# EU safety regulations and standards for autonomous mobile machinery

Malm T[1]., Tiusanen R[1]. & Berger J. [1]

1 : VTT Technical Research Centre of Finland

KEYWORDS: Mobile machinery, autonomous, safety of machinery, regulations

## ABSTRACT

There are high hopes to autonomous mobile machines to increase productivity in large systems, where mobile machines carry loads and operate without continuous human control. One driving force to use autonomous mobile machines is safety. If all hazardous tasks are done by autonomous machines and no persons are near, in ideal case the system can be safe. However there are exceptions, when persons need to go to the autonomous area and there can be tasks for manual mobile machines and persons. Then to achieve adequate safety can be challenging task.

Autonomous mobile machines are described first time in in Machinery Regulation in 2023/1230 year 2023. It gives basic requirements and guidelines how protective measures should be designed. However, more detailed guidelines are needed to design protective measures to many kinds of autonomous mobile machine systems. On the other hand, the requirements cannot be too specific, since there are many kinds of autonomous machinery, technologies are developed rapidly and also new risks related to new applications may be found. There are already some standards associated to the old Machinery Directive, but they will be updated.

According to the Machine Regulation risk need to be minimized according to risk assessment, but there are also more specific requirements. Autonomous mobile machinery system must have either peripheral guard or onboard safety system, which can detect objects and collisions can be avoided. In practice peripheral guard means isolated autonomous area and if someone enters the area, then autonomous mode is turned off at least partly. Onboard safety system means in practice that the autonomous machine is able to stop to avoid collisions. The Machine Regulation describes only two options to protective systems, but these protective measures can be combined and also additional methods can be applied to ensure safety. It can be assumed that in the near future new safety measures are developed and also devices are improved in many ways. This means that examples and guidelines are needed to use new safety measures, which are also related to the baseline of the risk assessment.

## 1 INTRODUCTION

There are a lot of expectations to autonomous mobile machines. They can provide innovative way to increase productivity. Safety is both one of the main concerns, but also an important opportunity. If there were no persons in hazardous area, the system would be safe in ideal case. However, there are exceptions, when person needs to go to hazardous area and in many systems, there are both autonomous and manual machines and persons in the same autonomous area. It may be challenging to ensure safety in a system, which has both autonomous and manual operations in an environment, where sensors have limited capabilities compared to the production needs, but there are safe options now and, in the future, even more. The focus of this this paper is on mixed fleet case, which has both autonomous and manual machines in the same area.

This paper aims to show an overview of requirements and guidelines, which are presented to autonomous mobile machines and give some ideas how the machines and machinery systems can operate safely. The focus is on machines, which operate in difficult environment, where the capability of sensors for object detection is limited. Regulations and standards give both mandatory and voluntary guidelines to make safe autonomous mobile machine systems. In all cases the systems must be adequately safe and risk assessment is applied judge the level of safety. There are many kinds of autonomous mobile systems and it is difficult to fit the rules in similar way to all of them. There are new requirements and they will affect many autonomous mobile machines.

## 2 REQUIREMENTS

New Machinery Regulation (EU) 2023/1230 of June 2023 gives first time in legislation requirements for autonomous mobile machines [1]. According to the Machinery Regulation the definition for ‘Autonomous mobile machinery’ is:

> mobile machinery which has an autonomous mode, in which all the essential safety functions of the mobile machinery are ensured in its travel and working operations area without permanent interaction of an operator. [1]

Also supervisory function and supervisor for supervising autonomous mobile machines remotely have been defined.

> ‘Supervisory function’ means remote non-permanent surveillance of autonomous mobile machinery by a device allowing to receive information or alerts and to give limited orders to this machinery. ‘Supervisor’ means a person responsible for the supervision of autonomous mobile machinery ‘Driver’ means an operator responsible for the movement of machinery or a related product, who may be transported by the machinery or may be on foot, accompanying the machinery, or may guide the machinery by remote control [1].

If relevant, supervisory function is obligatory and its purpose is to stop, start, or move the machine to safe state or position. It is not meant for other remote control operations and when it is applied, protective devices are operational and the operator must be able to see directly or indirectly the machine and the working area. There should be available also information that can alert the supervisor of the occurrence of unforeseen or dangerous situations present or impending, which require the intervention of the supervisor. This supervisory function requirement will presumably be described more detailed in standards. The supervisory function does not exclude safety functions, but safety functions need to perform the safety functions by itself.

According to the Machine Regulation autonomous mobile machinery must have either a peripheral protection system comprising guards (and) or protective devices or they must be equipped with devices intended to detect any human, or any other obstacle in its vicinity, where those obstacles could give rise to a risk to the health and safety [1]. This means that protective devices are obligatory either onboard the autonomous mobile machine or in the infra. Apparently, standards are going to specify the requirement in more detailed level.

The Machinery Regulation has also specific requirements for autonomous mobile machinery failure in the steering system. The failure must not have an impact on the safety of the machinery. This is new requirement in legislation and specific for steering system. Some more detailed requirements can be found for earth-moving machinery (ISO 5010:2019) [8]. It is obvious that steering must operate correctly to move autonomous mobile machine to right direction. If the speed of the machine is slow, then safe state after a failure, may be reached by stopping the machine, but if the speed is high, then control of steering needs to maintained even during a failure by applying redundancy. Some machine dependent guidelines can be found in the standard [8]. Risk assessment is applied to estimate steering system failure consequences in a specific case, but it may be difficult to give universal rules for protective measures. In manual machines the driver can detect the malfunction and do necessary actions intuitively. Also other failures need to be considered, but the requirements are in standards, not in legislation.

Also trailers and towing and other related products are considered in Machinery Regulation. The movements of autonomous mobile machine or related product shall not cause risks to persons or other objects [1]. The judgement is made according to the risk assessment.

Autonomous mobile machines or highly automated machines are mentioned in several safety standards, but the presented guidelines are focusing on their own domains.

- Standard ISO 17757:2019 “Earth-moving machinery and mining—Autonomous and semi-autonomous machine system safety”. The standard describes, among others, autonomous mobile machine system, which can include a fleet of machines. The standard shows an overview of autonomous mobile machine system and which are typical subsystems. Although the focus of the standard is on earth-moving and mining machinery, the ideas are applicable for other domains too.
- Standard ISO 3691-4 “Industrial trucks—Safety requirements and verification — Part 4: Driverless industrial trucks and their systems”. The standard describes, among others, onboard safety functions and devices, which suit best for indoors use. The standard shows the level of safety requirements for ideal case in good operating environment. The ideas of the safety functions can be applied to many kinds of mobile systems, but they need to be adapted to outdoors and high speed applications.
- Standard “ISO 18497:2018. Agricultural machinery and tractors — Safety of highly automated agricultural machines”. The standard describes, among others, the onboard protective functions and

devices. The guidelines of the standard give ideas of protective measures and sensor systems to many kinds of automated applications.

The current situation with autonomous mobile machine requirements is that in upper level the Machine Regulation gives strict requirements, but standards need to specify more detailed the intentions. In outdoors applications the sensors can be in hostile environment and detection beams of sensors may wobble as the machine drives forward on a bumpy terrain. It is difficult to have common requirements for all autonomous mobile machines. The requirements need to be domain specific now, since there are no multipurpose solutions for autonomous operations.

Figure 1. shows examples of safety standards related to autonomous mobile machine systems in different domains. There are examples of standards related to onboard systems in the centre of the figure. The yellow part in the figure shows safety and functional safety standards related to different domains. The outer ring of the figure shows mobile machine and system standards. Beside the outer border there are presented domains (orange text), which are developing standards for autonomous mobile vehicles.

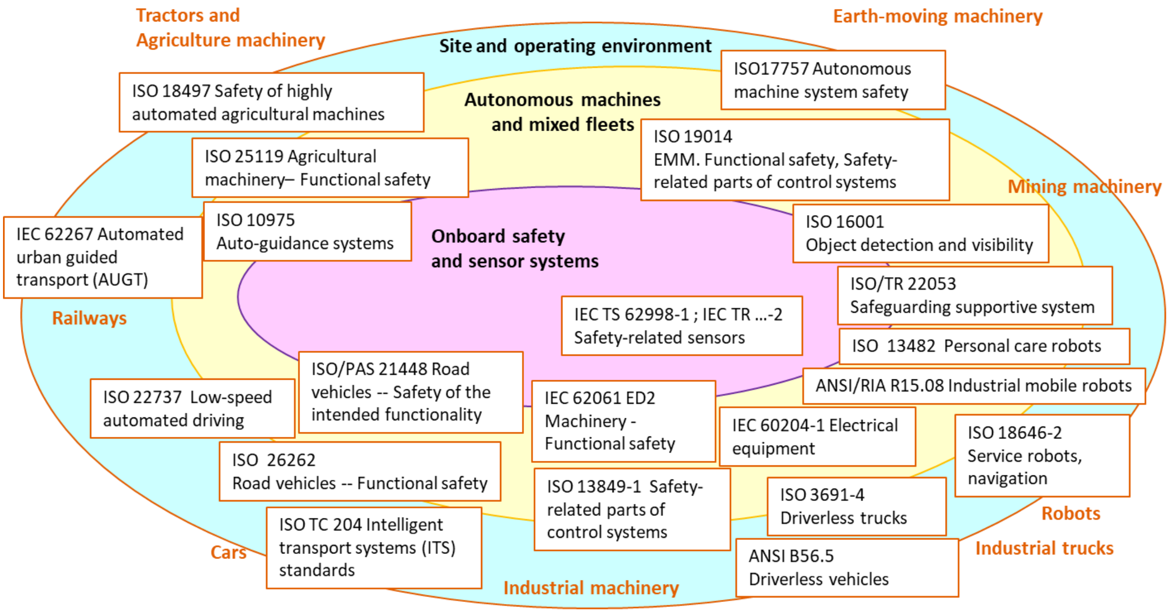


***Figure 1.*** *Examples of safety standards related to autonomous mobile machine systems in different domains. [4] (modified).*

## 3 APPROACHES TO SAFETY MEASURES

Autonomous mobile machine system can have different subsystems depending on the case. Figure 2. presents typical subsystems related to autonomous mobile machine system according to ISO 17757:2019. The standard is associated to earth-moving and mining machinery, but it can be applied in other domains too since it shows well the overview. In the autonomous mobile system there are usually following subsystems or objects:

- monitored autonomous mobile machines, manual mobile machines, persons,
- unmonitored manual machines and persons,
- access control system to the autonomous area,
- supervisor system, communication system, traffic control and other systems related to fleet control,
- systems onboard the machines, like, communication, task planner, navigation, safety, positioning and orientation and perception systems.

Usually all machines and persons are monitored inside the autonomous area, in autonomous mode. If there are unmonitored machines or persons in the autonomous area then a good perception system is required or operation mode may need to be changed to e.g. manual mode. The onboard systems of the autonomous mobile machine are communicating continuously among others with fleet control and access control systems. Usually the fleet control gives tasks to the machines, but it is possible that the machines have continuous tasks, which they can follow. There can be communication also with devices located into the infrastructure of the area.

The safety of the complete autonomous mobile machine system depends on many subsystems, not only the safety block. A collision can happen for example if navigation, perception, speed control, steering or communication (fleet control, access control, sensors) fails. In many cases there are multiple systems to, for example, position the machine (radio triangulation, optical measurements, local RFID, IMU, GPS, GNSS etc.). Mismatch between information can be detected and it can initiate a safety function according to the need, like slow speed, limping mode or stopping.

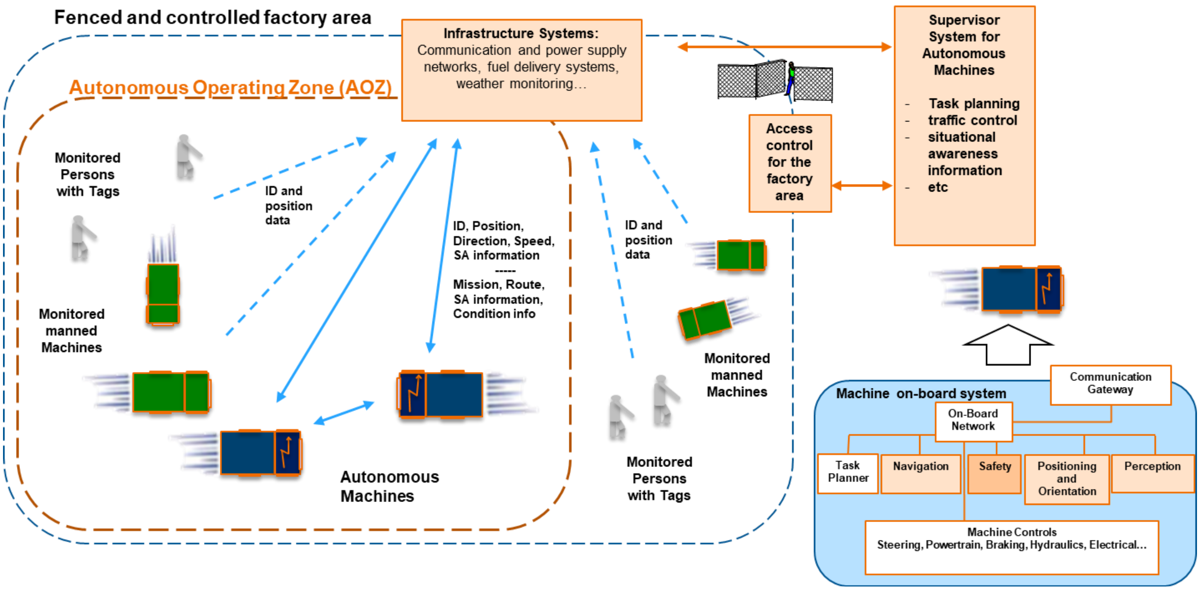


***Figure 2.*** *Autonomous mobile machine system and typical subsystems. [3] (modified).*

When designing protective measures to autonomous mobile machine system, it is possible to have several different approaches, which can be applied together or alone. For each approach there are requirements, which need to be considered. For a specific case, there can be several approaches and the requirements are not the same for all cases or parts of the system. The idea is to apply one or more approaches and, in some cases, additional measures to complete the safe autonomous mobile machine system. Figure 3. presents five approaches how protective measures can be applied in autonomous mobile machines. Note that the approaches a) and c) are described in the new Machinery Regulation and by applying them the related requirements can be fulfilled. However, approaches a) and c) are not always completely feasible and therefore it can be useful to apply additional other approaches. The letters in the list refer to Figure 3.

a) The traditional approach is to isolate the autonomous area. (Fences, gates and virtual gates). This approach suits peripheral protection system, which is described in the new Machine Regulation [1].

b) All persons and vehicles are tracked and the system can prevent collisions of tracked objects. This enables smooth stopping before collision and it resembles onboard sensors approach, see c). However, if all objects are not tracked or there becomes a new object (e.g. load) then an additional system is needed to detect untracked objects to avoid collisions.

c) Also an approach with onboard sensors, which can detect persons and other objects is described in new machine regulation [1]. The principle is that the machine stops before collision, but in practice good and safe sensors are needed and often also an additional system, which slows down the speed according to the distance to the detected object in order to be able to stop the machine before collision.

d) Traffic rules and signs are necessary to get smooth traffic. Quite often autonomous vehicles have priority to move, since there are production demands and it is easier for persons to avoid autonomous vehicles. How successful this approach can be is depending on how well rules are obeyed. Traffic rules are typically applied together with other measures.

e) Communication and situational awareness approach gives information to persons and machines about situation and what should be done next. The information can be delivered in advance so that tasks and paths can be optimized. The actual decisions are made by persons and the capability of the system depends on awareness information and how well it is utilized. The information that the autonomous machines get is applied also to avoid collisions and the protective ability depends on the system.

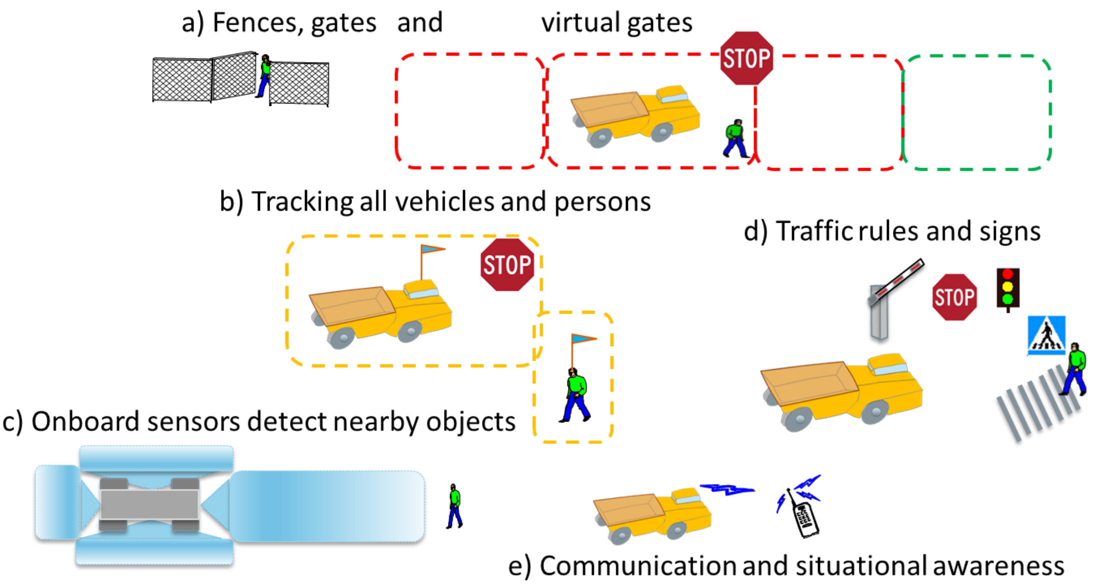


***Figure 3.*** *Approaches to mitigate autonomous mobile machines collisions. [2]*

## 4 DISCUSSION

New Machinery Regulation shows the basic principles for safe autonomous mobile machine systems. The basic approach for safety system is between peripheral guard, see case a) in Figure 3, and onboard safety system, see case c) in Figure 3. However, there are other possible protective measures as Figure 3. shows. These other measures like tracking objects, traffic rules and situational awareness can improve safety, but often they are considered as additional measures. However, technologies are improved and the five mentioned approaches in Figure 3. can be linked together. Situational awareness is linked to object detection, traffic rules monitoring detects failed operations, new found objects are informed to fleet control, which generates virtual objects that can be seen by all vehicles and also other monitoring functions can be linked with each other. There are many new possibilities to link information and to compare consistency of different systems. Such consistency problem can be related for example to sensor information, more complex anomaly of object movements or existence of the machine state. One new challenge can be that a consistency problem may be difficult to see from a large amount of information. One possibility in the future could be AI (Artificial Intelligence), but currently it is difficult to safety validate conclusions made by AI.

When applying current technologies in difficult environment it is possible to make safe peripheral safety system, but there may be some practical problems. The area that needs to be guarded can be very large such as forest or the area may be changing often and therefore peripheral guard can be unpractical to be used as a single safety solution. Many companies are trying to find new solutions to replace simple peripheral guards.

Onboard safety systems have many good possibilities to safeguard mobile machines and the principle is described in the new Machinery Regulation. However, in difficult outdoors environment sensors have limited capability to give applicable information about objects. It is difficult to find objects in fog, rain, sunshine, beside a large object, a laying object, negative object/hole or an object in a bumpy terrain (sensors sway up and down). The problems can be solved when the speed is slow, but there are production demands to keep the speed. Often several sensors are needed first to detect from far away and slow the speed, and finally apply safety sensor to stop safely. The whole process may need several phases and redundancy of sensors.

Since the described single approaches to ensure safety have practical problems, they cannot be applied in all cases, but solutions with many approaches are needed. However, the safety system become complex and there are more challenges to ensure and validate such safety systems. In the future, AI might be applied to configure and validate complex safety systems, but currently there are no accepted methods to validate safety AI according to functional safety requirements. In hardware, the (maximum) average frequency of dangerous failure per hour requirement for SIL 1 (lowest SIL) or PL b is PFH = $10^{-5}$ per hour, which equals to about one failure per 11 years. If we assume that the requirements are about at the same level for all technologies then speculating that there would be only one

AI failure per 11 years can be hard to achieve. Anyway, as mentioned we don't know yet the requirements for validating AI and the presented value may be misleading.

**Acknowledgement**

This review of EU safety regulations and standards for autonomous mobile machinery and the study of their implications have been conducted in VTT as a part of the research project 'Shared Situational Awareness for Optimized and Safe Mixed Fleets' (MixedFleet) , which is mainly funded by Business Finland.

## 5 REFERENCES

1. Machinery Regulation (EU) 2023/1230 of 14 June 2023. https://eur-lex.europa.eu/eli/reg/2023/1230/oj. 102 p.
2. Malm T., Pakkala D., Heikkilä E. *Autonomous mobile machines in mines using 5G enabled operational safety principles.* VTT TECHNOLOGY 412. 65 p.
3. Malm T., Tiusanen R., Heikkilä E., Sarsama J. Safety risk sources of autonomous mobile machines. Open Engineering 2022; 12: pp. 977–990. https://doi.org/10.1515/eng-2022-0377
4. Tiusanen R., Malm T., Ronkainen A. *An overview of current safety requirements for autonomous machines – review of standards*. Open Engineering 2020; 10: pp. 1-9. https://doi.org/10.1515/eng-2020-0074
5. ISO 17757 2019 2019. *Earth-moving machinery and mining — Autonomous and semiautonomous machine system safety*. 36.
6. ISO 3691-4 2020. *Industrial trucks — Safety requirements and verification — Part 4: driverless industrial trucks and their systems*. 2020. p. 84.
7. ISO 18497 2018. *Agricultural machinery and tractors — Safety of highly automated agricultural machines — Principles for design*; 2018. p. 18.
8. ISO 5010. 2019. *Earth-moving machinery — Wheeled machines — Steering requirements.* 18 p.