



BSI Standards Publication

Earth-moving machinery — Functional safety

Part 5: Tables of performance levels

National foreword

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**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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Contents

Page

Foreword	v
Introduction	vi
1 Scope	1
2 Normative references	1
3 Terms and definitions	1
4 General	4
4.1 General principles.....	4
4.1.1 Safety requirements.....	4
4.1.2 Information for use.....	4
4.2 Mapping of functions to a SCS.....	4
4.3 Applicability of the listed MPL _r to machines.....	4
4.4 Truncation.....	5
4.5 Effects of different technologies on MCSSA.....	5
4.6 Supporting diagrams and data for the tables of machine performance levels.....	5
5 Additional MCSSA scenario information	6
5.1 Traffic rate on road.....	6
5.2 Steering while roading.....	6
5.3 Slow/stop and machine speed.....	7
5.4 Work cycles.....	8
5.4.1 Dumpers.....	8
5.4.2 Excavators.....	8
5.4.3 Wheel loaders.....	9
5.4.4 Skid steer loaders.....	10
5.5 Swing/slew of backhoe loaders and excavators.....	11
5.5.1 H variable for working beside traffic or co-workers.....	11
5.5.2 P values for swinging into traffic or co-workers.....	12
5.6 Maximum foreseeable P variables for typical areas on a site.....	13
5.7 Seat belts.....	13
5.8 Maintenance tasks.....	13
5.9 Backhoe arm out and wheeled excavator or backhoe stabilizer down while travelling or roading.....	13
Annex A (normative) Rigid frame dump trucks performance level tables	15
Annex B (normative) Articulated-frame dumpers equal to or greater than 22 000 kg performance level tables	25
Annex C (normative) Articulated-frame dumpers equal to or less than 22 000 kg performance level tables	30
Annex D (normative) Crawler excavators less than 109 000 kg performance level tables	36
Annex E (normative) Wheeled excavators performance level tables	51
Annex F (normative) Backhoe loaders performance level tables	66
Annex G (normative) Large wheel loaders equal to or greater than 24 000 kg performance level tables	77
Annex H (normative) Medium, small and compact wheel loaders less than 24 000 kg performance level tables	87
Annex I (normative) Wheeled and crawler skid steer loaders performance level tables	94
Annex J (normative) Landfill compactor performance level tables	103
Annex K (normative) Roller performance level tables	109
Annex L (normative) Grader performance level tables	116

Annex M (normative) Crawler dozer performance level tables	126
Annex N (normative) Pipelayer performance level tables	133
Annex O (normative) Crawler loader performance level tables	140
Annex P (normative) Wheeled dozer performance level tables	148
Annex Q (normative) Scraper performance level tables	153
Annex R (normative) Crawler excavators equal to or greater than 109 000 kg performance level tables	159
Annex S (normative) Cable excavator (front shovel) performance level tables	167
Annex T (normative) Cable excavator (dragline) performance level tables	173
Annex U (normative) Compact trencher less than 4 500 kg performance level tables	179
Annex V (normative) Medium trencher greater than or equal to 4 500 kg and less than 18 000 kg performance level tables	196
Annex W (normative) Heavy trencher greater than or equal to 18 000 kg performance level tables	205
Annex X (normative) Telescopic wheel loader performance level tables	216
Annex Y (normative) Compact tool carrier performance level tables	218
Annex Z (normative) Powered attachments performance level tables	225
Annex AA (normative) Miscellaneous functions	229
Bibliography	234

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, 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

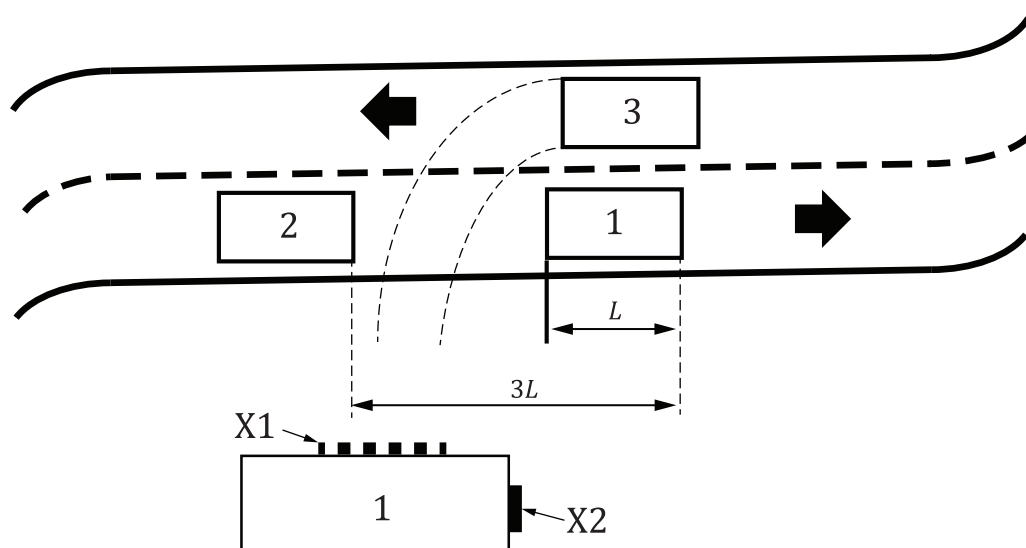
After reviewing the scenarios that earth-moving machines are used in, it was determined that the highest P value was bystanders in other vehicles when roading. The exposure of bystanders to an uncommanded steering event is largely dictated by the distance between vehicles. Machines cannot be designed 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 $\frac{1}{2}$ 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 $\frac{1}{2}$ 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 %;

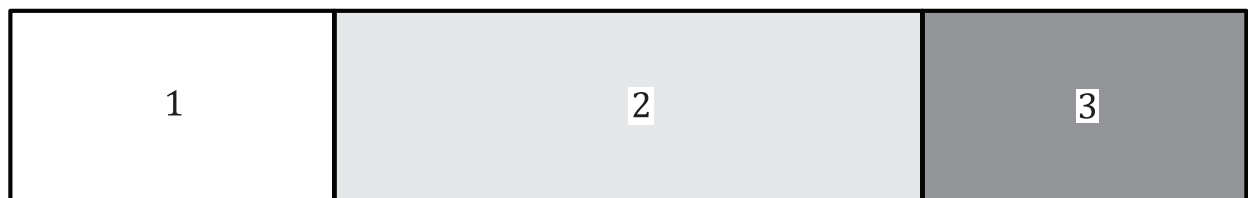
$P_L =$ P variable for the left-hand uncommanded steering;

$T_R =$ 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

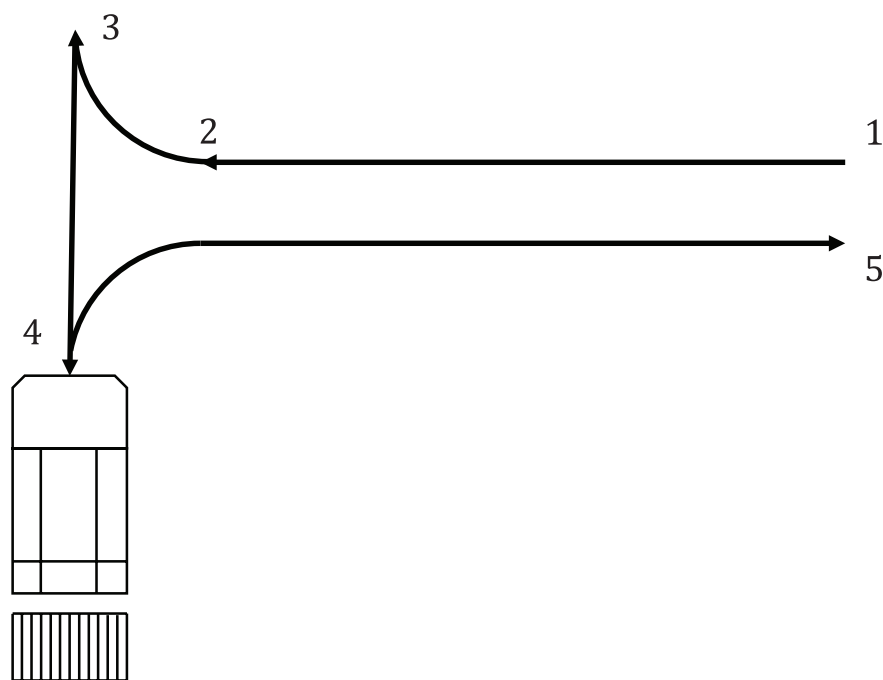


Figure 3 — Truck unloading and queuing cycle

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 %

Table 2 (continued)

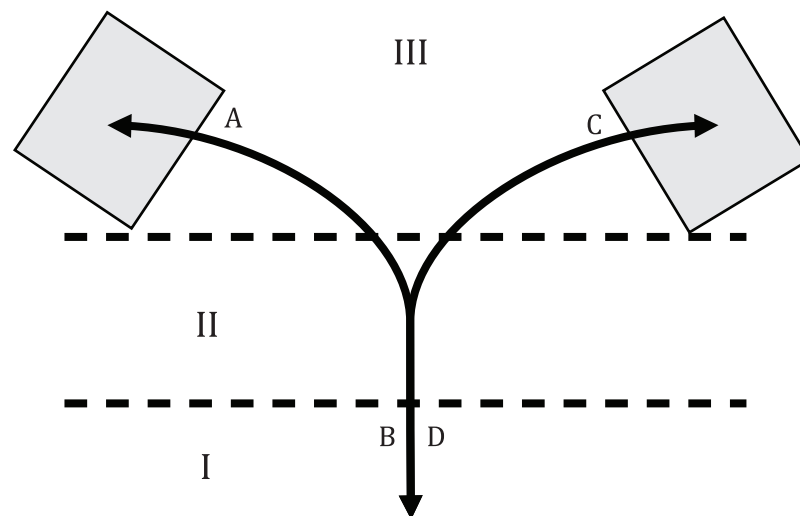
Object handling cycle		
Step	Time [s]	% cycle
⑤ unlash	45	21,3 %
⑥ lift	4	1,9 %
⑦ swing	2	0,9 %
⑧ travel	10	4,7 %
total cycle time	211	100,0 %

Table 3 — Excavator trenching work cycle

Trenching use case	
dig (includes some lift)	35 %
swing CCW	25 %
dump	10 %
swing CW	25 %
travel	5 %

5.4.3 Wheel loaders

5.4.3.1 Wheel loader bucket work



Key

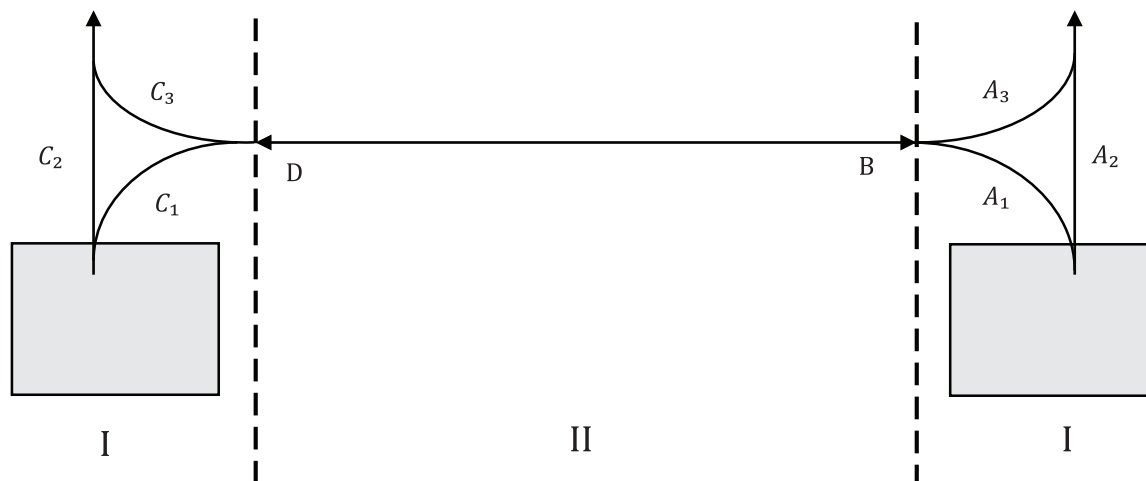
- A loading
- C unloading
- B/D travel during cycle
- I zone with offsite traffic $P = 50 \%$
- II zone with site traffic $P = 20 \%$
- III zone where it is considered machine abuse, between machine and destination $P = 0 \%$

Figure 4 — Wheel loader bucket work cycle

Table 4 — Wheel loader bucket work cycle

Wheel loader bucket work cycle – see Figure 4	
Segments A, C	30 %
Segments B, D	20 %

5.4.3.2 Wheel loader loading/unloading and lifting



Key

- A unloading
- C loading
- B/D travel during cycle
- I zone with more pedestrian traffic, less vehicular traffic P = 20 %
- II zone with more vehicular traffic, less pedestrian traffic P = 20 %

Figure 5 — Wheel loader work lifting and loading/unloading cycle

Table 5 — Wheel loader lifting and loading/unloading cycle

Lifting and loading/unloading use case – see Figure 5	
A1	6,25 %
A2	6,25 %
A3	6,25 %
A-Positioning	6,25 %
B	25 %
C1	6,25 %
C2	6,25 %
C3	6,25 %
C-Positioning	6,25 %
D	25 %

5.4.4 Skid steer loaders

Lifting, material handling, low to the ground and bucket work cycles look similar to the wheel loaders, however, instead of doing a 3-point turn, the machine rotates by counter steer.

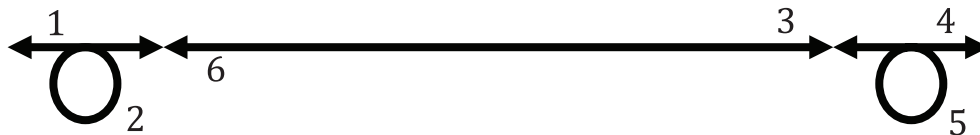


Figure 6 — Skid steer loader lifting, loading/unloading, low to ground cycle diagram

Table 6 — Skid steer loader lifting, loading/unloading, low to ground cycle

Lifting, loading/unloading, low to ground use case	
1	1 %
2	1 %
3	48 %
4	1 %
5	1 %
6	48 %

5.5 Swing/slew of backhoe loaders and excavators

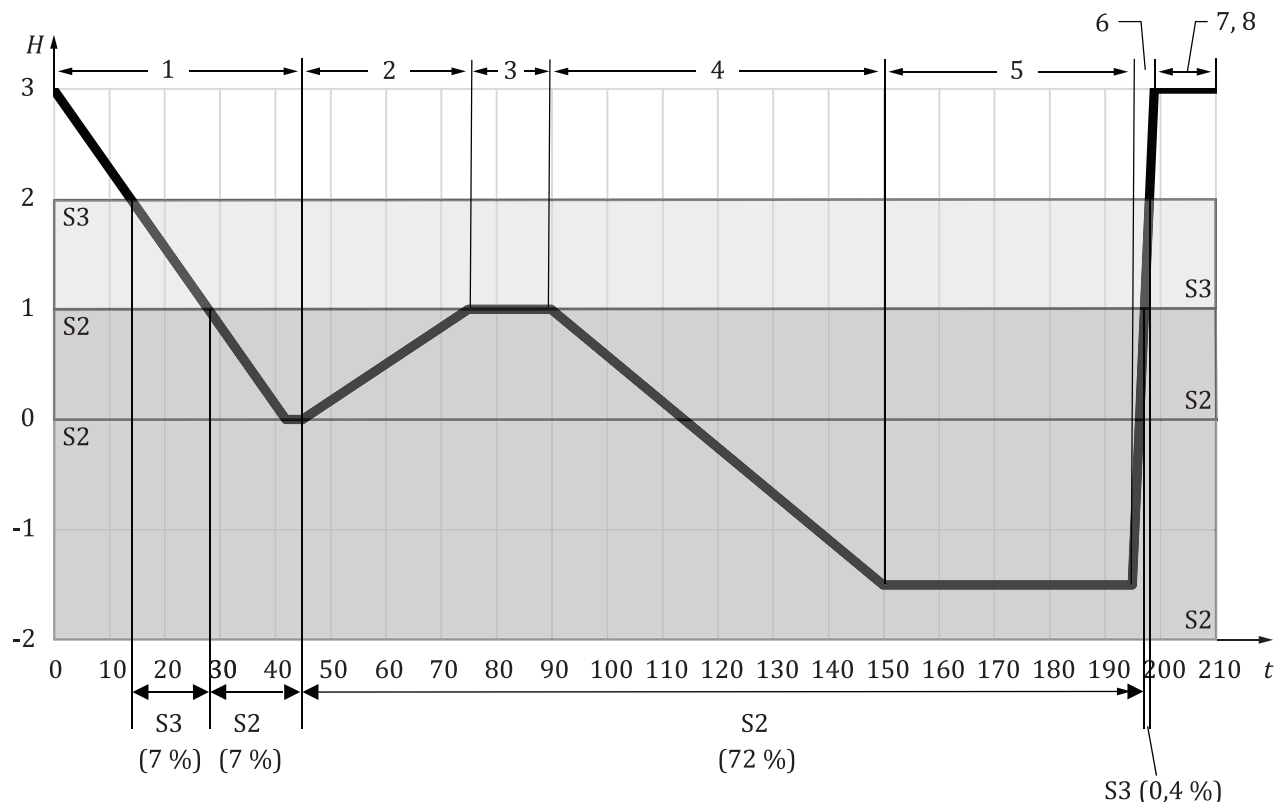
5.5.1 H variable for working beside traffic or co-workers

An excavator swing radius is a hazard zone and it is not intended for people, objects or traffic to be within the hazard zone. These MCSSA assume sufficient worksite hazard mitigations are in place (such as barriers and worksite rules).

Contact with an excavator tool during swing has three-dimensional zones in which the severity differs. Between the ground and 1 m from the ground, the worst credible injury is an S2. Between 1 m – 2 m from the ground, the worst credible injury is an S3. When the tool is within a trench, it is machine abuse to stand between the arm and the trench wall, however, a limb may momentarily be in this area and has been considered an S2. When the tool is on the ground or 2 m above, it is not considered a hazard.

When the motion of the lowest point of the tool is plotted over the object handling work cycle it can be determined which portions of the work cycle fall within the S2 and S3 zones. Both zones were analysed with the dominant score being shown in the scenarios contained in the tables in [Annexes D, E, and F](#).

A representation of this is shown in [Figure 7](#) and [Table 2](#).



Key

t time in seconds

H height in meters

S2 zones in which an S2 severity could occur (0 m - 1 m above the ground or in the trench)

S3 zone in which an S3 severity could occur (1 m - 2 m above the ground)

Figure 7 — Different severity score zones of the swing cycle (see cycle in [Table 2](#))

The result is the following H variables:

— $H_{S2} = 79 \%$,

— $H_{S3} = 7 \%$.

5.5.2 P values for swinging into traffic or co-workers

The assumption of one vehicle every three vehicle lengths remains from 5.2. The proportion of the vehicle length that could result in an S3 injury is assumed to be $\frac{1}{2}$ the vehicle length (combination of surfaces along the length and width of the vehicle where a person may be contacted by the machine tool – which is narrow compared to the exposed area) $P = \frac{1}{2} \times \frac{1}{3} = \frac{1}{6}$.

A P value of 5 % has been added to one or both sides of machines to account for co-workers who momentarily pass into the swing radius of the machine to perform tasks that are necessary for the cycle (e.g. to check trench depth or attach / release a pipe from a chain). These co-workers are aware of hazard of swinging machines and would avoid being in the swing radius whenever possible. These values are then averaged across both sides of the machine because the machine can only swing in one direction at a time.

Where there is a co-worker on both sides of the machine $P = [(\frac{1}{6} + 5 \%) + 5 \%]/2 = 14 \%$.

Where there only is a co-worker on one side of the machine $P = (\frac{1}{6} + 5 \%)/2 = 11 \%$.

5.6 Maximum foreseeable P variables for typical areas on a site

Mine haul road – other machines: $P = 10\%$

Mine haul road – light vehicles and pedestrians: $P = 5\%$

Busy construction sites: $P = 20 - 50\%$ depending on the task, applications and machine type

Scenarios where people should not be, however specific scenarios may rarely, however legitimately, require someone to be: $P = 1 - 5\%$

Scenarios where it is considered machine abuse, however it is foreseeable that there may be momentary incidental exposure: $P = 1 - 2\%$

Site park up area (e.g. area where shift changes, breaks, maintainers and activities that may cause machines to converge on at certain times): $P = 25 - 50\%$ depending on machine type and applications

5.7 Seat belts

Earth-moving machines with seated operators are fitted with operator restraint systems—seat belts—and all MCSSA for such machines in this document were assumed that the operator was properly restrained. It is considered machine abuse to operate a machine fitted with a seat belt without wearing it.

5.8 Maintenance tasks

Only machine maintenance tasks that require or are reasonably foreseeable to be done with the engine running are considered in these assessments. The proportion of maintenance time is calculated based on the length of time the task takes and the frequency of those tasks. The H variable is calculated from the proportion of the time the maintainer would be exposed to the hazard while performing those tasks.

Depending on the size of the machine, maintenance tasks typically involve (70 – 75) % of the tasks on machine, with the rest of the time changing tools, performing job hazard analysis and other tasks. The P variables used reflect this.

5.9 Backhoe arm out and wheeled excavator or backhoe stabilizer down while travelling or roading

When travelling or roading, if a wheeled excavator or backhoe (centre mount only) stabilizer lowers without command, the stabilizer protrudes into the space beside the existing machine envelope. A similar situation occurs when a backhoe (side shift only) arm moves out without command; however, the arc of motion is up and out rather than down and out (see [Figure 8](#)). If traffic or pedestrians are in these spaces, they could be contacted by the machine.

It is not reasonable for people or traffic to be close to a moving machine (approximately 1 m). However, at the outer most portions of the range of motion, it is possible that people or traffic are present, such that they could be contacted.

For stabilizers and arm, the portion of the motion where someone could be present is approximately 20 %. For stabilizers, a P variable of 16 % (see [5.2](#)) for traffic has been used per [5.1](#). For arm, a P variable of 10 % is used (lower because of the height of the motion at this stage would only contact high vehicles) (see [Figure 8](#)).

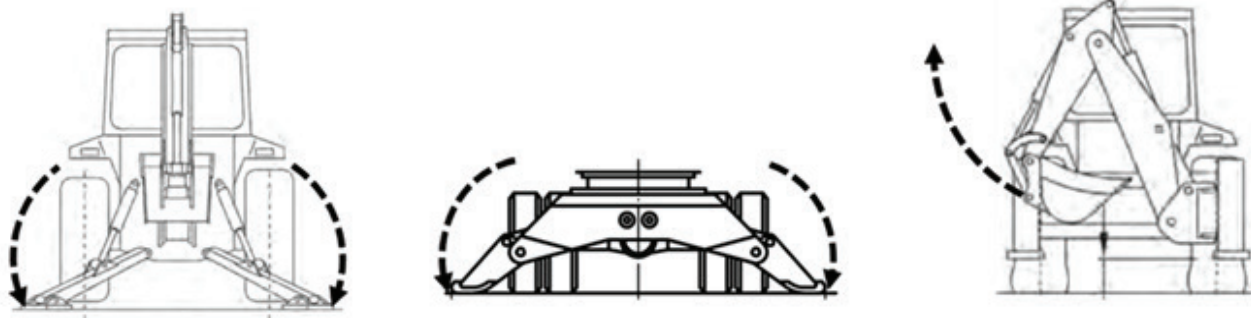


Figure 8 — Wheeled excavator, backhoe stabilizer down and backhoe arm out during travel H diagram

Annex A

(normative)

Rigid frame dump trucks performance level tables

A.1 Rigid frame dump trucks

Scores and percentages for S, A, H, P, E, AC, AW and AR and C are given in the tables for dominant scenarios along with the dominant MPL_r for the function. More details can be found in the subsequent subclause ([Tables A.1 to A.5](#)) or in [Clause 5](#).

Table A.1 — MPL_r table for rigid frame dump truck

Ref #	Machine function	Use case	Failure type	Hazardous outcome	Person group exposed	S	A variable	H variable	P variable	E	AC	AW	AR	C	MPL _r
RD1	body up	traveling	uncommanded activation	machine rolls due to body being stuck in the up position	operator	S1	80 %	100 %	100 %	E2	AC1	AW1	AR3	C2	b
RD2		traveling	uncommanded activation	collision with rolled machine	bystander	S2	80 %	50 %	5 %	E1	AC1	AW1	AR3	C2	
RD3	body down	traveling	failure to apply on demand	machine rolls due to body being stuck in the up position	operator	S1	80 %	50 %	100 %	E2	AC1	AW2	AR3	C1	a
RD4		traveling	failure to apply on demand	collision with rolled machine	bystander	S2	80 %	25 %	5 %	E1	AC1	AW2	AR3	C1	
RD5	neutralize	unloading and queuing	uncommanded deactivation	machine moves into machine in front / behind or over high wall / steep slope	operator	S3	20 %	9 %	100 %	E1	AC1	AW2	AR3	C1	b
RD6	machine speed	traveling	uncommanded activation	runaway machine - machine goes off high wall	operator	S3	90 %	55 %	100 %	E2	AC1	AW3	AR3	C0	b
BAD2	machine direction	considered to be the same unloading and queuing for articulated-frame dumpers greater than 22 000 kg													c

^a For pressure vessel discharge and isolation systems, uncommanded activation of the systems has the same MPL_r as the system they are controlling.

^b For a steering hydraulic system that automatically discharges stored energy when the machine is powered off, the controllability for failure on demand would be AC0 due to the hazard of someone moving the steering when they think the system is discharged. In this case the MPL_r would be c.

Table A.1 (continued)

Ref #	Machine function	Use case	Failure type	Hazardous outcome	Person group exposed	S	A variable	H variable	P variable	E	AC	AW	AR	C	MPL _r
RD7	slow/stop	traveling	failure to apply on demand	runaway machine - machine goes off high wall or a collision	operator	S3	90 %	28 %	100 %	E2	AC1	AW2	AR2	C2	d
RD8		traveling	uncommanded activation	machine goes into uncontrollable skid - goes off high wall or head to tail collision	operator	S3	90 %	4 %	100 %	E1	AC1	AW2	AR2	C2	c
RD9	hold still	slow speed maneuvering	failure to apply on demand	machine rolls away - collision with light vehicle or pedestrian - operator out of cab	bystander	S3	20 %	10 %	25 %	E0	AC0	N/A	N/A	C3	c
RD10		maintenance	failure to apply on demand	maintainer run over	maintainer	S3	7 %	13 %	100 %	E0	AC0	N/A	N/A	C3	
RD11	steering	traveling	uncommanded activation	machine steers off high wall	operator	S3	90 %	90 %	100 %	E2	AC1	AW2	AR2	C2	d
RD12		traveling	uncommanded activation	collision with light vehicle or pedestrian	bystander	S3	90 %	100 %	5 %	E1	AC1	AW2	AR0	C3	
RD13	powered access	slow speed maneuvering	uncommanded activation	access system lowers onto person	bystander	S2	20 %	100 %	25 %	E1	AC1	AW0	AR1	C3	c

For pressure vessel discharge and isolation systems, uncommanded activation of the systems has the same MPL_r as the system they are controlling.

For a steering hydraulic system that automatically discharges stored energy when the machine is powered off, the controllability for failure on demand would be AC0 due to the hazard of someone moving the steering when they think the system is discharged. In this case the MPL_r would be c.

Table A.1 (continued)

Ref #	Machine function	Use case	Failure type	Hazardous outcome	Person group exposed	S	A variable	H variable	P variable	E	AC	AW	AR	C	MPL _r
RD14	pressure vessel discharge ^a	maintenance	failure to apply on demand	oil injection from discharged oil	maintainer	S3	7 %	10 %	75 %	E0	AC1 ^b	AW3	AR1	C2	b
RD15	isolation system	maintenance	failure to apply on demand	electrocution from electric drive system, oil injection from hydraulic system	maintainer	S3	7 %	10 %	75 %	E0	AC0	N/A	N/A	C3	c

^a For pressure vessel discharge and isolation systems, uncommanded activation of the systems has the same MPL_r as the system they are controlling.

^b For a steering hydraulic system that automatically discharges stored energy when the machine is powered off, the controllability for failure on demand would be AC0 due to the hazard of someone moving the steering when they think the system is discharged. In this case the MPL_r would be c.

A.2 Supporting explanation

A.2.1 Supporting explanations for dominant scenarios

RD1 – body up

H: Hazard exists for the entire cycle. $H = 100 \%$

P: Operator is always in cab for this use case. $P = 100 \%$

AC: AC1 – Remove foot from throttle to reduce raise rate, brake to stop moving

AW: AW1 – Only if looking in mirror or body down indicator (if fitted)

AR: AR3 – Removing foot from throttle is a natural reaction

RD2 – body up

H: Hazard only exists if machine rolls in one direction – 50 % of hazards are dangerous. $H = 50 \%$

P: Light vehicle on haul road traffic rate. $P = 5 \%$

AC: AC1 – Remove foot from throttle to reduce raise rate, brake to stop moving

AW: AW1 – Only if looking in mirror or body down indicator (if fitted)

AR: AR3 – Removing foot from throttle is a natural reaction

RD3 – body down

H: Worst case when downhill hauling – 50 % of hazards are dangerous. $H = 50 \%$

P: Operator is always in cab for this use case. $P = 100 \%$

AC: AC1 – brakes

AW: AW2 – Operator should be watching body lower and machine feel will be different

AR: AR3 – Operator can choose not to start moving

RD4 – body down

H: Worst case when downhill hauling (50 %), hazard only exists if machine rolls in one direction (50 %). $H = 50 \% \times 50 \% = 25 \%$

P: Light vehicle traffic rate. $P = 5 \%$

AC: AC1 – Remove foot from throttle to reduce raise rate, brake to stop moving

AW: AW2 – Operator should be watching body lower and machine feel will be different

AR: AR3 – Operator can choose not to start moving

RD5 – neutralize

H: Only hazardous when dumping (queue would be at low idle and operator would have brake applied) see [Table 1](#) and [Figure 3](#) (17 %). 50 % failures are hazardous – moves into reverse only. $H = 50 \% \times 17 \% = 9 \%$

P: Operator always in cab for this use case. $P = 100 \%$

AC: AC1 – Operator should have foot on brake or have park brake applied

AW: AW2 – Operator should be watching body lower and machine feel will be different

AR: AR3 – Operator should have foot on brake or have park brake applied

RD6 – machine speed

H: When going downhill (45 %) or trying to stop (10 %). $H = 45 \% + 10 \% = 55 \%$

P: Operator is always in cab for this use case. $P = 100 \%$

AC: AC1 – brakes

AW: AW3 – Not immediately hazardous – hazard increases in time

AR: AR3 – Applying brakes is a natural reaction and applying brake during the operation is considered underfoot

RD7 – slow/stop

H: When going downhill (45 %) on a curve (40 %) or trying to stop (10 %) $((45 \% \times 40 \%) + 10 \% \text{ stopping})$. $H = 28 \%$

P: Operator is always in cab for this use case. $P = 100 \%$

AC: AC1 – park brakes

AW: AW2

AR: AR2 – Applying park brake required (by moving their hand)

RD8 – slow/stop

H: Hazardous when on curve (40 %), downhill (45 %), high wall present (90 %), conditions conducive to a skid (25 %). $H = 40 \% \times 45 \% \times 90 \% \times 25 \% = 4 \%$

P: Operator is always in cab for this use case. $P = 100 \%$

AC: AC1 – berm

AW: AW2

AR: AR2 – Berms are not always effective

RD9 – hold still

H: Amount of time machine could be left unattended not in V ditch or specifically designed parking area designed to prevent roll away (10 %). $H = 10 \%$

P: Typical bystander rate in central / parking areas. $P = 25 \%$

AC: AC0

RD10 – hold still

H: 10 % of refuel (58,6 %), 20 % of daily walk around (19,5 %), 10 % of window wash (only when on the ground - lesser severity on platform) (9,8 %), 0 % of brake test (4,9 %), 100 % troubleshooting (1 %), 25 % of camera wash (some lower severity) (4,9 %), 10 % of tyre inspection (1,4 %). $H = (10 \% \times 58,6 \%) + (20 \% \times 19,5 \%) + (10 \% \times 9,8 \%) + (0 \% \times 4,9 \%) + (100 \% \times 1 \%) + (25 \% \times 4,9 \%) + (10 \% \times 1,4 \%) = 13 \%$

P: Maintainer can be dedicated to these tasks for fleet of machines, P is considered H calculation. $P = 100 \%$

AC: AC0

RD11 – steering

H: Hazardous when high wall present (90 %). H = 90 %

P: Operator is always in cab for this use case. P = 100 %

AC: AC1 – berm

AW: AW2

AR: AR2 – Berms are not always effective

RD12 – steering

H: Hazard exists during the whole cycle. H = 100 %

P: Typical haul road light vehicle rate. P = 5 %

AC: AC1 – brakes

AW: AW2

AR: AR0

RD13 – powered access system

H: Hazard exists during the whole cycle. H = 100 %

P: Typical bystander rate in central / parking areas. P = 25 %

AC: AC1 – brakes (stop machine before it hits someone)

AW: AW0

AR: AR1

RD14 – pressure vessel discharge

H: Only maintenance tasks within the system that could be charged. H = 10 %

P: Maintenance task on / off machine split. P = 75 %

AC: AC1 – It is considered machine abuse to perform tasks where pressure could be released from a pressurized system without first checking to ensure that the energy is discharged.

AW: AW3 – Checks are performed before work commences and the hazard presents itself.

AR: AR1 – Maintainer required to move hands and feet to perform this task.

RD15 – isolation system

H: Only maintenance tasks within the system that could be charged. H = 10 %

P: Maintenance task on / off machine split. P = 75 %

AC: AC0

A.2.2 Application use cases

Table A.2 — Application use case table

Application	Traveling	Loading and queuing	Unloading and queuing	Slow speed maneuvering	Maintenance
Less than 100 000 kg rigid trucks	80 %	40 %	20 %	30 %	7 %

Table A.2 (continued)

Application	Traveling	Loading and queuing	Unloading and queuing	Slow speed maneuvering	Maintenance
Greater than or equal to 100 000 kg payload large trucks	90 %	40 %	20 %	20 %	7 %

A.2.3 Maintenance task breakdown

Table A.3 — Maintenance task breakdown

	Time (min/day)	% Maintenance time
refuel	60	59
walk around, oil check	20	20
wash mirror and windows	10	10
brake test	5	5
troubleshooting		1
clean camera	5	5
tire maintenance	1,4	1

A.2.4 Function dominant failure type matrix

Function-dominant failure type matrices reflect the approach that was taken during the MCSSA and outline where some truncation occurred. The notion is that some failure types result in the same hazardous outcomes as other failure types and, therefore, result in the same performance level required (e.g. failure to apply on demand and uncommanded deactivation of the park brake would result in the same hazardous outcome; park brake is off when the operator expects it to be on).

Table A.4 — Function dominant failure type matrix

Function	Failure to apply on demand	Failure to re-lease on demand	Uncommanded activation	Uncommanded deactivation	Notes
machine speed			1		Failure to release on demand is considered the same as uncommanded activation. Other failure types are less severe.
machine direction	1				Failure to apply is treated as a failure to change direction or changing into wrong direction. An uncommanded direction change is considered the same as uncommanded park brake.
transmission neutralize				1	Shifting out of N without command
machine start			1		Uncommanded shutdown is considered the same as uncommanded hold still or stop or N depending on machine design. Uncommanded activation is only dangerous when in maintenance and the machine is keyed on.
NOTE A "1" has been placed in the cell for function - failure type combination that would or could potentially cause the most hazardous failure.					

Table A.4 (continued)

Function	Failure to apply on demand	Failure to re-release on demand	Uncommanded activation	Uncommanded deactivation	Notes
body up			1		Other failure types are less or not hazardous.
body down	1		1		Failure to lower the body is less dangerous than the body lowering without command, but is still assessed.
ejector out			1		Other failure types not hazardous
ejector in					Only dangerous when in maintenance and machine is running, however it is machine abuse to be behind ejector plate when the machine is running.
slow/stop	1		1		Other failure types have the same outcome as what is being analyzed.
hold still	1				Failure to apply on demand considered the same as uncommanded release. Uncommanded activation considered the same as uncommanded slow/stop.
pressure vessel discharge	1				Uncommanded discharge is covered under system integrity of the system the pressure vessel is installed in.
steering			1		Failure to apply on demand is considered the same as uncommanded activation.
isolation system	1				Uncommanded activation is the same as uncommanded slow/stop. Uncommanded release is the same as failure to apply on demand.
powered access			1		Other failure types are less or not hazardous.
NOTE A "1" has been placed in the cell for function - failure type combination that would or could potentially cause the most hazardous failure.					

A.2.5 Notes and assumptions

- Due to sites with machines this size typically having controlled access, the following assumptions were made:
 - co-workers were people in other similar sized machines,
 - bystanders were co-workers in light vehicles and pedestrians.
- This assessment only considers trucks used as dump trucks and derivatives to the extent that they have common usage and features to the dump trucks considered in the MCSSA.
- Some data suggested that loading/queuing and unloading/queuing values could be higher than those used in this analysis, however it was determined that this was highly inefficient and would not be a sustainable business practice in the long term and would thus not be an accurate representation of machine usage.
- Consistent scoring guidelines:
 - S1 collision with another similar size or larger machine except for rear end collisions between 2 trucks of similar size (operator and co-worker),
 - S3 rear end collision between 2 trucks of similar size - rigid trucks only (operator and co-worker),
 - S3 machine off high wall (operator),

- S3 machine versus pedestrian or light vehicle (bystander),
- S1 rear end collision between 2 trucks of similar size - articulated trucks only (operator and co-worker),
- S1 roll over (operator).

A.3 MPL_r mapped to SCS table

Table A.5 shows function-based MPL_r (see Table A.1) mapped to SCS per the results of the MCSSA for a rigid frame dump truck. Other systems that fail in a way that cause a hazardous outcome similar to the function failures in Table A.1 would also be mapped to these MPL_r.

Table A.5 — MPL_r mapped to SCS

Machine function	Failure type	MPL re- quired	Example of mapped sys- tem
body up	uncommanded activation	b	hoist raise
	failure to release on demand		
body down	failure to apply on demand	a	hoist lower
neutralize	uncommanded deactivation	b	gear direction control
machine speed	uncommanded activation	b	throttle and speed gear control
machine direction	failure to apply on demand	c	gear direction control
slow down / stop	failure to apply on demand	d	service brakes
	uncommanded activation	c	
hold still	failure to apply on demand	c	parking brakes
steering	uncommanded activation	d	steering
powered access	uncommanded activation	c	powered access ladder
pressure vessel discharge ^a	failure to apply on demand	b	accumulator charge system
isolation system	failure to apply on demand	c	machine lockout system

^a For pressure vessel discharge and isolation systems, uncommanded activation of the systems has the same MPL_r as the system they are controlling.

Annex B

(normative)

Articulated-frame dumpers equal to or greater than 22 000 kg performance level tables

B.1 Articulated-frame dumpers equal to or greater than 22 000 kg

Scores and percentages for S, A, H, P, E, AC, AW and AR and C are given in the tables for dominant scenarios along with the dominant MPL_r for the function. More details can be found in the subsequent subclause ([Tables B.1](#) to [B.4](#)) or in [Clause 5](#).

Table B.1 — MPL_r table for articulated-frame dumpers equal to or greater than 22 000 kg

Ref #	Machine function	Use case	Failure type	Hazardous outcome	Person group exposed	S	A variable	H variable	P variable	E	AC	AW	AR	C	MPL _r
LAD1	body up														b
LAD2	body down														a
BAD1	ejector out	traveling	uncommanded activation	hit ejected material - could tip	co-worker	S1	80 %	50 %	10 %	E1	AC0	N/A	N/A	C3	b
RD5	neutralize														b
LAD3															
RD6	machine speed														b
BAD2	machine direction	unloading and queuing	failure to apply on demand	machine reverses over high wall or steep slope	operator	S3	40 %	2 %	100 %	E0	AC1	AW2	AR0	C3	c
BAD3		traveling	failure to apply on demand	runaway machine - machine goes off high wall. ^a	operator	S3	80 %	6 %	100 %	E1	AC1	AW2	AR2	C2	c
BAD4	slow/stop	traveling	uncommanded activation	uncontrollable skid - machine collision with light vehicle	bystander	S3	80 %	2 %	5 %	E0	AC0	N/A	N/A	C3	c
RD10	hold still														c
LAD8-9															
BAD5		traveling	uncommanded activation	machine steers off high wall	operator	S3	80 %	30 %	100 %	E2	AC1	AW2	AR2	C2	
BAD6	steering	traveling	uncommanded activation	collision with light vehicle or pedestrian	bystander	S3	80 %	100 %	5 %	E1	AC1	AW2	AR0	C3	d
^a The severity of head to tail collision for articulated trucks is lower than rigid frame trucks due to geometry.															

B.2 Supporting explanation

B.2.1 Supporting explanations for dominant scenarios

BAD1 – ejector out

H: Only hazardous while loaded. H = 50 %

P: Typical haul road machine rate. P = 10 %

AC: AC0

BAD2 – machine direction

H: Only hazardous at the precise moment when the operator goes to drive away from the dump point. H = 2 %

P: Operator is always in cab for this use case. P = 100 %

AC: AC1 – brakes

AW: AW2

AR: AR0

BAD3 – slow/stop

H: Only hazardous when going downhill (15 %) and on a curve (40 %). H = 6 %

P: Operator is always in cab for this use case. P = 100 %

AC: AC1 – park brake

AW: AW2

AR: AR2

BAD4 – slow/stop

H: Only hazardous when on curve (40 %), going downhill (15 %), 25 % conditions conducive to a skid (25 % - high wall and downhill reduced to 1/3rd of large rigid trucks). $H = (40 \% \times 15 \% \times 25 \%) = 2 \%$

P: Light vehicle on haul road traffic rate. P = 5 %

AC: AC0

BAD5 – steering

H: Only hazardous when high wall is present. H = 30 %

P: Operator is always in cab for this use case. P = 100 %

AC: AC1 – park brake

AW: AW2

AR: AR2

BAD6 – steering

H: Hazard exists for the whole cycle. H = 100 %

P: Light vehicle on haul road traffic rate. P = 5 %

AC: AC1 – brake

AW: AW2

AR: AR2

B.2.2 Application use cases

Table B.2 — Application use case table

Application	Traveling	Loading and queuing	Unloading and queuing	Slow speed maneuvering	Maintenance
22 000 kg and greater payload articulated-frame dumpers	80 %	30 %	40 %	30 %	5 %

B.2.3 Maintenance task breakdown

Table B.3 — Maintenance task breakdown

	Time (min/day)	% Maintenance time
refuel	10	17
walk around, grease and oil check	20	33
wash machine	5	8
wash mirror and windows	10	17
brake test	5	8
troubleshooting		1
install body-lock pins	1,7	3
install articulation lock	1,7	3
clean camera	5	8
tire maintenance	1,7	3

B.2.4 Function dominant failure type matrix

See [Table A.4](#).

B.2.5 Notes and assumptions

See [A.2.5](#).

B.3 MPL_r mapped to SCS table

[Table B.4](#) shows function-based MPL_r (see [Table B.1](#)) mapped to SCS per the results of the MCSSA for a 22 000 kg and greater payload articulated-frame dumper. Other systems that fail in a way that cause a hazardous outcome similar to the function failures in [B.1](#) would also be mapped to these MPL_r.

Table B.4 — MPL_r mapped to SCS

Machine function	Failure type	MPL required	Example of mapped system
body up	uncommanded activation	b	hoist raise
body down	failure to apply on demand	a	hoist lower
ejector out	uncommanded activation	b	ejector
neutralize	uncommanded deactivation	b	gear direction control

Table B.4 *(continued)*

Machine function	Failure type	MPL re-quired	Example of mapped system
machine speed	uncommanded activation	b	throttle and speed gear control
machine direction	failure to apply on demand	c	gear direction control
slow down / stop	failure to apply on demand	c	service brakes
	uncommanded activation	c	
hold still	failure to apply on demand	c	parking brakes
steering	uncommanded activation	d	steering

Annex C (normative)

Articulated-frame dumpers equal to or less than 22 000 kg performance level tables

C.1 Articulated-frame dumpers less than 22 000 kg

Scores and percentages for S, A, H, P, E, AC, AW and AR and C are given in the tables for dominant scenarios along with the dominant MPL_r for the function. More details can be found in the subsequent subclause ([Tables C.1 to C.3](#)) or in [Clause 5](#).

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Rear end collision with light vehicle is considered less severe than larger machines.

Table C.1 (continued)

Ref #	Machine function	Use case	Failure type	Hazardous outcome	Person group exposed	S	A variable	H variable	P variable	E	AC	AW	AR	C	MPL _r
RD10	hold still			considered to be the same rigid dump trucks											c
LAD8		slow speed maneuvering	failure to apply on demand	machine rolls away - collision with light vehicle or pedestrian - operator out of cab	bystander	S3	30 %	10 %	10 %	E0	AC0	N/A	N/A	C3	
LAD9		maintenance	failure to apply on demand	maintainer run over	maintainer	S3	5 %	15 %	7 %	E0	AC0	N/A	N/A	C3	
LAD10	steering	roading	uncommanded activation	collision with light vehicle, pedestrian	bystander	S3	80 %	10 %	16 %	E1	AC1	AW2	AR0	C3	d
^a Rear end collision with light vehicle is considered less severe than larger machines.															

C.2 Supporting explanation

C.2.1 Supporting explanations for dominant scenarios

LAD1 – body up

H: Hazard exists for the entire cycle. H = 100 %

P: Operator is always in cab for this use case. P = 100 %

AC: AC1 – Remove foot from throttle to reduce raise rate, brake to stop moving

AW: AW1 – Only if looking in mirror or body down indicator (if fitted)

AR: AR3 – Removing foot from throttle is a natural reaction

LAD2 – body down

H: Worst case when downhill hauling – 50 % of hazards are dangerous. H = 50 %

P: Operator is always in cab for this use case. P = 100 %

AC: AC1 – brakes

AW: AW2 – Operator should be watching body lower and machine feel will be different

AR: AR3 – Operator can choose not to start moving

LAD3 – neutralize

H: Time when machine is idle while waiting. H = 20 %

P: Typical bystander rate in central/parking areas. P = 25 %

AC: AC1 – brakes

AW: AW2 – Operator should be watching body lower and machine feel will be different

AR: AR3 – Operator can brake as soon as movement is felt

LAD4 – machine speed

H: When going downhill (45 %) or trying to stop (10 %). H = 45 % + 10 % = 55 %

P: Light vehicle on haul road traffic rate. P = 5 %

AC: AC1 – brakes

AW: AW3 – Not immediately hazardous – hazard increases in time

AR: AR3 – Applying brakes is a natural reaction and applying brake during the operation is considered underfoot

LAD5 – machine direction

H: Only hazardous when machine is changing direction (10 %). H = 10 %

P: Typical bystander rate in central/parking areas. P = 25 %

AC: AC1 – brakes

AW: AW2

AR: AR3

LAD6 – slow/stop

H: Only hazardous when roading and stopping to avoid pedestrian (1 %). H = 1 %

P: Pedestrian always present when stopping to avoid pedestrian. P = 100 %

AC: AC1

AW: AW2

AR: AR2 – park brake

LAD7 – slow/stop

H: Only hazardous when slick underfoot conditions (25 %), curve present (40 %), downhill (15 %).

$H = 25 \% \times 40 \% \times 25 \% = 2 \%$

P: Light vehicle on haul road traffic rate. P = 5 %

AC: AC0

LAD8 – hold still

H: Amount of time machine could be left unattended not in V ditch or specifically designed parking area designed to prevent roll away (10 %). H = 10 %

P: Only hazardous at this severity for pedestrians in area. P = 10 %

AC: AC0

LAD9 – hold still

H: 0 % of refuel (16,5 %), 10 % of daily walk around (33 %), 10 % of machine wash (8,25 %), 20 % of window wash (should 3 points of contact) (16,5 %), 0 % of brake test (8,5 %), 100 % troubleshooting (1 %), 50 % of body pin install (2,75 %), 100 % of articulation lock install (2,75 %) 25 % of camera wash (some lower severity) (8,25 %), 10 % of tyre inspection (2,75 %)

P: P: Typical P for maintenance tasks – 70 % of task on machine, 30 % of task off machine (changing / obtaining tools, preparation, cleaning etc.). P = 70 %

AC: AC0

LAD10 – steering

H: Not used as haul unit on the road (highway trucks are used then - more efficient), only used on road for relocation between sites. H=10 %

P: See 5.2. P = 16 %

AC: AC1 – brake

AW: AW2

AR: AR0

C.2.2 Application use cases

Table C.2 — Application use case table

Application	Roading	Loading and queuing	Unloading and queuing	Slow speed maneuvering	Maintenance
Less than 22 000 kg payload - articulated-frame dumpers	80 %	30 %	20 %	30 %	5 %

C.2.3 Maintenance task breakdown

See [Table B.3](#).

C.2.4 Function dominant failure type matrix

See [Table A.4](#).

C.2.5 Notes and assumptions

See [A.3](#).

C.3 MPL_r mapped to SCS table

[Table C.3](#) shows function-based MPL_r (see [Table C.1](#)) mapped to SCS per the results of the MCSSA for a less than 22 000 kg payload articulated-frame dumper. Other systems that fail in a way that cause a hazardous outcome similar to the function failures in [Table C.1](#) would also be mapped to these MPL_r.

Table C.3 — MPL_r mapped to SCS

Machine function	Failure type	MPL required	Example of mapped system
body up	uncommanded activation	b	hoist raise
body down	failure to apply on demand	a	hoist lower
neutralize	uncommanded deactivation	b	gear direction control
machine speed	uncommanded activation	a	throttle and speed gear control
machine direction	failure to apply on demand	a	gear direction control
slow down / stop	failure to apply on demand	b	service brakes
	uncommanded activation	c	
hold still	failure to apply on demand	c	parking brakes
steering	uncommanded activation	d	steering

Annex D (normative)

Crawler excavators less than 109 000 kg performance level tables

D.1 Crawler excavators less than 109 000 kg

Scores and percentages for S, A, H, P, E, AC, AW and AR and C are given in the tables for dominant scenarios along with the dominant MPL_r for the function. More details can be found in the subsequent subclause ([Tables D.1 to D.5](#)) or in [Clause 5](#).

This MPL_r table shall be used in conjunction with [5.4](#). If the assumptions in [5.5](#) do not apply, then an MCSSA shall be performed.

Table D.1 — MPL_r table for crawler excavators less than 109 000 kg

Ref #	Machine function	Use case	Failure type	Hazardous outcome	Person group exposed	S	A variable	H variable	P variable	E	AC	AW	AR	C	MPL _r
CH1		object handling	failure to release on demand	slow speed swing into traffic - co-worker	co-worker	S3	80 %	4 %	5 %	E0	AC1	AW2	AR0	C3	c
CH2		object handling	failure to release on demand	slow speed swing into traffic - collision	bystander	S3	80 %	4 %	14 %	E0	AC1	AW2	AR0	C3	
CH3		object handling	uncommanded activation	slow speed swing into traffic - collision	operator	S1	80 %	40 %	100 %	E2	AC1	AW2	AR0	C3	
CH4		travel	failure to release on demand	rotation of machine instead of stopping - collision	co-worker	S3	20 %	5 %	5 %	E0	AC1	AW2	AR0	C3	
CH5		travel	failure to release on demand	rotation of machine instead of stopping - collision	bystander	S3	20 %	5 %	5 %	E0	AC1	AW2	AR0	C3	
CH6	acceleration / machine speed / direction	transport	failure to release on demand	machine rotates off truck and can tip (mini HEX could be carried on higher trucks)	operator	S2	5 %	100 %	100 %	E1	AC1	AW2	AR0	C3	

Table D.1 (continued)

Ref #	Machine function	Use case	Failure type	Hazardous outcome	Person group exposed	S	A variable	H variable	P variable	E	AC	AW	AR	C	MPL _r
CH7		transport	failure to release on demand	machine rotates off truck and can tip on person (mini HEX could be carried on higher trucks)	co-worker	S3	5 %	100 %	5 %	E0	AC1	AW2	AR0	C3	
CH8		trenching	uncommanded activation	collision with pedestrian or car	co-worker	S3	70 %	9 %	14 %	E0	AC1	AW2	AR0	C3	
CH9		trenching	uncommanded activation	collision with pedestrian or car	bystander	S2	70 %	14 %	14 %	E1	AC1	AW2	AR0	C3	
CH10		object handling	uncommanded activation	slow speed swing into traffic - co-worker	co-worker	S3	80 %	5 %	11 %	E0	AC1	AW2	AR0	C3	
CH11		object handling	uncommanded activation	slow speed swing into traffic - collision	bystander	S2	80 %	40 %	10 %	E1	AC1	AW2	AR0	C3	
CH12	track width extension	object handling	uncommanded deactivation	machine tips - no significant injury for this size machine	operator	S0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	QM

Table D.1 (continued)

Ref #	Machine function	Use case	Failure type	Hazardous outcome	Person group exposed	S	A variable	H variable	P variable	E	AC	AW	AR	C	MPL _r	
CH13	boom up														c	
		Considered to be the same as arm in														
CH14		object handling	uncommanded activation	injury to fingers if in the process of lashing or unlashng	co-worker	S2	80 %	34 %	10 %	E1	AC0	N/A	N/A	C3		
CH15		travel	uncommanded activation	boom raises into overhead object or power lines	operator	S3	20 %	1 %	100 %	E0	AC0	N/A	N/A	C3		
CH13	boom down														c	
		Considered to be the same as arm in														
CH16		object handling	uncommanded activation	crushed by boom, object on ground for parts of cycle that are hazardous	co-worker	S3	80 %	19 %	2 %	E0	AC0	N/A	N/A	C3		
CH21-28	boom swing (L / R)	considered to be the same as upper structure slew / swing													c	
CH21-28	boom offset	considered to be the same as upper structure slew / swing													c	
CH13	arm in	object handling	uncommanded activation	co-worker hit by object	co-worker	S3	80 %	5 %	5 %	E0	AC0	N/A	N/A	C3	c	
CH17		maintenance	uncommanded activation	crushed by boom	maintainer	S3	5 %	8 %	70 %	E0	AC0	N/A	N/A	C3		
CH13	arm out	considered to be the same as arm in													c	
CH13	telescopic arm	considered to be the same as arm in													c	
CH13	bucket dump	considered to be the same as arm in													c	
CH13	bucket curl	considered to be the same as arm in													c	

Table D.1 (continued)

Ref #	Machine function	Use case	Failure type	Hazardous outcome	Person group exposed	S	A variable	H variable	P variable	E	AC	AW	AR	C	MPL _r	
CH18	auxiliary flow	object handling	uncommanded activation	grabbing bucket / clamshell bucket opens dropping load.	co-worker	S2	80 %	26 %	5 %	E1	AC0	N/A	N/A	C3	c	
WE23	implement rotate	considered to be the same as wheeled excavator														c
CH13	blade up	considered to be the same as arm in														c
CH19	blade down / float / tilt / angle	travel	uncommanded activation	blade lowers suddenly causing machine to come to abrupt stop – no significant injury for this type of machine due to low speed	operator	S0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	QM	
CH20	coupler engagement	trenching	uncommanded deactivation	bucket thrown from machine	co-worker	S3	70 %	1 %	1 %	E0	AC0	N/A	N/A	C3	c	
CH13		considered to be the same as arm in														
CH21		travel	uncommanded activation	machine swings / slews into co-worker	co-worker	S3	20 %	50 %	5 %	E0	AC1	AW2	AR0	C3		
CH22		travel	uncommanded activation	machine swings / slews into bystander	bystander	S3	20 %	50 %	5 %	E0	AC1	AW2	AR0	C3		
CH23		trenching	failure to release on demand	collision with pedestrian or car	co-worker	S3	70 %	6 %	5 %	E0	AC1	AW2	AR0	C3		

Table D.1 (continued)

Ref #	Machine function	Use case	Failure type	Hazardous outcome	Person group exposed	S	A variable	H variable	P variable	E	AC	AW	AR	C	MPL _r
CH24	upper structure swing/slew	trenching	failure to release on demand	collision with pedestrian or car	bystander	S2	70 %	11 %	14 %	E1	AC1	AW2	AR0	C3	c
CH25		trenching	uncommanded activation	collision with pedestrian or car	co-worker	S3	70 %	9 %	14 %	E0	AC1	AW2	AR0	C3	
CH26		trenching	uncommanded activation	collision with pedestrian or car	bystander	S2	70 %	12 %	14 %	E1	AC1	AW2	AR0	C3	
CH27		object handling	uncommanded activation	collision with pedestrian or car	co-worker	S3	80 %	6 %	11 %	E0	AC1	AW2	AR0	C3	
CH28		object handling	uncommanded activation	collision with pedestrian or car	bystander	S2	80 %	71 %	10 %	E1	AC1	AW2	AR0	C3	
CH21-28	swing/slew - stop / slow / hold still	considered to be the same as upper structure slew/swing													
	cab tilt	considered machine abuse to be under cab unblocked in operation – not a safety function													
	cab elevate	considered to be the same as cab tilt													
	cab slide	considered to be the same as cab tilt													
	counterweight removal	not a safety function													
	engine speed	cannot cause increase in implement speed, therefore no significant hazard													

D.2 Supporting explanation

D.2.1 Supporting explanations for dominant scenarios

CH1 – acceleration / machine speed / direction

H: Only applicable during travel portion (4,7 %) – see [Table 2](#), 90 % idle factor. H = 4 %

P: Co-workers are aware of hazard and avoid being directly under the boom wherever possible but may not always be able to. P = 5 %

AC: AC1 – Turn machine off or apply park brake

AW: AW2

AR: AR0 – Not all operators would be able to react in time

CH2 – acceleration / machine speed / direction

H: Only applicable during travel portion (4,7 %), 90 % idle factor. H = 4 %

P: See [5.5](#). P = 14 %

AC: AC1 – Turn machine off or apply park brake

AW: AW2

AR: AR0 – Not all operators would be able to react in time

CH3 – acceleration / machine speed / direction

H: See [5.5](#), 50 % of failures hazardous. H = 40 %

P: Operator always present. P = 100 %

AC: AC1 – Turn machine off or apply park brake

AW: AW2

AR: AR0 – Not all operators would be able to react in time

CH4, CH5 – acceleration / machine speed / direction

H: Only when in tight confines (50 %) and when stopping (10 %). H = 5 %

P: Co-workers are aware of hazard and avoid being directly under the boom wherever possible but may not always be able to. P = 5 %

AC: AC1 – Turn machine off or apply park brake

AW: AW2

AR: AR0 – Not all operators would be able to react in time

CH6 – acceleration / machine speed / direction

H: Could happen at any point while loading machine onto transport. H = 100 %

P: Operator always present during cycle. P = 100 %

AC: AC1 – Turn machine off or apply park brake

AW: AW2

AR: AR0 – Not all operators would be able to react in time