EMM) as defined in ISO 6165. These $MPL_r$ can then be mapped or applied to safety control systems (SCS) used to control or that affect the functions defined in the table.

The $MPL_r$ in this document are determined through the machine control system safety analysis (MCSSA) process outlined in ISO 19014-1. A brief explanation of how the levels were derived and the associated assumptions are contained herein.

This document is not applicable to EMM 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 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*

ISO 19014-1, *Earth-moving machinery — Functional safety — Part 1: Methodology to determine safety-related parts of the control system and performance requirements*

ISO 19014-2:2019, *Earth-moving machinery — Functional safety – Part 2: Design and evaluation of hardware and architecture requirements for safety-related parts of the control system*

ISO 19014-3, *Earth-moving machinery — Functional safety — Part 3: Environmental performance and test requirements of electronic and electrical components used in safety-related parts of the control system*

ISO 19014-4, *Earth-moving machinery — Functional safety — Part 4: Design and evaluation of software and data transmission for safety-related parts of the control system*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 6165, ISO 12100, ISO 19014–1, ISO 19014-2, ISO 19014-3, ISO 19014-4 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**
**idle factor**
factor applied as part of determining the H variable (hazard time) to account for maximum or minimum idle time (100 % - max / min idle %)

EXAMPLE 1 Minimum idle time would be applied to loading a machine waiting for hauling machines during the loading cycle (idle factor = 10 %).

EXAMPLE 2 Maximum idle time would be applied to hazards associated with a stationary machine [*hold still* (3.2) function – idle factor = 50 %].

**3.2**
**hold still**
function that keeps the wheels or crawler tracks stationary, preventing the machine from moving

EXAMPLE A SCS that would control the hold still function is a park brake.

**3.3**
**slow/stop**
function which reduces or brings to zero the *machine speed* (3.4)

EXAMPLE A SCS that would control the slow/stop function is a service brake.

**3.4**
**machine speed**
function which controls the rate of travel

EXAMPLE A SCS that would control the machine speed function is a throttle control, propel control or gear selection control.

**3.5**
**engine speed**
function which controls the rotational speed of the engine

EXAMPLE A SCS that would control the engine speed function is a throttle control.



**3.6**
**machine direction**
function which controls the longitudinal direction of the machine travel

EXAMPLE A SCS that would control the machine direction function is a forward/neutral/reverse selection control.

**3.7**
**steering**
function which controls the lateral direction of machine travel

EXAMPLE A SCS that would control the steering function is a steering wheel or joystick.

**3.8**
**swing/slew**
function which controls the clockwise or anti-clockwise rotation of the upper structure of an excavator or digging linkage

EXAMPLE A SCS that would control the swing/slew function is a joystick.

**3.9**
**machine abuse**
activities that are outside the intended use of the machine and are beyond the reasonably foreseeable usage as communicated in the machine operation and service literature

EXAMPLE 1 Standing under a suspended load.

EXAMPLE 2 Using an earth-moving machine as an elevating work platform.

EXAMPLE 3 Intentionally driving machines in a way that would harm oneself or others.

EXAMPLE 4 Performing activities that are illegal.

Note 1 to entry: It is considered abuse to perform some maintenance tasks with the engine running or systems de-energized unless otherwise stated in the operator’s manual.

**3.10**
**roading**
machines moving on a *road* (3.14)

Note 1 to entry: A suitably designed machine and road homologation can be required.

**3.11**
**traveling**
machine moving from one point on a worksite to another without going on a *road* (3.14)

EXAMPLE On a haul road, unimproved road or other thoroughfare on a site.

**3.12**
**high wall**
mine, quarry or other similar type wall associated with the worksite that a machine may be working near

Note 1 to entry: It is considered *machine abuse* (3.9) to operate machines near high walls without *berms* (3.13) in place.



**3.13**
**berm**
pile of dirt, rocks or other material intended to prevent a machine from passing into an area it is not intended to be operated in

Note 1 to entry: Some regions use different terms, e.g. bund, windrow.



**3.14**
**road**
public traffic area for use by automotive vehicles for travel or transportation

Note 1 to entry: Public traffic area does not include the sites of temporary road works (e.g. for repairs, maintenance, alteration, improvement, installation, or any other works to, above or under the road, including work to road equipment, lighting, barriers, walls etc) or roads not open to the public (e.g. on new housing and industrial developments), or on which public traffic is not permitted.

[SOURCE: ISO 17253:2014, 3.2]

**3.15**
**work cycle**
repeated process or task a machine performs within a use case

Note 1 to entry: Work cycles can be broken down into segments and steps (examples can be found in 5.4).

**3.16**
**operator presence system**
system fitted to a machine that detects if an operator is positioned in an operator station and automatically takes a control system action based on that determination

# 4 General

## 4.1 General principles

### 4.1.1 Safety requirements

The $MPL_r$ provided in this document may be used as an alternative to performing an MCSSA for like machinery per ISO 19014-1 and were derived using that process. The functions, applications and use cases used to determine these levels are based on generic limits of machine application for the machine type. If the $MPL_r$ in this document are used, the $MPL_r$ shall be in accordance with Annexes A - AA after following the review outlined in 4.1.2, 4.2, 4.3, 4.4, 4.5, and 4.6.

Machinery shall comply with the safety requirements and/or protective/risk reduction measures of ISO 19014-1, ISO 19014-2, and ISO 19014-4. 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.

### 4.1.2 Information for use

Limits of machine use, notable assumptions or examples of machine abuse considered in this document shall be communicated in the information for use according to ISO 19014-2:2019, Clause 8 and ISO 12100:2010, 6.4 and 6.4.5.

## 4.2 Mapping of functions to a SCS



The MCSSA supporting these $MPL_r$ were carried out by function rather than system. In practice, there can be several SCS that could fail in a way that is described by the failure type listed for any particular function. All SCS on a machine shall be reviewed to determine if any failure could cause a hazardous outcome associated with a failure type of the functions listed. For example, a brake system may be mapped from a slow/stop or hold still function, as could another system that interferes with the ability of the machine to brake at an appropriate rate to meet the ISO 3450 stopping distance.

Measures beyond SCS may be applied to mitigate hazardous failures (e.g. mechanical lock outs, guards, administrative controls). In such a case, a MCSSA shall be completed to assess the MPL requirements of any residual risk associated with the SCS.

## 4.3 Applicability of the listed $MPL_r$ to machines

This document does not eliminate the need to do a risk assessment per ISO 12100 as defined in ISO 19014-1.

The MCSSA supporting these $MPL_r$ were carried out considering the limits of the machine type usage across the industry. Unique or limited applications or use cases can result in a different $MPL_r$ for the machine function. If a machine is specifically designed or modified for an application other than what is considered in the tables in this document, an MCSSA shall be performed to determine if any functions require a different $MPL_r$.

While every effort was made to perform the supporting MCSSA in a general sense, there can be times where the assessment does not match a specific machine design; this is particularly relevant to the selection of the controllability factors (AC, AR, AW). The supporting MCSSA assume a common operator control layout around the operator station and no common cause failures. If there is a common cause failure between the SCS mapped to the function being assessed and the MCS or SCS being used for controllability, the $MPL_r$ in the table is not applicable (e.g. two systems sharing a control element or a control unit). Likewise, where the control used to activate the avoidance on a particular design does not align with the AR score in the table, the table is not applicable (e.g. a brake is assumed to be on the floor immediately next to a throttle/propel pedal, if the brake is controlled with a lever the AR score would change from an AR3 to an AR2, a size difference within a machine type that results in a change in severity). In this case, the designer shall perform a MCSSA according to ISO 19014-1 to consider these facts. If the remaining data used in the assessment are applicable to the machine being assessed, the data can be used in that MCSSA and the non-applicable score changed. It is the responsibility of the machine designer to review and assess whether the scoring used in the MCSSA are applicable to their machine.

## 4.4 Truncation

Due to the large number of combinations of inputs, the MCSSA supporting these tables are focused on scenarios that would clearly dominate the $MPL_r$ (scenario that drives the highest $MPL_r$ for the same function). Where a dominant scenario was not clearly identifiable, multiple scenarios were assessed to find the scenario(s) that led to highest $MPL_r$. Non-dominant scenarios were truncated from MCSSA. Part of the truncation process included equating scenarios to be the same, no worse, or less than scenarios already assessed; where this is the case, detail is not provided in the tables for the sake of legibility.

Only the scenarios that led to the highest $MPL_r$ are included in the tables in the annexes unless a different failure type with a different hazardous outcome existed, in which case the scenarios with the highest $MPL_r$ for all those failure types are included in the tables. Additional explanation in this space can be found in the function dominant failure type matrices. When more than one scenario of the same failure type led to the highest $MPL_{r,}$ all such scenarios have been included.

## 4.5 Effects of different technologies on MCSSA

In most cases, the $MPL_r$ in this document apply regardless of the technology used in the SCS; however, there are times when this is not the case, e.g. mechanical drivetrains versus electric or hydrostatic drivetrains.



When considering an alternative SCS technology (e.g. electric or hydrostatic), the assessments in the tables in this document shall be reviewed. Any assumptions or assessments that are invalidated by the introduction of a different technology shall be reassessed according to 4.3. Additionally, the functionality of these systems can cause $MPL_r$ to be mapped to different SCS.

NOTE Not all machines were assumed to have mechanical drivetrains; dozers, excavators, skid steer loaders and rollers were assumed to have a hydrostatic drivetrain.

The following are some situations where technology differences can affect $MPL_r$:

— there are changes in response to machine speed, propel, brake or direction commands (e.g. compared to mechanical drivetrains, some electric and hydrostatic drivetrains apply functions differently);

— retarders may not have been considered a safety function on a mechanical drive system but can possibly be the primary means of slowing the machine in an electric drive machine;

— controllability assessments may be different due to common components and other common cause failure considerations;

— there are additional safety functions associated with new hazards created by using a different energy type;

— engine speed can become decoupled from other systems (e.g. no longer has a direct effect on machine speed);

— there are changes in SCS performance due to system stored energy level (e.g. output performance varying due to battery charge).

## 4.6 Supporting diagrams and data for the tables of machine performance levels

Scenarios that dominated the $MPL_r$ score in the MCSSA are listed in the tables and a brief explanation are contained in the annexes. Where more detail is deemed necessary additional diagrams and information are provided in Clause 5.

# 5 Additional MCSSA scenario information

## 5.1 Traffic rate on road

After reviewing the scenarios that earth-moving machines are used in, it was determined that the highest P value was bystanders in other vehicles when roading. The exposure of bystanders to an uncommanded steering event is largely dictated by the distance between vehicles. Machines cannot be designed to mitigate situations where illegal or unsafe actions are committed by other road users. The MCSSA considered traffic rates with 2 car lengths distance between cars as the norm (less distance between cars being commonly considered unsafe across the world).

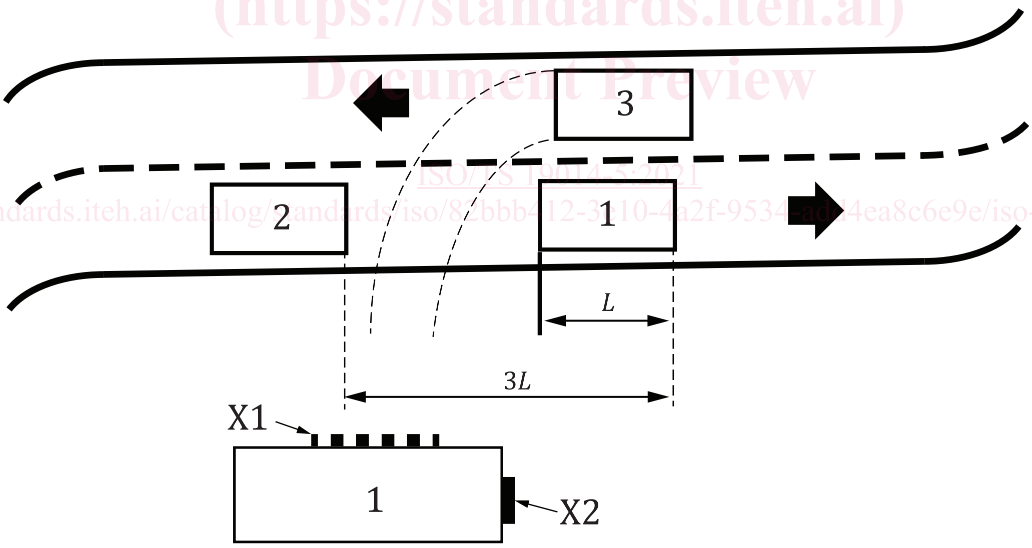
While traffic can momentarily exceed this rate, the P value needs to account for the machine lifecycle. Traffic rates with less spacing would not occur continually over the entire machine lifecycle; this makes the traffic rate of 1 car every 3 car lengths conservative (see Figure 1).

NOTE This document refers to cars, light vehicles, and vehicles. Car is typically used in the context of a roading use case. Light vehicles is typically used in mining applications and weigh less than 3 500 kg. Vehicles is used generically.

## 5.2 Steering while roading

All failure types for steering create the same hazard, depending on whether the desired path is straight or curved (i.e. uncommanded steering on a straight road has the same hazardous outcome as failure to steer on a curved road) – the machine will leave the intended travel lane.






**Key**

1 vehicle 1

2 vehicle 2

3 machine

X1 zone 1

X2 zone 2

*L* length

**Figure 1 — Steering hazard zone for on road travel**

Earth-moving machines can cause an S3 injury if there is contact between the machine and a vehicle. The proportion of the vehicle that results in an S3 injury is quantified below.

— The passenger cabin of the vehicle (i.e. machine contacts the side of the vehicle); this equates to approximately ½ the car length (see dotted line on vehicle in Figure 1, X1).

— The front of the vehicle (i.e. the vehicle drove straight into the side of machine due to the machine steering in front of the vehicle); this equates to approximately ½ the width of the vehicle (see solid line on vehicle in Figure 1, X2). Contact on the corners of the vehicle would be less likely to cause an S3 Injury.

— The ratio of length to width varies by vehicle; however, an estimation of an average ratio of 1:3,5 has been used.

When roading there is a risk of contacting a vehicle, a bystander or an object on the other side of the machine; this is less than the traffic rate. A P variable of 10 % has been used.

Based on these limiting factors the H and P variables for machines roading can be shown to be no higher than:

$$H_R P_R + H_L P_L = H_R P_R + H_L \left( T_R \left( \frac{L}{2} + \frac{W}{2} \right) \right) = (50\ \% \times 10\ \%) + \left( 50\ \% \left( \frac{1}{3} \left( \frac{1}{2} + \frac{1}{7} \right) \right) \right) = 16\ \%$$

where

$L$ = 1 car length;

$H_R$ = H variable for right hand uncommanded steering = 50 % (if the machine steers without command, half the failures would steer the machine to the left, the other half to the right);

$P_R$ = P variable for the right-hand uncommanded steering = 10 %;

$H_L$ = H variable for left hand uncommanded steering = 50 %;

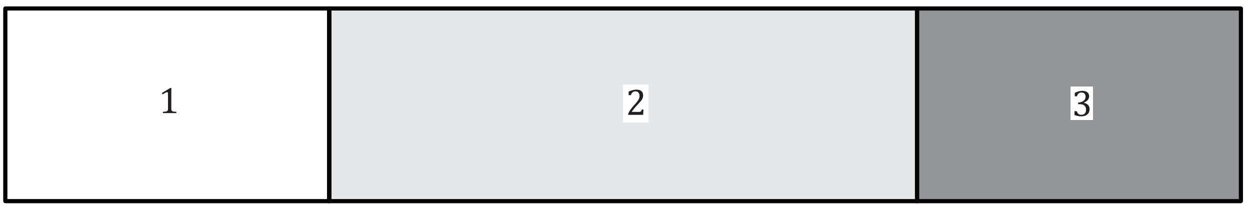
$P_L$ = P variable for the left-hand uncommanded steering;

$T_R$ = traffic rate per 5,1 = 1/3;

$W$ = $L$/3,5.

## 5.3 Slow/stop and machine speed

The hazard zone for a brake failure is the area beyond the machine's normal stopping distance. An uncommanded increase in machine speed has a similar hazard zone (see Figure 2).




**Key**

1 machine

2 intended stopping distance

3 increased stopping distance

**Figure 2 — Slow/stop and machine speed hazard zone**

### 5.4 Work cycles

This section contains descriptions of common work cycles for the various machine types used in the MCSSA evaluations to determine $MPL_r$.

The values used in the percentage breakdown in Tables 1 through 6 represent the worst credible scenario for the failure type being assessed as determined in the MCSSA.

Figures 3 through 6 represent work cycles as considered in the MCSSA.

#### 5.4.1 Dumpers

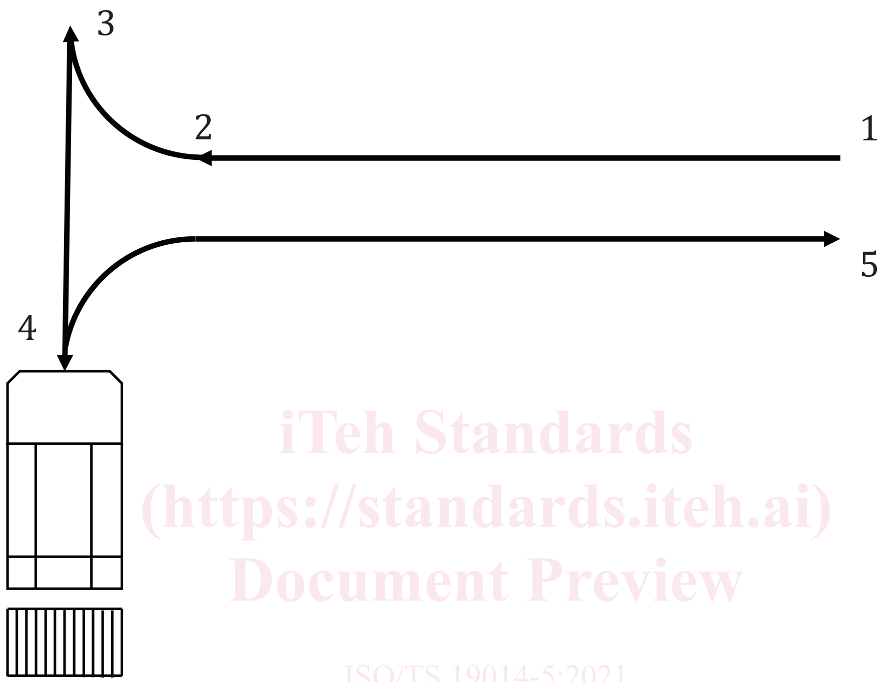





**Figure 3 — Truck unloading and queuing cycle**

**Table 1 — Truck unloading and queuing cycle**

| **Unloading and queuing – long cycle – see Figure 3** | |
|---|---|
| 1 – 2 (slow forward speed, high traffic) | 50 % |
| 2 – 3 (slow forward speed, low traffic) | 8 % |
| 3 – 4 (slow reverse speed, low traffic) | 17 % |
| Dump | 17 % |
| 4 – 5 (medium forward speed, high traffic) | 8 % |

#### 5.4.2 Excavators

**Table 2 — Excavator object handling work cycle**

| **Object handling cycle** | | |
|---|---|---|
| Step | Time [s] | % cycle |
| ① lower/lash | 45 | 21,3 % |
| ② lift | 30 | 14,2 % |
| ③ swing | 15 | 7,1 % |
| ④ lower | 60 | 28,4 % |