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Intermediate report on contribution to standards

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Executive summary

The project vision of PAN-Robots is to develop a highly automated logistics system supporting future factories to achieve maximum flexibility, cost and energy efficiency while at the same time ensuring accident-free operation. However, today's technology for factory logistics automation is still in an early stage of development and its deployment in the factory requires a trained staff and involves several time consuming, costly, inflexible and sometimes even error-prone manual tasks.

Therefore, PAN-Robots project aims to develop, demonstrate and validate advanced technologies that enable large improvement in the deployment and management of automatic logistics system, to overcome current limitations and inefficiencies.

Technologies developed in the framework of PAN-Robots overcome standard characteristics of components usually employed into AGV market. Therefore, PAN-Robots technologies should be assessed versus (1) current safety regulations and (2) technology standards (e.g. interfaces and communication standards) as a part of project implementation plan.

In particular, with respect to (1), the aim of this deliverable is to identify the concerns about safety which must be considered in future commercial development of PAN-Robots outcome, while the development of technical documentation and risk assessment for supporting an application to safety certification is outside the scope of this work. Indeed, the future implementation of PAN-Robots technologies will require the certification of safety conformity of devices and components before any commercial exploitation. However, this effort is considerably above the budget and outside the target of the PAN-Robots project, and it will be considered in the future exploitation plan.

The document is organized in three parts:

- In the **first part (**▸ Chapter 2**)**, the principles of safety regulations are described with references to the European standard (EN1525 'Safety of industrial trucks - Driverless trucks and their systems') and American standard (ANSI B56.5 Safety Standard for Guided Industrial Vehicles and Automated Functions of Manned Industrial Vehicles).
- The **second part** describes an analysis based on such standards about safety concerns that should be considered in future commercial exploitation of PAN-Robots technologies (▸ Chapter 3). In particular, this analysis is based on system characteristics and features as described in Deliverable D4.1 'Specification and Architecture' [7]. Considering that the European standard is under development by an international committee, some requests for amendments that concerns PAN-Robots specific characteristics are also described (▸ Chapter 4).
- The **final part** of this document (▸ Chapter 5) describes the technology standards of components and devices (e.g. interfaces of electrical communications). In particular, the devices developed in PAN-Robots are analyzed to describe the impact and possible request for amendment to current technology standards developed in order to enlarge the scope of existing standards to cover the new functionality achieved in PAN-Robots (▸ Chapter 6).

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1 Introduction

Standards are agreed definitions or specifications of units, methods, products, processes or services. They provide people and organizations with a basis for mutual understanding, and are used as tools to facilitate communication, measurement, commerce and manufacturing.

Standards are everywhere. They make life easier, safer and healthier for businesses and consumers. Standards are useful for optimizing performance, ensuring the health and safety of consumers and workers, protecting the environment and enabling companies to comply with relevant laws and regulations.

Most people are aware of standards for building materials, paper size (such as A4), optical media (such as DVD), mobile telephones (such as GSM) and connecting cables (such as USB or HDMI). These standards ensure connectivity and interoperability among products made by different suppliers.

Safety standards are a particular kind of standards designed to ensure the safety of products, activities or processes, etc. They may be advisory or compulsory and are normally laid down by an advisory or regulatory body that may be either voluntary or statutory.

This document analyzes the current state of the art of the main standards relevant to the PAN-Robots system. The focus is both on safety and technological standards. Based on the currently available standards and regulations, and based on the technological developments foreseen within PAN-Robots, this document proposes a few guidelines for improvements in the standards themselves.

2 Analysis of current safety regulations

This chapter analyses the current regulation in terms of safety regarding mobile vehicles for industrial applications.

2.1 Generalities

Directives and standards are documents that provide basic requirements and guidelines to the manufacturers, for the production of goods compliant with regulations, and with the state of the art technologies in terms of safety and operation.

In particular, directives are legislative acts of the European Union, which require member states to achieve some results, in a specific field. Subsequently, standards are developed to specify guidelines that ensure compliance with the directives themselves.

In order to commercialize machinery in the European Union, a supplier has to ensure compliance with the Directive 2006/42/CE on machinery [1], with the Low Voltage Directive 2006/95/CE [2], and with the Directive 2004/108/CE on Electromagnetic Compatibility [3].

In addition, compliance to further directives, such as 1994/9/CE [8] and 1997/23/CE [9] for explosive atmosphere and pressure equipment, can be required for specific systems.

2.2 EN 1525:1999 – Safety of industrial trucks. Driverless trucks and their systems

Within the European Union, the reference standard for AGVs is the EN 1525:1999 "*Safety of industrial trucks. Driverless trucks and their systems*" [4].

This standard is applied to every kind of industrial truck, except for

- Trucks driven by means of mechanical systems (e.g. tracks or rails)
- Trucks operating in areas open to people not aware of the dangers associated with the operation of the trucks themselves

A *driverless truck* is defined as a motorized vehicle, including any trailer, developed for autonomously moving in the environment, for which safety of the operations does not depend on the actions of a human operator. It is worth remarking that remotely operated trucks are not considered driverless trucks.

Requirements on the subsystems of driverless trucks will be hereafter summarized.

The current European standard EN 1525 for Automatic Guided Vehicles is an obsolete document, published in 1999 and obviously based on the state-of-the-art at that time. It is necessary to update the standard in reference to the new technology and changed usage requirements, in particular with regard to the application of laser detection devices.

ISO (International Organization for Standardization) raised the question attempting to find an agreement among states with a solution applicable to all nations in the world. Around 2003 a dedicated ISO working group started to develop a new standard for automated vehicles, classified as ISO/DIS 3691-4 Industrial trucks — Safety requirements and verification — Part 4: Driverless industrial trucks and their systems. The work stopped suddenly in 2006.

In 2013 a new ISO working group recovered the previous analysis with the aim to complete the document and publish the new ISO standard within 3 years.

The following subsections summarize the main contents of current regulations that apply to the PAN-Robots system.

2.2.1 Braking system

The braking system is supposed to be working in the absence of power supply, or in the case of malfunctioning of the speed control or of the guidance system.

Moreover, it is supposed to completely stop the truck within the field of detection of the sensors in charge of detecting people, taking into account the load, the current speed, and all the environmental conditions that might influence the braking space.

The braking system is supposed to guarantee complete stop of the truck with its maximum allowed load, on the maximum slope specified by the truck manufacturer.

2.2.2 Emergency and maintenance commands

Specific commands have to be installed in order to be used in the case of emergency, for maintenance operations, or for other temporary activities.

These commands have to be physically installed on the truck during the operation, and are required to be fail-safe (live-man control).

2.2.3 Battery charging

Protection systems have to be installed to guarantee protection of people from accidental contact with the battery itself and the charging system.

Automatic charging systems have to be developed in such a way that their activation is possible only when the truck is in contact with them. When the truck is removed from the charging system, power connections have to be automatically deactivated.

2.2.4 Load handling

Load handling devices are required to be designed in such a way that the load cannot move from the predefined position under any circumstance, included emergency braking and load transfer.

2.2.5 Stability

Truck stability must be guaranteed in any working position, and during all load handling movements, including emergency braking. Specific stability tests need to be performed if the lifting height exceeds 1.8 m.

2.2.6 Safety devices

If an onboard human operator is allowed, it is necessary to inhibit any automatic function in the presence of the operator. Automatic functions cannot be automatically restored once the operator leaves the truck.

Emergency braking devices need to be installed on each side of the truck, and need to be well visible.

Blinking lights have to be installed on the trucks, when they are moving or are about to move. The allowed path for the pedestrians need be clearly marked in the vicinity of the area where the trucks move. Acoustic signals need to be activated when the trucks move in a direction that is not protected by devices for the detection of people.

People detection devices

Trucks need to be equipped with devices for the detection of people on their path: examples of these devices are bumpers or proximity sensors.

Detection devices need to operate (at least) on all the length of the truck, and in any movement direction. They need to generate a signal that stops the truck by means of the braking system, before the impact happens between the rigid parts of the truck itself and the people.

Detection devices are required to detect the part of the body that is closest to the floor.

Activation of the safety devices must not cause damages to the people.

Detection devices are required to detect a test gauge with diameter equal to 70 mm, and height equal to 400 mm, positioned vertically on the truck's path. When the person goes out of the detection area, automatic behavior can be restored with a minimum delay of 2 seconds.

Speed must be limited to 0.3 m/s in those areas where detection is not possible (loading/unloading positions). However, those areas should be clearly marked as "dangerous areas".

2.3 Sensing device regulation

Current sensing device regulations and standards are defined in IEC 61496 and IEC 60947 series.

IEC 61496 series is used for sensing devices as protection equipment based on detection of body or part of body. Requirements for so called safety laser scanners are defined by combination of part 1 and part 3 of this standard series. Depending on region or country these standards are listed under directives, like European MD 2006/42, or mandatory Chinese GB 19436.3. The laser scanner standard is actual in maintenance and SICK is an expert member of the working group. It is under discussion to add requirements for single beam 1D and 3D devices using time of flight techniques. Further techniques like 3D stereoscopic sensing devices will be described in part IEC 61496-4-x which is already available as committee draft and should be finished during 2015.

Pure proximity switches with defined behaviors are described in IEC 60947-5-3 and IEC 60947-5-2. Their use is limited to safety related object detection but not useful for body or parts of body detection.

2.4 Residual risk

The main danger of an AGV system is due to the movement of the vehicles in the free space, where generally boundaries are not limited with barricades and personnel can walk and operate at the same time. Each AGV vehicle is equipped with protection and warning devices to prevent incidents and collision with obstacles, and to stop in emergency conditions.

Following the standardized risk reduction procedures the operator shall use at first safe design principles before implementing technical measures to reduce the risk. Only as last possibility organizational measures shall be used to reduce the residual risk for persons to an uncritical level.

Even if all technological protective measures are applied, some risks related to autonomous truck systems remain unsolved. These risks are known as *residual risks*, and should always be taken into account when deploying a plant. Residual risks related to an AGV system might be:

- Impact;
- Crushing;
- Cutting;
- Entanglement;
- Squeeze;
- Falling objects;
- Electrocution;
- Fire (with batteries);
- Explosion (with batteries).

Because of the presence of personnel and possible mixed traffic of manual vehicles in the same area, it is necessary to adopt rules and working procedures for employees to prevent risky situations and avoid incidents by organizational measures

3 Identification of PAN-Robots safety concerns

This chapter will describe how the technologies developed within PAN-Robots are related with the safety regulations described in Chapter 2.

A top-level view on the key aspects and key technologies of PAN-Robots as well as their interactions are visualized in the following Figure 1.

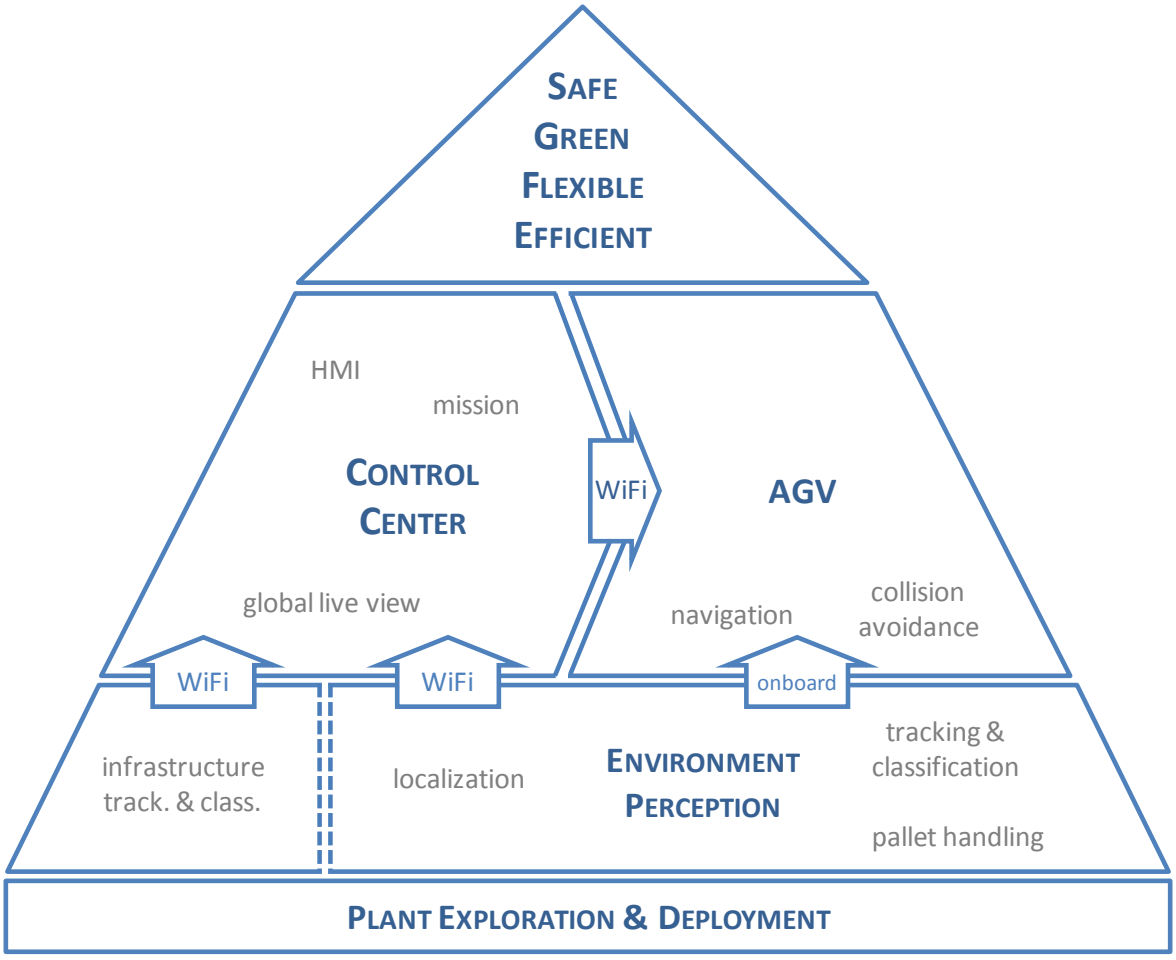

Figure 1: Key technologies of PAN-Robots

3.1 Infrastructure based cooperative environment perception

In order to improve the safety of the PAN-Robots AGV movements, the *infrastructure-based cooperative environment perception system* will be composed of laser scanners placed on the infrastructure for the purpose of monitoring blind spots.

Infrastructure sensors are then required to detect all stationary and moving objects in the monitored blind spot, to classify them, and to track their velocity. Acquired data will then be transmitted to the control center, which will collect them into the global live view.

From the point of view of the safety regulation, the main concern raised by the implementation of these systems in related to the fact that obstacle detection is performed by a device that is not installed on-board the AGV. It is then necessary to certify the data transmission system, as well as

the sensors themselves. A new generation of generic standard covering complex Sensor Systems used for person protection is necessary to fill the gap between existing single device sensing device standards and realistic situations in an industrial plant. In practice there is more than only one driverless truck with assembled sensing devices on it or static protection fields. In PAN-Robots, the infrastructure systems provide a dedicated 'intersection is free' message.

SICK is looking forward to push such a new approach.

3.2 Global live view

The information about the status of the PAN-Robots AGV fleet, as well as data acquired by the cooperative infrastructure sensor systems, will be integrated into the *global live view*. The global live view is a software module that keeps track of all static and dynamic entities that act inside it. Therefore, it collects static entities (the 3D map of the plant, the route map) and dynamic entities (the current position and velocity of the AGVs, the position and velocity of currently identified objects).

Data regarding the current position (and velocity) of static and dynamic objects in the environment are exploited for ensuring a safe behavior of the AGVs.

In fact, information from the global live view is required to enable local path planning (i.e. local deviation from the route map for circumnavigating obstacles): the AGV is allowed to perform local path planning only if the required area is considered free, based on the information contained in the global live view.

Similarly, when approaching an intersection monitored by infrastructure sensors, the AGV is allowed to avoid slowing down if the intersection is considered free, based on the information contained in the global live view. The infrastructure system provides a dedicated 'intersection is free' message.

3.3 On-board multi-sensor environment perception

The *on-board multi-sensor environment perception* system is composed of a set of sensors that, opportunely placed on-board each PAN-Robots AGV, provide the AGV itself with three-dimensional sensing capabilities, used for enhancing perception. In fact, exploiting 3D sensing, it is possible to introduce object recognition capabilities that will allow avoiding collisions with objects which are not connected to the ground. Both stationary and dynamic objects are of interest for the on-board multi-sensor environment perception system.

From the safety regulation perspective, several concerns are raised regarding the on-board multi-sensor environment perception system, as will be detailed hereafter.

3.3.1 Safety vision sensors

Computer vision technologies are increasingly being used for implementing advanced perception and classification systems. Samples of this development are the rear-view cameras and parking assistants used by the automotive industry. They are, however, currently not considered as safety sensors.

One of the reasons why the computer vision technologies have not been considered as safety sensors has been the cost and complexity of the available systems. These are expected to have

minor effect as the technology gets more widely used by car industry. This will also increase reliability of the used systems. In PAN-Robots project camera based stereo vision sensor is used to detect and classify object around the AGV. Environmental conditions like the vibrations and risk of contamination will set a challenge on the designed system. Environmental Definitions as already mentioned in drafts of IEC 61496-4-x standard for stereoscopic sensing devices will be used as guideline to move forward to a safety vision sensor.

3.3.2 3D perception vs. safety

As described in Section 2.2.6, current safety regulation requires the person detection devices installed on-board AGVs to be able to detect the presence of parts of body near the floor. This is effective for detecting humans walking near the AGV itself, since feet and legs of the humans can be detected. However, for detecting hanging obstacles, and hence avoiding collisions, it would be necessary to have three-dimensional object detection sensors. The definitions in pure obstacle detection standards are not satisfying as guideline for safety related obstacle detection. Size, shape, texture and so on must be defined in a reliable way to move forward.

3.3.3 Automatically variable safety areas

In currently developed AGVs, for each safety laser scanner, two safety areas of arbitrary shape within its field of view are defined: a warning area and an emergency area, as sketched in Figure 2. If an object is detected within the larger warning area, the AGV automatically decreases its velocity to shorten the braking distance. If an object enters the smaller emergency area, the AGV initiates an emergency braking in order to avoid a collision with the object.

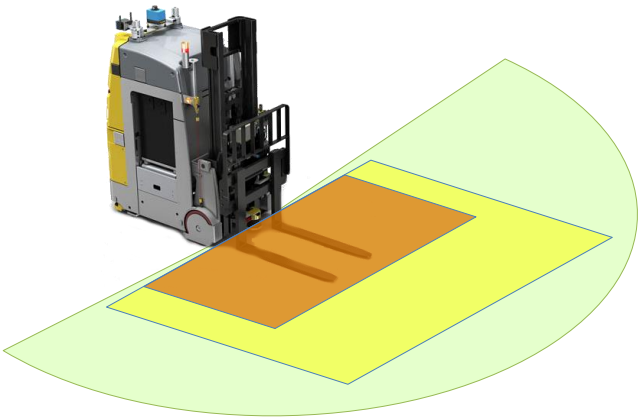

Figure 2: Field of view (green), warning area (yellow) and emergency area (red)

The safety areas are defined manually for each segment of the route map considering the available free space, the number of lanes and the maximum AGV speed of the considered segment.

Automatic definition of the safety areas based on the current AGV speed, as well as on the current position of the AGV itself in the environment, would greatly improve both safety and efficiency of the system.

4 Proposal for safety regulations amendments and new working items

As clearly appears from the previous chapter, current European safety regulation in the field of autonomous vehicles for industrial applications might be heavily improved, considering state-of-the-art technological developments.

A first step towards the improvement of European safety regulation could consist in including contents borrowed from the recently updated ANSI regulation on *Safety Standard for Driverless, Automatic Guided Industrial Vehicles and Automated Functions of Manned Industrial Vehicles* [5].

Existing safety regulation is based only on single sensing devices for person protection in presence of driverless or manned Industrial vehicles. This is not satisfying for realistic, complex industrial plant situation. Pure deterministic approaches for detection capability as defined in IEC 61496 and IEC 60947 series are inappropriate for enhanced safety related functions like object classification.

4.1 ANSI regulation on Safety Standard for Driverless, Automatic Guided Industrial Vehicles and Automated Functions of Manned Industrial Vehicles

This regulation foresees the presence of contactless safety sensors for object detection. These sensors are required to be fail-safe in their operation and mounting. When sensing people (or an object) in the path of the vehicle at a distance no less than the leading edge of the sensing field in the main direction of travel, they shall cause a safety stop of the vehicle prior to contact between the vehicle structure and the obstacle (that could be represented by people or objects).

The ANSI B56.5-2012 includes also some general safety practices for the user, who shall be responsible for all factors affecting safety in operation and maintenance. The most important items involving the user are:

- Environment preparation: warnings, respect of clearances along vehicle path, floor markings, restricted areas identification.
- Training for operators and other user personnel.
- Maintenance for all vehicles and system.

4.2 Amendment proposal from the PAN-Robots consortium

Safety regulations changes referred to current regulations (EN 1525 and ANSI B56.5):

- Update standards with the current technology and state-of-the-art devices, starting from the installation and use of laser detection devices.
- Set minimum levels of safety for all devices and functions that affect vehicle safety (lifting, speed control, manual operations, etc.). These requirements must be feasible and not only theoretical.
- Admit that AGV systems are not exclusive, indeed working areas must be shared with personnel and other manual vehicles: this means that some rules must be mandatory for the user and not only for the manufacturer, so as authorizations for operations and changes. Rules and practices for installation and use must be given to the user too.

- Consider the AGV working area as part of the system, with rules and restrictions of use and changes for the user even after commissioning, in order to maintain and preserve safety, performance and operational conditions set at the end of installation.

4.3 New working item proposal for sensor systems used for person protection

Data collected during the PAN-Robots project will be of high value for the definition of a new generic standard for sensor systems used for person protection. The new standard should fill the missing gaps as defined in Section 3 for

- multi sensors fused warning/emergency areas.
- fusion of different sensing devices to get a multi direction view in a real plant situation – Real 2D/3D.
- safe detection of objects which are no part of body.
- safety related use of raw measurement data to generate information of e.g. moving vectors or speed of object respective parts of persons.
- safety related classification of objects, especially related to how to distinguish safety related objects from surroundings based on probabilistic concepts.

A new working item proposal for an IEC working group will be prepared and pushed by SICK. It is essential that results out of PAN-Robots are available to define requirements for methods and techniques which are tested, verified and practical useful to develop an acceptable standard.

5 Analysis of current technology standards

This chapter briefly analyses the current standards adopted for the development of the components and their combination that define the PAN-Robots system. In particular, the analysis focuses on the standards related to interfaces and communication technologies.

A top-level view on the key aspects and key technologies of PAN-Robots as well as their interactions are visualized in the following figure. Detailed description of the key technologies can be found in D4.1 [7].

As highlighted in Figure 1 on page 7, the control center, the AGVs, and the infrastructure perception systems communicate among each other exploiting wireless technologies. In particular, this communication is exploited to gather information into the control center, where data fusion is performed to create the global live view. Data included in the global live view are then utilized for performing mission assignment and coordination of the fleet of AGVs.

Moreover, each AGV is equipped with a multi-sensor environment perception system: data acquired by this system are used for taking decisions at local level (e.g. for performing collision avoidance or for localization). A wired communication infrastructure is then exploited to link the perception system with the navigation and control ECU of the AGV.

However, it is worth noting that communication infrastructure adopted in AGV systems are generally standard ones. In particular, wireless communication is implemented exploiting standard 802.11b/g/n or 802.11a technologies. Regarding wired communication, standard Ethernet infrastructure (generally available in any industrial plant) is exploited, assuming that is provides at least a 100 Mb/s data rate (i.e. Fast Ethernet).

There are several technology related standards which are related to optical components developed and tested within the project. Optical instrument environmental test methods are described in ISO-9022 standard. Optical distortion measurement which is needed for the stereo vision optics of the environment perception system is specified in ISO-9039.

Already running maintenance of IEC 61496-3 for future 1D, 2D and 3D Time of flight sensing devices and ongoing IEC 61496-4-x for stereoscopic protection devices will give guidelines for reliable detection of environment entities and relevant parts of human body, for single sensing devices.

6 Proposal for technology standards amendments

For the development of the future AGV sensors it would help if the environmental conditions which the AGV sensors have to stand for would be clearly defined. For example the IP rating and vibration and shock requirements would be needed when new sensors are designed.

7 Summary and Conclusions

This document analysed current standards and regulations related to the PAN-Robots system. In particular, the main focus of the document is on safety standards, which are highly relevant when developing moving systems that operate in a shared environment with human operators.

As highlighted in the document, safety regulation might highly benefit from the outcomes of PAN-Robots project. In fact, the experience gathered within PAN-Robots will help in the update of current standards (to make them more compliant with state-of-the-art technology) and in the definition of new ones, to fill current gaps.

From a technological point of view, the application of innovative sensing systems to AGVs highlights the need for the definition of technological standards. Based on the PAN-Robots experience, guidelines for their definition have been (and will be) drafted.

In conclusion, the PAN-Robots project is highly relevant, in terms of contribution to the standardization, both from the safety point of view and from the technological point of view.

8 Acknowledgements

The PAN-Robots research project is part of the 7th Framework Programme, funded by the European Commission. The partners of the consortium thank the European Commission for supporting the work of this project.

List of abbreviations and acronyms

AGV	automated guided vehicle
CAS	Compañia Castellana de Bebidas Gaseosas S.A. (Casbega), Spain
E80	Elettric 80 S.p.A. – Unico Socio, Italy
SICK	SICK AG, Germany
UCLUJ	Technical University of Cluj-Napoca, Romania
UniMORE	University of Modena and Reggio Emilia, Italy
VTT	VTT Technical Research Centre, Finland
ISO	International Organisation for Standardisation

List of figures

References

[1] Directive on machinery 2006/42/EC

[2] Low Voltage Directive 2006/95/CE

[3] Directive 2004/108/CE on Electromagnetic Compatibility

[4] EN 1525:1999 "*Safety of industrial trucks. Driverless trucks and their systems*"

[5] ANSI/ITSDF B56.5-2012 "*Safety Standard for Driverless, Automatic Guided Industrial Vehicles and Automated Functions of Manned Industrial Vehicles*"

[6] PAN-Robots deliverable D3.1 "User needs and Requirements", 2013.

[7] PAN-Robots deliverable D4.1 "Specification and Architecture", 2013.

[8] Directive 1994/9/EC on Equipment for explosive atmospheres, 1994.

[9] Directive 1997/23/CE on Pressure equipment, 1997.