Safety on Automated Guided Vehicles

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THE SPIRIT OF SAFETY

How to ensure safety on Automated Guided Vehicles/
Autonomous Mobile Robots and their systems?

White paper
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1. Edition

At a glance

The spatial, static separation between man and machine traditionally ensures safety in factory halls. In modern industrial environments, however, flexible production processes are replacing rigid production lines. Against this background, the use of Automated Guided Vehicles (AGV) and Autonomous Mobile Robot/Vehicles (AMR/V) is becoming more and more popular, especially as they have become more autonomous, flexible and less dependent on the fixed infrastructure they are operated in. With this change, modern safety concepts need to ensure that the interaction between man and machine takes place smoothly and without accidents.
A 'safe' AGV application is the result of the right technology, an understanding of the specific application and the normative framework. With such a holistic view of the AGV application, safety and productivity can best be reconciled.

This whitepaper provides you with information on the requirements of relevant AGV standards. Furthermore, the safety process for AGVs is described including details on all relevant aspects necessary to make an AGV application safe, illustrated by a small practical example.

Contents

1. Information on Standards

The release of standards for Automated guided vehicle (AGV)/Autonomous Mobile Robot (AMR), in particular ISO 3691-4 in 2020, was in response to the fast development of emerging technologies in the field of automated vehicles. The ISO standard was long overdue since its predecessor (EN 1525:1997) was published 23 years earlier. It can now be regarded as the primary international AGV standard. In Europe, ISO 3691-4 is supplemented by the standard EN 1175:2020, which relates to specific electrical aspects of self-propelled trucks (including AGV). Both standards are awaiting harmonisation under the relevant European directives (status 09/2021).

Additional to the international launch of ISO 3691-4, the USA also updated relevant standards in 2019 and 2020: ANSI/ITSF B56.5:2019 (AGV) and ANSI/RIA R15.08-1:2020 (AMR).

2. Process for safe AGVs

The standard ISO 3691-4 outlines a clear process to achieve safety for an **individual AGV**. Interestingly, the standard is not only applicable to the AGV manufacturer as it also includes requirements for the user of the **AGV System**. An AGV System is defined as the combination of one or multiple AGV/AMR and the facility environment.

The process for an **individual AGV** can be summarised as follows:

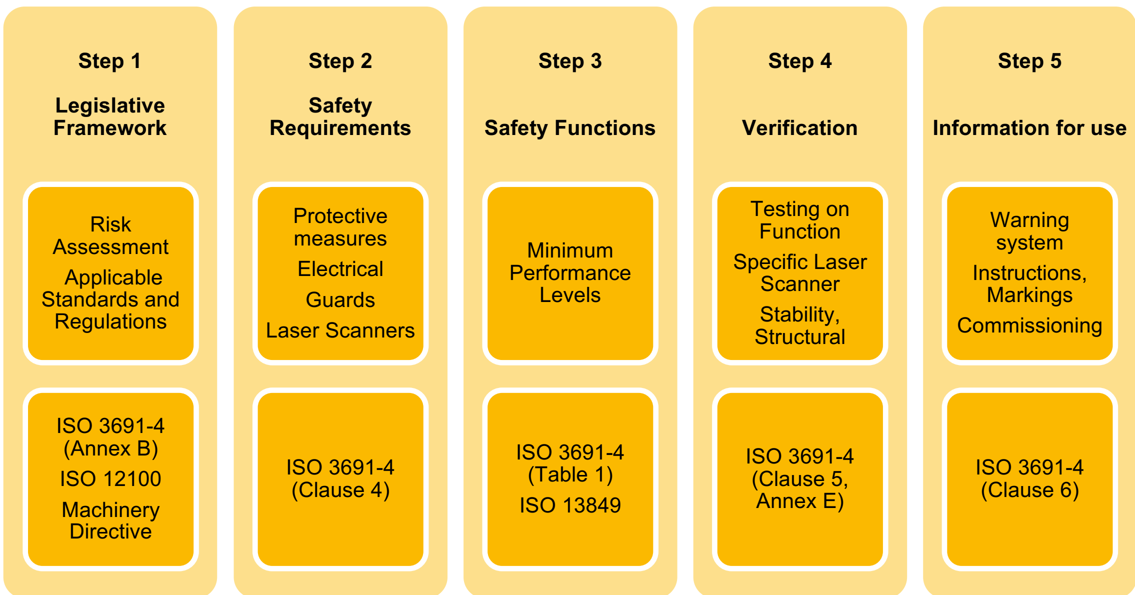


Figure 1: Process for an individual AGV incl. examples of references

In addition, for the **AGV System**:

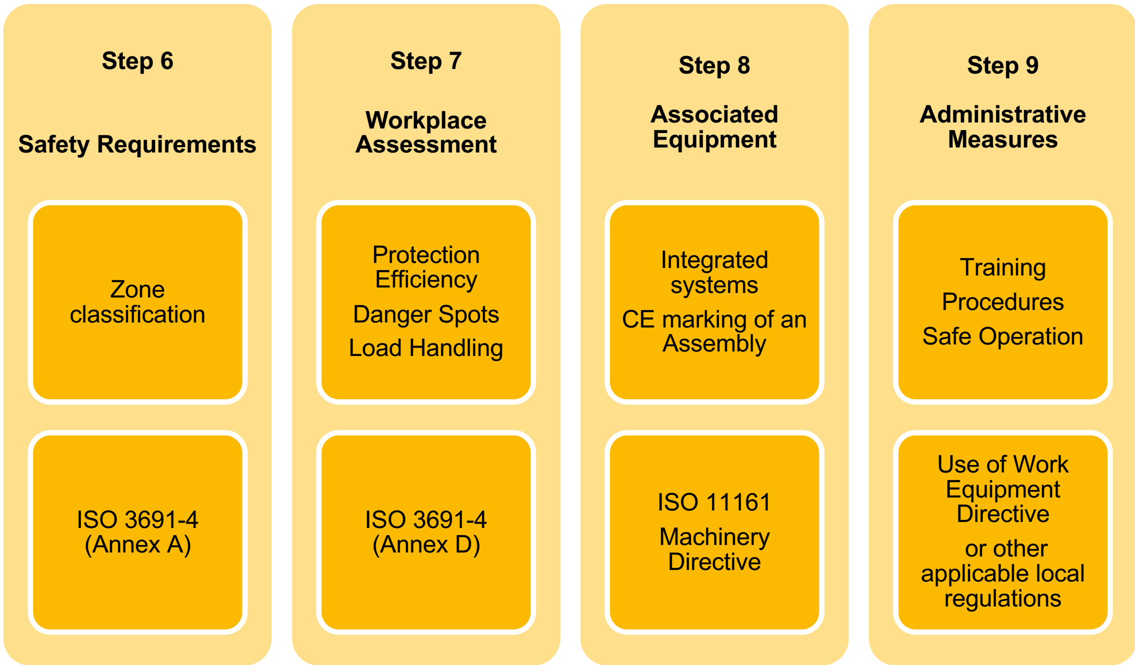


Figure 2: Process for an AGV System incl. example of references

3. Safety aspects of individual AGVs

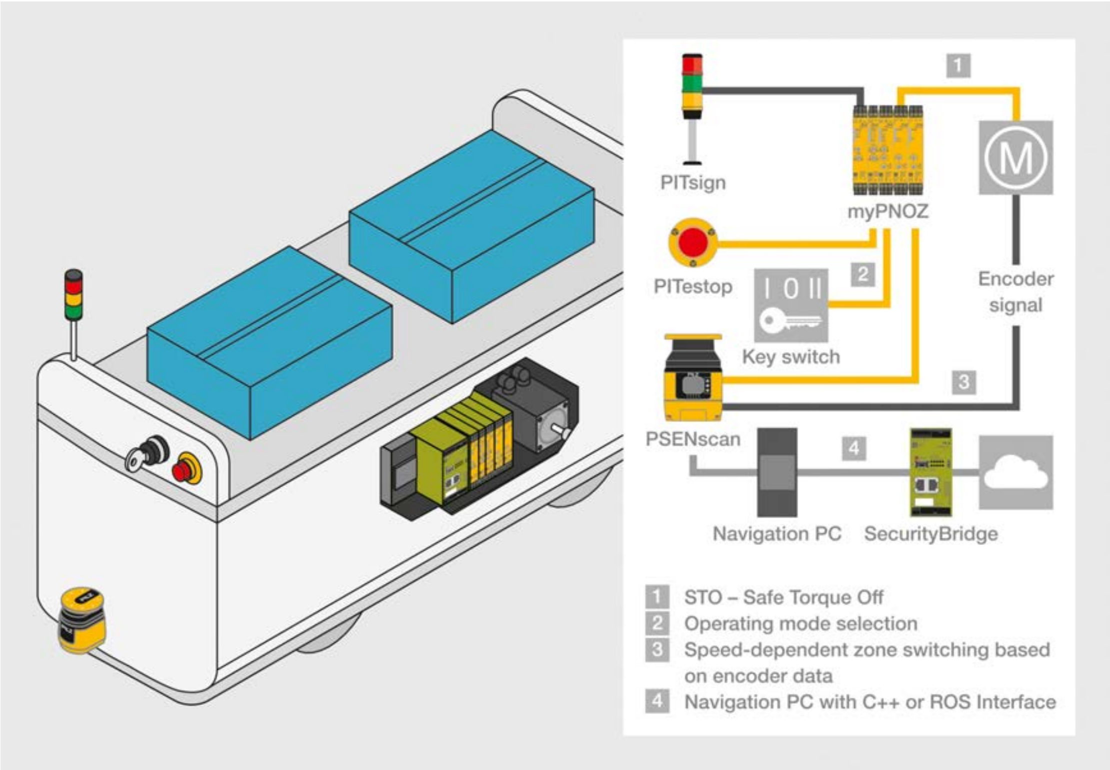
Individual AGVs are defined as machines. Within Europe, this means that they are required to comply with the Machinery Directive and associated standards and are required to be CE marked by the manufacturer. Outside of Europe, the compliance aspects of the individual AGV may be dealt with as part of the final integration.

One obvious risk of an AGV is the impact hazard associated with the moving vehicle. This risk and further risks with their associated requirements are detailed quite specifically within ISO 3691-4. To cover those requirements a thorough AGV risk assessment approach is needed to include topics such as:

- **GENERAL** intended use, mechanical hazards, sharp edges/angles or transmission parts
- **ELECTRICAL/SUPPLY** risk considering the unique aspect of the machine not being stationary and that electrical fault protection needs to be achieved through electrical separation and/or low voltages. Aspects of battery charging and other supply sources (e.g. hydraulic fluid) need to be considered also
- **CONTROL** functions such as start/stop of operation, driving, steering and braking. Also important is when and how automatic restart of the vehicle can take place

- **MODES OF OPERATION** including automatic mode and manual mode for set-up and maintenance

- **PROTECTIVE MEASURES** in relation to the main impact hazard to detect persons in the path such as laser scanners, cameras or radar sensors. Not to forget other protective measures, for example e-stop, pressure sensitive equipment and interlocking devices



Example of protective measures on an AGV

- **SAFETY CONTROL/FUNCTIONS** as relevant from table 1 of ISO 3691-4 with a focus on how the performance level (PL) acc. to ISO 13849-1 is achieved, how active detection fields are selected and how safety functions are deselected/overridden

Safety Function (Examples)	Required Performance Level (PLr)
Braking system control	d
Personnel detection system	d
Emergency stop function	d
Over speed detection	c
Hold-to-run function (manual mode)	c
Load Handling	b*

Table 3: Minimum required PLr for Safety Functions

- **LOAD HANDLING** in relation to the position of the load, the mass and energy of the load when handled or moving and to what extent these factors influence the risk and required PL.
  * As such the requirement PLr = b for Load Handling may often need to be increased depending on the risk assessment

- **SPECIAL CASE** consideration for trucks towing trailers or when being equipped with conveyors

- **INFORMATION FOR USE** in particular regarding the information which shall be provided for the application (floor condition, maintenance, stopping distance test, warnings, etc) in form of
  - Signals and warning devices
  - Markings, signs and written warnings
  - Accompanying documents (instructions, maintenance and application information)

4. Safety aspects of AGV Systems

One or more AGVs which are installed in an industrial environment form an "AGV System", with specific risks which may not have been fully addressed by the AGV manufacturer. Examples of particular risk areas of an AGV/AMR system include:

- **DESIGN SUITABILITY** to ensure that the individual AGV design related aspects (mentioned above) match the intended usage of the AGV in the final environment

- **PROTECTION EFFICIENCY** of the Safety equipment which may be limited due to certain objects which are not detectable within the plant environment or the floor condition having a negative impact on the braking performance of the AGV/AMR

- **ZONE CLASSIFICATION** of the warehouse to determine where additional risk reduction measures (e.g. slower speeds or additional stop control devices) are needed. Zones are differentiated into:

  Operating Zone | Operating hazard Zone | Restricted Zone | Confined Zone

- **LOAD TRANSFER / HANDLING** where safeguarding detection capabilities in load/unload areas need to be reduced or for hazards inherent to the load itself and its stability in respect of travelling speed, steering and "hard" safety stop situations

- **DANGER SPOTS** where for example access onto the AGV path is possible from around corners, areas where the AGV encounters other moving objects/vehicles (e.g. manual driven forklifts) or to avoid that an AGV stops at emergency exits

- **ASSOCIATED EQUIPMENT** such as conveyors, storage racks or other warehouse machinery which operate in conjunction with the AGVs and especially if and where safety aspects correlate between them

- **ENERGY SUPPLY AND BATTERY HANDLING** to deal with risk related to energy supply, potential stored energies (Lockout Tagout), use of batteries and the charging of same

- **ADMINSTRATIVE MEASURES** necessary to reduce residual risk through the creation and application of procedures, training, regular maintenance and inspections etc.

Depending on the control and interaction of the various AGVs in the operational environment, the combination of multiple AGV/AMRs within an **AGV System** can further create the need within Europe for CE Marking of the system as an assembly of machines.

Independently of that, for usage of the **AGV System** it is the end-user's responsibility to provide a safe work environment in compliance with local health and safety legislations. This may include the need for additional administrative measures, training and regular and specific validation activities.

5. Safety example

To illustrate some of the aspects mentioned earlier let's look at a small example.

An AGV where a safety laser scanner and the ROS (Robot Operating System) package from the Open Source Framework are used not only for safe, productive area monitoring but also to produce maps for dynamic navigation and to avoid obstacles:

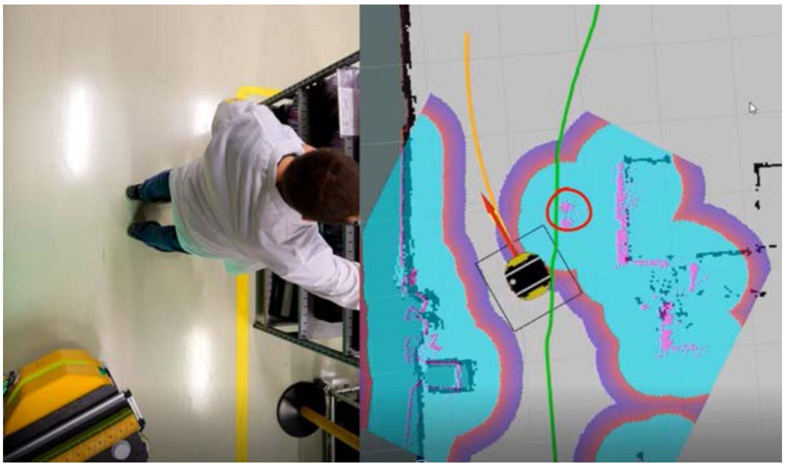
In this example, the AGV is moving in an aisle at one side of a production hall to deliver material needed for a machine. The aisle is wide enough to be assessed as a normal "operating zone" with the AGV operating at full operation speed, since clearances of 500 mm or more to each side are achievable.

If a person is entering the aisle multiple options are possible:

- The person is positioned in the middle of the aisle with no possibility for the AGV to bypass with sufficient clearance of 500 mm. The appropriate safety stop function needs to be activated and verified.

- The person is positioned close to one side of the aisle. The obstacle avoidance function (non safety rated functionality) can find a way to bypass the person and still achieve 500 mm clearances. In order for the AGV to navigate around the person while still adhering to the safety distance requirements specified in ISO 3691-4, the AGV may need to reduce safety fields and travel speed. The associated functionality of scanner field switching and speed adaptation needs to be verified.

- The person is close to the production side of the aisle. The obstacle avoidance function (non safety rated functionality) can find a way to bypass the person but the AGV would need to go between 100mm and 500mm distance from the wall side. In addition to the consequences of the previous option, this situation would mean that the wall side needs to be declared an “operating hazard zone”. The travel speed of the AGV would need to be limited to 1.2 m/s and additional warnings and signage are required in that zone. The associated functionality of scanner field switching and speed adaptation needs to be verified.



- The possible options would expand if multiple AGV can travel in that area, especially if going in multiple directions and around corner areas.

For all of these scenarios, the associated workers need to be fully aware and well instructed about the AGV operation and understand the residual risk associated with them.

As illustrated through this example, safety and production requirements need to be aligned as early as possible. It would be up to the AGV System project team to define all of the use cases and – depending on floor space, traffic requirements and operational processes – to decide if it is better to declare several operating hazard zones and accept resulting speed reductions or alternatively to stop the AGV when obstacles are in the way and go full speed otherwise.

In the context of this example, the reader might also be interested in the AGV example of ISO/TR22100-5 which deals with the relationship with ISO 12100 and the risk assessment implications of artificial intelligence machine learning.

6. Conclusion/Summary

In conclusion, the following recommendations can be given:

- Familiarise yourself with the details and limits of your AGV technology (especially in relation to Sensors and Safety Functions)
- Prepare and risk assess your facility environment well in advance to ensure suitability for AGVs and to determine how far safety requirements impact the productivity (e.g. due to zone dependent speed reductions)
- "Tighter space", "Higher Speeds" or "Material Throughput" are safety counterproductive and require suitable zone classification and additional safety measures
- Consider the risk related to interfaces (e.g. load transfer) of the AGV within your existing infrastructure and possible compliance needs
- Perform regular training, process audits, vehicle inspection and maintenance to ensure the safety of your AGV system

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