"Employers will ensure the safety and health of their employees in all work-related matters. Do you have full control over the operation of your cobots and the associated risks to your employees in their workplace?"

Technological developments in the field of AI-assisted learning will enable organizations in the field of robotics to make great strides in terms of efficiency. This will mean more cobots in the workplace. In the process, the primary physical barriers that separate man and machine will – eventually – no longer apply to collaborative human-robot systems.

In the light of the rapid development of this technology and of its capabilities, however, companies and organizations must continue to anticipate and to update their working practices if they are to stay one step ahead of potential incidents involving robots and humans. Any designs for the use of cobots in a shared working environment will have to be inherently safe. This is because cobots operate in what is known as a human-cobot-environment system. In this system, cobots and people work as a team in a shared working environment. Each of them has their own tasks and responsibilities, which require mutual coordination and communication.

In a recent report, TNO and the Ministry for Social Affairs and Employment conducted a joint study into risk management factors for occupational safety with regard to Automated Guided Vehicles (AGVs). These factors form a basis for the risks and risk management measures involved in safe human-cobot-environment interactions.

This safety chart is a practical tool for businesspeople, employers and employees. It can help them design safe and healthy workplaces that are suitable for the use of cobots.

The figure below shows various types of AGVs and cobots, together with differences in their applications ((inspired by Michalos et al. (2015) and Schmidtler et al. (2015)). This provides clarification about collaboration and about the relationship with the concepts of co-existential, cooperative and collaborative job performance, in terms of AGVs and cobots.

Table 1: risks per phase of the life cycle

Phase	Risks	Description
Design (source)	Hazardous (autonomous) behaviour	(1) Learning involves a risk that what the AGV has learned cannot be traced. (2) Emergencies involving AGVs lead to different risks, depending on the type of emergency involved. (3) Incorrect operation of the software can cause the AGV to exhibit risky behaviour. Erroneous (unexpected) manoeuvres by AGVs can result in risks to bystanders.
	Human-Robot Interaction	(4) Learning systems take no account of human-robot interaction effects.
Design (collective)	Ergonomics	(5) Lack of clarity about an AGV's status can lead to misinterpretations by users. (6) Limited or incorrect communication by an AGV can undermine its user friendliness, and may limit the user's situational awareness. (7) A non-ergonomic user interface can trigger unsafe behaviour.
	Hazardous substances	(8) The batteries used in cobots contain hazardous acids, to which service engineers can be exposed.
	Hoisting and moving	(9) If an AGV's route changes, this can result in a risk of collision.
	Psychosocial factors	(10) The unexpected introduction of AGVs into the workplace can lead to inappropriate behaviour, including vandalism.
Configuration/Introduction (collective)	Hazardous (autonomous) behaviour	(11) If insufficient requirements have been imposed on implementation, hazards may arise when a machine is commissioned. (12) The main problem with future AGVs with learning capabilities is that advanced Artificial Intelligence (AI) algorithms will no longer be testable.
	Psychosocial factors	(13) If employees are insufficiently involved in the introduction of autonomous systems in the workplace, this can pose psychosocial workload (PSA) risks and undermine their confidence in AGVs.
	Environment	(14) If there are too many hazards in the environment, the risk of information being missed by people or by an AGV increases the risks to employees.
Use (collective)	Hazardous (autonomous) behaviour	(15) Inadequate agreements concerning when programming may be modified and by whom give rise to risks in the programming, which are no longer traceable. This will impact any employees working with the AGV in question. (16) A failure to verify software updates may lead to the unjustified assumption that the AGV is operating in accordance with the new update.
	Hazardous hoisting and moving	(17) Design errors discovered during the operational phase. (18) AGVs can reduce visibility, thus posing a risk of hazardous contact.
	Manual use	(19) Incorrect AGV start-up, in terms of log off/log on and load capacity/capacity/ratio, may pose a transport risk. (20) Unclear operational agreements about the fine tuning of AGVs (manual interventions) can be hazardous in terms of human-robot interactions.
	Environment	(21) If there are too many hazards in the environment, the risk of information being missed by people or by an AGV increases the risks to employees. (22) Risks in the environment due to falling payloads, protruding objects, or obstacles along the route may pose risks to people and to AGVs.
	Maintenance	(23) A lack of clear agreements with – or follow-up by – the supplier with regard to defects in the AGV system increases employee exposure to occupational risks. A timely and adequate response by the supplier in the event of breakdowns in the AGV system will make it possible to avoid any risk of serious incidents. (24) The absence of a key (encryption) plan within the risk management plan poses an undue risk of energy release.
	Psychosocial factors	(25) Work pressure poses risks to employee health and well-being (PSA).
	Accidents involving the emergency response team and the emergency procedure	(26) In the event of incidents and emergencies, appropriate remedial measures should be taken to avoid any risk of serious effects.
	Cognitive ergonomics	(27) If the language used is unclear to operators, this can lead to ambiguity and differences in interpretation.
Use (individual)	Competence	(28) If the employees responsible for maintaining AGVs are incompetent, they may engage in risky behaviour during operation and maintenance. (29) If risks are not continuously monitored and managed, there is a risk that the AGV system will no longer function reliably.
	Hazardous contact during human-robot interactions	(30) There is a risk that, if the AGV displays unpredictable behaviour, people will lose confidence in the system. This, in turn, will cause them to start anticipating unforeseen situations.

Table 2: occupational risk management measures

	Description
Design (source)	(1) Limiting learning capacities. (2) Build emergency procedures into the software. (2) Attune emergencies involving AGVs with Risk Assessment & Evaluation (RI&E) and with the emergency protocol. (3) Put a safety management system in place around the operating system, to safeguard the 'core safety requirements'. (4) When programming learning systems, take the human factor into account, in terms of how this affects the safety of human-robot interactions. (4) Include safety factors such as training, and a knowledge of teams and organizations in simulation programs that incorporate the human factor into the simulation environment.
Design (collective)	(5) Provide details of the significance of error categories (redundancy and advice on debugging). (5, 6) Develop an interface that covers all statuses (including risky ones) and that communicates clearly, in a way that is not open to more than one interpretation. (6) Develop a standardized (and validated) communication protocol for AGV interactions with users, to deliver an optimum user experience. (7) Make people and the environment visible in the AGV's logistic system interface. (7) Integrate innovative, ergonomic, cobot applications with AGV interfaces and vice versa. (Comparisons could be made between different SMART pad interfaces). (8) Install the battery in a separate space from the rest of the system (separation of functions). (9) Protect programmed routes with a security password, to ensure that they cannot be modified by unauthorized users. (10) Combat vandalism by installing a camera on the AGV.
Configuration/Introduction (collective)	(11) Use a three-traffic-light model: Does the product meet the specified procurement standards? Can inspections be visibly verified during commissioning? Has a power test been performed and has a verifiable training course been conducted? (12) Implement the learning procedure in the AGV's testing and development phases. This will provide a relatively controlled means of determining what behaviour the robot learns, how it learns, how it adapts over time, and what impact this has in relation to cooperation with employees. (13) Involve employees in decision making and implementation right from the start, to create support and ownership. (13) Address aspects of distrust (PSA) about incidents in incident analyses. (14) Separate logistic flows by separating logistic areas, for example (manual work versus automated processes) or time zones (e.g. no manual procedures between 09:00 and 13:00, and interfaces between 17:00 and 22:00).
Use (collective) Use (individual)	(15) A 'Management of Change procedure' should be used to set conditions for the process by which software changes are implemented. This makes it possible to trace any changes, and to provide follow-up with regard to their impact. (16) Test the effect of software updates on different types (or versions) of AGVs, to determine the requisite universal output. (17) Supply Chain management – provide feedback on lessons learned and best practices to the designer and vice versa; this can be an internal process or it can be shared with external sector partners, to develop universally safe systems. (18) Application of sensors (including redundant sensors) in the technical design (e.g., 3rd or 4th camera and sensors, an emergency shutdown, or automatic brake). (19) Clear working arrangements regarding correct AGV log off/log on in a specific area. (19) Adjusting equipment in line with the AGV's detection zone (e.g. the forks of a forklift truck). (20) Protocols covering responsibilities for manual use: who is authorized to 'overrule' in given situations (other agreements apply in the event of incidents and emergencies). (21, 22) An environment must have enough space to enable both the AGV and people to avoid obstacles. (21, 22) Orderliness and tidiness procedure, including any situational factors that could be usefully monitored. (23) A rapid response from the engineering department (and from the supplier) to resolve any incidents with (or malfunctions of) the AGV. (23) In the event of a cyber attack, the rest of the system must be made safe or rendered inoperative as soon as possible. (23) Effective follow-up is expedited by the efficient inventory management of perishable items (by the supplier). (24) The cobot can be deactivated using locks (key or codes), which cut off the power (e.g. password policy). (25) The AGV eliminates a rest factor for the employees. The risk of work tempo compulsion could be monitored by the AGV/cobot. The AGV can then provide feedback to the operator. (26) A 'push back' button or 'pull bar', which 'pushes' the AGV back. (26) When it is linked to the emergency reporting system, GPS localization helps First Aiders and emergency response teams to quickly get where they are needed. (27) Program (or reprogram) the AGV's language interface to suit the user. This will help make the voice picking system understandable to users, helping operators to interpret and control the AGV.
Use (individual)	(28) Personal certification of competences: senior secondary vocational education and training (VET) professional and intellectual ability; Experience with MS Outlook; ability to understand and resolve fault codes; ability to operate 2D/3D navigation programs; interest in engineering (AGV intelligence, brake, steering, engine); risks associated with large AGVs and mobile platforms. Staff working the night shift must follow the same training courses as those on the day shift. (29) The appointment of a fleet operator (for AGVs) responsible for the overall management and incident management of the AGV fleet. (30) In the interactive design, program on the basis of human perceptions. The goal is to ensure that AGVs remain as predictable as possible. (30) Safety factors should be included in simulation programs, such as training, a knowledge of teams and organizations, deep learning, and Virtual Reality (VR). In this way, the human factor is introduced into the simulation environment. (30) Use instructional video clips to make employees aware of the risks of human-robot interaction.