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Agricultural machinery and tractors — Safety of partially automated, semi-autonomous and autonomous machinery —

Part 3: Autonomous operating zones

Tracteurs et matériels agricoles — Sécurité des machines partiellement automatisées, semi-autonomes et autonomes —

Partie 3: Zones de fonctionnement autonome

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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 document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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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 23, *Tractors and machinery for agriculture and forestry*, Subcommittee SC 19, *Agricultural electronics*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 144, *Tractors and machinery for agriculture and forestry*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This first edition of ISO 18497-3, together with ISO 18497-1, ISO 18497-2 and ISO 18497-4, cancels and replaces ISO 18497:2018, which has been technically revised.

The main changes are as follows:

— autonomous operating zones were defined and were made its own part (i.e. ISO 18497-3), accounting for the wide range of functionality and use cases within agricultural machines and tractors.

A list of all parts in the ISO 18497 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 is a type-B1 standard as stated in ISO 12100:2010.

This document is of relevance, in particular, for the following stakeholder groups representing the market players with regard to machinery safety:

— machine manufacturers (small, medium and large enterprises);

— health and safety bodies (regulators, accident prevention organisations, market surveillance, etc.).

Others can be affected by the level of machinery safety achieved with the means of the document by the above-mentioned stakeholder groups:

— machine users/employers (small, medium and large enterprises);

— machine users/employees (e.g. trade unions, organizations for people with special needs);

— service providers, e.g. for maintenance (small, medium and large enterprises);

— consumers (in case of machinery intended for use by consumers).

The above-mentioned stakeholder groups have been given the possibility to participate at the drafting process of this document.

In addition, this document is intended for standardization bodies elaborating type-C standards.

The requirements of this document can be supplemented or modified by a type-C standard.

For machines which are covered by the scope of a type-C standard and which have been designed and built according to the requirements of that standard, the requirements of that type-C standard take precedence.

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.

The purpose of the ISO 18497 series is to establish general design principles for partially automated, semi-autonomous and autonomous (see ISO 18497-1:2024, Clause 3) functions of agricultural machinery and tractors.

Manual non-automated functions are addressed in existing agricultural machinery and tractor safety standards. Due to the potential number of different functions of agricultural machinery and tractors and the mixed type and mode to which these functions can exist, it is necessary to establish general design principles. In this way, the combination, operator location, and types of interaction of these functions can be guided so that further type-C safety standards can be developed consistently and explicitly to address the mitigation of risk of injury to operators and bystanders. This is the primary focus of safety standards. Attempting to specify risk mitigation requirements based on combinations of type and mode of functions alone cannot be accomplished accurately for all agricultural machinery and tractors due to the wide variety of the machinery and variety of functionality.

Therefore, the familiar representation of SAE J3016[1] with six levels of automation was deliberately not chosen as a basis for the ISO 18497 series and it is necessary to develop more specific type-C safety standards, using the general design principles of this document, to adequately account for the risks of agricultural machinery and tractors used in a specified way with various types of partially automated, semi-autonomous and autonomous functions.

When the requirements of the ISO 18497 series for partially automated, semi-autonomous and autonomous functions of agricultural machinery and tractors are different from those which are stated in a machine-specific type-C standard dealing with partially automated, semi-autonomous and autonomous functions of agricultural machinery and tractors, the requirements of the machine-specific standard take precedence over the requirements of the ISO 18497 series.

Agricultural machinery and tractors — Safety of partially automated, semi-autonomous and autonomous machinery —

Part 3:
Autonomous operating zones

1 Scope

This document specifies principles for the design of agricultural machinery and tractors utilizing systems (perception, supervisory or other) to prevent unintended excursions beyond the boundary of the autonomous operating zone which are used in agricultural applications and that have partially automated, semi-autonomous and autonomous functions. Additionally, it provides guidance on the type of information to be provided by the manufacturer on safe working practices (including information about residual risks).

The autonomous operating zone itself is not within the scope of this document. The autonomous operating zone can include, for example, considerations for the autonomous operating zone location, physical or virtual boundaries, physical boundary types (natural or man-made) and the associated risks with the systems (perception, supervisory or other) to prevent unintended excursions beyond the boundary of the autonomous operating zone design.

The purpose of this document is to assist in the provision of more specific safety requirements, means of verification and information for use to ensure an appropriate level of safety for agricultural machinery and tractors with partially automated, semi-autonomous and autonomous functions used in a specified way.

This document deals with the significant hazards relevant to agricultural machinery and tractors with partially automated, semi-autonomous and autonomous functions when used as intended and under the conditions of misuse reasonably foreseeable by the manufacturer during normal operation and service.

Applicability of the design principles and any additional detailed requirements for design, verification, validation or information for use are outside the scope of this document. When risk assessment concludes that hazards are not significant hazards, the principles of this document do not apply.

NOTE Safety requirements for specific non-automated functions of agricultural machinery and tractors can be available in machine-specific type-C standards.

This document is not applicable to:

— forestry applications;

— operations on public roads including relevant requirements for braking and steering systems.

This document is not applicable to agricultural machinery and tractors which are manufactured before the date of its publication, or to systems applied to agricultural machinery and tractors put into use 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 3767-1:2016, *Tractors, machinery for agriculture and forestry, powered lawn and garden equipment — Symbols for operator controls and other displays — Part 1: Common symbols*

ISO 3767-1:2016/Amd 1:2020, *Tractors, machinery for agriculture and forestry, powered lawn and garden equipment — Symbols for operator controls and other displays — Part 1: Common symbols — Amendment 1*

ISO 3767-2:2016, *Tractors, machinery for agriculture and forestry, powered lawn and garden equipment — Symbols for operator controls and other displays — Part 2: Symbols for agricultural tractors and machinery*

ISO 3767-2:2016/Amd 1:2020, *Tractors, machinery for agriculture and forestry, powered lawn and garden equipment — Symbols for operator controls and other displays — Part 2: Symbols for agricultural tractors and machinery — Amendment 1*

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

ISO 13849-1:2023, *Safety of machinery — Safety-related parts of control systems — Part 1: General principles for design*

ISO 13849-2:2012, *Safety of machinery — Safety-related parts of control systems — Part 2: Validation*

ISO 18497-1:2024, *Agricultural machinery and tractors — Safety of partially automated, semi-autonomous and autonomous machinery — Part 1: Machine design principles and vocabulary*

ISO 18497-2:2024, *Agricultural machinery and tractors — Safety of partially automated, semi-autonomous and autonomous machinery — Part 2: Design principles for obstacle protective systems*

ISO 18497-4:2024, *Agricultural machinery and tractors — Safety of partially automated, semi-autonomous and autonomous machinery — Part 4: Verification methods and validation principles*

ISO 25119-1:2018, *Tractors and machinery for agriculture and forestry — Safety-related parts of control systems — Part 1: General principles for design and development*

ISO 25119-1:2018/Amd 1:2020, *Tractors and machinery for agriculture and forestry — Safety-related parts of control systems — Part 1: General principles for design and development — Amendment 1*

ISO 25119-2:2019, *Tractors and machinery for agriculture and forestry — Safety-related parts of control systems — Part 2: Concept phase*

ISO 25119-3:2018, *Tractors and machinery for agriculture and forestry — Safety-related parts of control systems — Part 3: Series development, hardware and software*

ISO 25119-3:2018/Amd 1:2020, *Tractors and machinery for agriculture and forestry — Safety-related parts of control systems — Part 3: Series development, hardware and software — Amendment 1*

ISO 25119-4:2018, *Tractors and machinery for agriculture and forestry — Safety-related parts of control systems — Part 4: Production, operation, modification and supporting processes*

ISO 25119-4:2018/Amd 1:2020, *Tractors and machinery for agriculture and forestry — Safety-related parts of control systems — Part 4: Production, operation, modification and supporting processes — Amendment 1*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 18497-1:2024 apply.

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

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

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

4 Safety requirements and protective or risk reduction measures

4.1 General

Agricultural machinery and tractors that have partially automated, semi-autonomous and autonomous functions (see Figure 1) and which utilize systems (perception, supervisory or other) to prevent unintended excursions beyond the boundary of the autonomous operating zone as a measure to reduce risks related to person and/or obstacle contact as a significant hazard, as defined in ISO 12100:2010, 3.8, shall be designed according to the principles of 4.2 for protective or risk reduction measures.

Significant hazards are dependent on the use case of agricultural machinery and tractors with partially automated, semi-autonomous and autonomous functions and shall be determined using a risk assessment according to ISO 12100:2010.

In addition, agricultural machinery and tractors that have partially automated, semi-autonomous and autonomous functions and which utilize systems (perception, supervisory or other) to prevent unintended excursions beyond the boundary of the autonomous operating zone 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. For significant hazards not covered in 4.2, the determination of requirements and corresponding verification procedures shall be done according to ISO 12100:2010.

Specific type-C standards, when available, can give more detailed requirements.

	Manual non-automated (see ISO 18497-1:2024, 3.1)	Partially automated (see ISO 18497-1:2024, 3.2)	Semi-autonomous (see ISO 18497-1:2024, 3.3)	Autonomous (see ISO 18497-1:2024, 3.4)
Functions (see ISO 18497-1:2024, 3.5)	Non-automated (see ISO 18497-1:2024, 3.6)			
		Automated (see ISO 18497-1:2024, 3.7)		
Modes	Manual mode (see ISO 18497-1:2024, 3.9)			
			Autonomous mode (see ISO 18497-1:2024, 3.10)	

NOTE See ISO 18497-1:2024

Figure 1 — Terms used for combinations of functions and modes

Design of machine systems and obstacle protective systems shall be designed in accordance with ISO 18497-1:2024 and ISO 18497-2:2024, respectively.

Verification methods of ISO 18497-4:2024 shall be applied to the design principles of 4.2.

4.2 Design principles

4.2.1 General

For ensuring an appropriate level of safety of partially automated, semi-autonomous (when automated machine functions operate in autonomous mode) and autonomous functions of agricultural machinery and tractors, the following protective or risk reduction measures shall be provided in the design of agricultural machinery and tractors when utilizing systems (perception, supervisory or other) to prevent unintended excursions beyond the boundary of the autonomous operating zone as a measure to reduce significant hazards related to person and/or obstacle contact.

4.2.2 Boundary detection

4.2.2.1 Perception and supervisory systems

a) Prevention of failures to detect, late detection, misclassification and errors in location/orientation of a detected boundary of an autonomous operating zone shall be provided.

NOTE 1 Due to the variety of perception systems, some of the failures above might not be applicable.

EXAMPLE 1 Reasons for typical failure to detect a boundary or late detection of a boundary:

1) boundaries are occluded due to crops, dust, fog, snow, rain or other obscurants;
2) perception results become unreliable due to poor or intense lighting conditions (e.g. direct sunlight, reflected sunlight, darkness, shadows);
3) uneven ground causes scanning plane to vary, (e.g. the laser beam might hit the ground or point to the sky when the vehicle is pitching down or up or tilting side to side);
4) vehicle vibration or motion causes misalignment of sensors;
5) boundaries are approaching too fast to be detected;
6) boundaries are too small, (e.g. the reliability of the radar technology depends on the effective radar cross-section of the boundary to identify it);
7) boundaries do not reflect back in the direction of the receiver, (e.g. laser beam or radar sensor does not detect reflected signal from organic, or transparent; e.g. ultrasonic sensor does not detect acoustic energy from sound-absorbing boundary);
8) boundaries reflect or emit too much energy and saturate the sensor;
9) boundaries at the same temperature as the environment are not detected by thermal sensor;
10) boundary colour is indistinguishable from that of the background (e.g. camouflage);
11) negative boundaries (e.g. holes in the terrain) are not detected;
12) latency may increase due to other applications or computation loading used for the boundary detection or classification system;
13) dust or other obscurants on the sensors itself can reduce the sensor field of view;
14) difficult terrain condition (e.g. mud, significant slopes) or body of water are not detected;
15) sensor is moved out of alignment or sensor is blocked by a part or parts of a machine (e.g. cover, shield, tool);
16) sensors interfere each other (e.g. due to artificial lighting for cameras);
17) electromagnetic compatibility interference from internal or external sources;
18) erratic power supply and/or under/over voltage to system components.

EXAMPLE 2 Reasons for typical misclassification of a boundary:

1) dust, fog, snow, rain or obscurants blur the edges;
2) inadequate model to capture sufficient ground truth conditions (due to training or validation e.g. over-fitting, under-fitting, data leakage of model or model inability to capture sufficient corner conditions);
3) boundaries are occluded due to crops, dust, fog, snow, rain or other obscurants.

EXAMPLE 3 Reasons for typical erroneous location/orientation of a detected boundary:

1) sensor misalignment causing inaccurate position estimate;
2) positioning and orientation system errors (e.g. GNSS error) causing inaccurate machine position or orientation;

3) vibration of the sensor mounting causing sensor motion that is not accounted for by the perception system;

4) dust, fog, snow, rain or obscurants blur the edges of the boundary or environment;

5) inaccurate sensor calibration or registration;

6) wrong estimated location of boundary due to multi-path propagation.

b) The restriction of adjustment outside the manufacturer's defined operational limits shall be provided.

NOTE 2 Operational parameter limit of system defined by manufacturer (e.g. temperature, speed). Manufacturer does not allow access by operator to adjust parameters, or provides operator access to adjust specific parameters, but the range of allowable parameters is only within the defined manufacturers limit.

c) Adequate detection performance of an autonomous operating zone boundary for the intended use case shall be provided, which:

— includes the design principles found in ISO 18497-1:2024, 4.2.8;

— fulfils the required risk reduction level of the manufacturer's risk assessment.

4.2.2.2 Other systems

NOTE 1 Other systems are, for example: virtual fence, peripheral protection systems, fixed path systems, buried wire, etc.

a) Prevention of failures to detect and late detection of a boundary or condition establishing a boundary of an autonomous operating zone shall be provided.

EXAMPLE Reasons for typical failure to detect or late detection:

1) latency may increase due to other applications or computation loading on the processor used for detection;

2) sensor is moved out of alignment or sensor is blocked by a part of or parts of a machine (e.g. cover, shield, tool) either installed correctly or not for operation;

3) sensor position does not allow for sufficient contact with boundary;

4) sensor misalignment causes inaccurate position estimate;

5) positioning and orientation system errors (e.g. GNSS error) causing inaccurate machine position or orientation;

6) inaccurate sensor calibration or registration;

7) wrong location of boundary due to multi-path propagation.

b) The restriction of adjustment outside the manufacturer's defined operational limits shall be provided.

NOTE 2 Operational parameter limit of system defined by manufacturer (e.g. temperature, speed). The manufacturer does not allow access by operator to adjust parameters, or provides operator access to adjust specific parameters, but the range of allowable parameters is only within the defined manufacturers limit.

c) Adequate detection performance of an autonomous operating zone boundary or condition establishing a boundary for the intended use case shall be provided, which:

— includes the design principles found in ISO 18497-1:2024, 4.2.8;

— fulfils the required risk reduction level of the manufacturer's risk assessment.

4.2.3 Operational limits

4.2.3.1 Perception and supervisory systems

Automatic change to a safe state to maintain operational limits shall be provided in the machine design that uses a perception system, or a supervisory system that uses a perception system, as a means to prevent unintended excursions beyond the boundary of the autonomous operating zone.

EXAMPLE 1 Typical operational limits:

1) Environmental-related parameters (e.g. sun radiation, darkness, fog, temperature, all kinds of atmospheric precipitation and conditions, terrain irregularities and crop irregularities);

2) Boundary identification-related parameters (e.g. small size of boundaries, fast speed of machine relative to boundary, and poor reflective properties of boundary);

3) Machine-related parameters (e.g. operating speed, sensor alignment, sensor field of view, vibrations, computation demands for processors);

4) Component-related parameters (e.g. dirt on the sensor, sensor temperature too high/too low).

NOTE Due to the variety of perception systems, some of the operational limits above might not be applicable.

EXAMPLE 2 Speed of machine exceeds operational limit (cannot maintain operational limit) of system used for the autonomous operating zone therefore the machine reduces speed to a controlled stop and changes out of the active state to a different safe state.

4.2.3.2 Other systems

Automatic change to a safe state to maintain operational limits shall be provided in the machine design that uses other types of systems as a means to prevent unintended excursions beyond the boundary of the autonomous operating zone.

EXAMPLE 1 Typical operational limits:

1) Environmental-related parameters (e.g. sun radiation, darkness, fog, temperature, all kinds of atmospheric precipitation and conditions, terrain irregularities and crop irregularities);

2) Machine-related parameters (e.g. operating speed, sensor alignment, vibrations, computation demands for processors);

3) Component-related parameters (e.g. dirt on the sensor, sensor temperature too high/too low).

NOTE Due to the variety of other types of systems, some of the operational limits above might not be applicable.

4.2.4 Monitoring

When hazardous machine functions can operate in autonomous mode, notification of the current state of systems (perception, supervisory or other) to prevent unintended excursions beyond the boundary of the autonomous operating zone shall be provided to the operator through the notification system.

4.2.5 Faults and failures

4.2.5.1 General

The machine design utilizing systems (perception, supervisory or other) to prevent unintended excursions beyond the boundary of the autonomous operating zone for partially automated, semi-autonomous and autonomous hazardous functions shall be in accordance with ISO 25119-1:2018, ISO 25119-1:2018/Amd 1:2020, ISO 25119-2:2019, ISO 25119-3:2018, ISO 25119-3:2018/Amd 1:2020, ISO 25119-4:2018 and ISO 25119-4:2018/Amd 1:2020, or ISO 13849-1:2023 and ISO 13849-2:2012.

Use of a supervisory system can be a means to detect and take action from faults and failures.