Design methods of safety for facilities considering productivity in collaborative workspace

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ABSTRACT

In Japan, labor shortages are accelerating due to the decline in the working population. For this reason, collaborative robots and Autonomous Mobile Robot (AMR), which allow for collaborative operations with humans, are increasingly used to promote the automation of human work in the manufacturing field. So the current approach to the safety of machinery is not enough for facilities with collaborative workspaces, and new safety approaches are required.
According to the current safety approach, guards are used to isolate the hazard from the operator, to prevent the operator from approaching the hazard, or, when a worker approaches a hazard, safeguards are used to stop the hazard. In facility utilization, it is not possible to completely isolate the worker from the hazard in a collaborative workspace, so shutting down the hazard becomes the primary protective measure.
However, if the task requires repeated safety function shutdowns, it is challenging for users to accept this type of facility, even if safety can be guaranteed, as it can lead to productivity issues. Therefore, protective measures for facilities with collaborative workspaces should be designed with productivity in mind. As an integrator, we have been implementing the validation of protective measures with consideration of productivity and promoting the development of work environments based on risk communication with users. Based on this experience, we introduce the concept of safety measures that take into account.

1 INTRODUCTION

The shortage of labour is expected to accelerate due to the decrease in the working population in Japan. Numerous analogy operations that depend on manual labour are still present at manufacturing sites. Such work places a heavy burden on workers. Extending the working hours of employees due to labour shortages will increase physical strain, fatigue, and health and safety risks. For this reason, human task is being replaced by collaborative robots and AMR. When simply replacing human tasks with collaborative robots or AMR, the placement and operating space are restricted because they are introduced into the human work area. Therefore, it is necessary to determine whether the target tasks can be achieved with collaborative robots and AMRs, and if needed, to review the work process.
In addition, protective measures should be designed to ensure safety, considering the operators' flow line, relationship with surrounding equipment, and the potential for other operators to approach the work area. If physical isolation of humans from hazards is not possible, implementing inherently safe design measures and safeguarding to stop the hazard are the primary measures.

***Figure 1**. Assembling work by the operators.*

2 PROTECTIVE MEASURES IN COLLABORATIVE WORKSPACE

In collaborative workspaces where operators and machines share the work area, it is not possible to completely isolate the hazards from the operator. Additionally, it is assumed that operators will be working near the hazard, so the basic consideration for protection measures is to not injure the operator if contacting the hazard, or to "avoid" the hazardous source before contacting with it, and if not avoidable, to "stop" the hazard.

2.1 3-step Method (Protective measure) according to ISO12100 (2010) *) [1]

*) ISO12100(2010) Safety of machinery - General principles for design - Risk assessment and risk reduction

Typical measures at each step of the 3-step method in the collaborative workspace are shown in Table 1.

***Table 1**. Typical protection measures in collaborative workspaces (ISO 12100:2010)*

3-step method	Measure	applicable clause in ISO12100	Example
STEP1	Inherently safe design measures	6.2.2 Consideration of geometrical factors and physical aspects	Direct visibility of the working areas and hazard zones
		6.2.8 Observing ergonomic principles	Remove pinched points between devices
		6.2.11 Applying inherently safe design measures to control systems	Clearance to prevent crushing by pinching
		6.2.12 Minimizing probability of failure of safety functions	Remove sharp edges
		6.2.13 Limiting exposure to hazards through reliability of equipment	Reduced speed and force
		6.2.14 Limiting exposure to hazards through mechanization or automation of loading (feeding)/unloading (removal) operations	Ensures visibility during work
			Reduce frequency of tasks in collaborative workspaces
			Restricted operating area
STEP2	Safeguarding	6.3.2.5 Selection and implementation of sensitive protective equipment	Stop by detecting approaching humans
		6.3.2.7 Other protective devices	Stop by detecting human contact
			Limit functions for speed and force
			Detection function of stop condition
			Limit function of movement
	complementary protective measures	6.3.5.2 Components and elements to achieve emergency stop function	installation of emergency stop devices
		6.3.5.3 Measures for the escape and rescue of trapped persons	Structures to release from a pinched situation.
		6.3.5.6 Measures for safe access to machinery	Layout to allow access with visibility to the collaborative workspace
STEP3	iInformation for use	6.4.2 Location and nature of information for use	Indications of collaborative workspace
		6.4.3 Signals and warning devices	Operation status indication and warning alarms by visual and audible signals
		6.4.5 Accompanying documents	Warning sign
			Safe operating procedures
			Wearing protective equipment such as protective caps, protective glasses, and protective shoes

Because the complete guard is not installed in the collaborative workspace, the measures that can be applied in safeguarding (STEP2) are restricted. As a result, the residual risk is increased.

2.2 Residual Risk

The largest residual risk is "contact with hazard" because of impossibility of physical separation between people and hazardous sources in a collaborative workspace. This cannot be solved by facility design so it shall be dealt with by additional protection measures by user.
The main protective measures are "information for use" in the 3-step method of ISO 12100 include warning signs, work procedures including the wearing of protective equipment, and worker restrictions. By applying protective measures based on the 3-step method in this way, facilities can be operated safely.
However, productivity is not considered when considering protective measures. Many risks are solved by physically isolating people from the source of the hazard. In facilities with collaborative workspaces, the relationship between safety and productivity cannot be ignored because complete physical isolation is not possible.

2.3 Considerations of Productivity in International Standards for Safety

ISO 12100 (2010) [1] describes the following with a view to preventing the defeating of protective measures.

a) the protective measure slows down production or interferes with another activity or preference of the user, (from clause 5.5.3.6)

ISO 11161 (2007) [2] describes the considerations of productivity in the functionality of the IMS for integrators as follows.

“The specification of the functionality of the IMS shall include, but not be limited to:
a) production rates that consider work tasks and IMS efficiency(ies);” (from clause 5.1.2)

The determination of the task zones shall consider the continued operation of the IMS described as follows.

“The parts of the IMS which, when stopped, will prevent the rest of the IMS from operating and will therefore have an immediate impact on production levels;” (from clause 7.2)

As described above, the international standard only considers the safety function as not interfering with the productivity of the facility for the prevention of the defeating of safety functions and the avoidance of hazardous events.

2.4 Issues of Protective Measures in Collaborative Workspaces

Generally, safety and production risk assessments for facilities are evaluated independently of each other. Therefore, the impact of production risks of equipment stoppage increases, and depending on the severity of the risk, the equipment becomes unusable because the specifications of the equipment cannot be satisfied. Therefore, risks related to productivity caused by protection measures are avoided in the design of facilities based on the only integrator's experience for now.
However, in facilities with collaborative workspaces, safety is mainly guaranteed by " stop by safety function". Therefore, the impact of production risks of equipment stoppage increases, and depending on the severity of the risk, the equipment becomes unusable because the specifications of the equipment cannot be satisfied in operation. These are related to facility operation, so the facility cannot be operated unless the user agrees to the condition finally. So, it is not sufficient to simply give users information and measures against residual risks. It is necessary for the integrator to conduct interactive risk communication with the user in the design phase to select the optimal measures. However, the 3-step method does not currently consider the productivity of the facility in the validation of the protection measures. For this reason, it is necessary to develop an appropriate process flow for protection measure implementation considering productivity.

3 PROTECTIVE MEASURES COSIDERING PRODUCTIVITY

The new process flow of the three-step method that we, as integrators, have been studying is shown in *figure 2*. This flow is specialized for facilities with collaborative workspaces.
The two areas in *1) and *2) in the yellow dashed line in the figure are the added process flow.

3.1 Purpose of the Added Process Flows

The purpose of the new process flow is to add a validation of productivity to the protective measure "safeguarding" to include consideration for productivity risk, and to clarify the responsibility of the implementation of the measures by the user by making the measures for residual risks independent from the "information for use" and by clarifying the risk reduction to be achieved by the human behaviour and work procedure.

Area *1)
Added "downtime by safety function" and "possibility of avoiding stop by safety function" to step 2 " Safeguarding" and added a condition requiring the integrator to choose safeguard considering productivity.
The purpose of this is to change the process flow of stop by the safety function to not only validation from the safety aspect but also to add validation from the productive aspect, and if not acceptable from the productive aspect, to start reviewing from the inherently safe design measures.

Area *2)
Between step2 "Safeguarding" and step3 "Information for use", a new flow to determine whether risk reduction can be achieved by limiting human behaviour was added and selection condition was added to allow the user to address the possibility of avoiding "hazardous events" or "stoppages due to safety functions" in the operational procedures.
The purpose of this is to be able to evaluate the contribution to risk reduction by leading human behaviour via labelling and work rule, independently from "Information for use". As a criterion for this evaluation, activated the condition that the operation of the occupational health and safety management system made operators voluntarily act in accordance with the work procedure. Alternatively, it is also possible to determine by the level of culture of prevention instead of occupational health and safety management system.

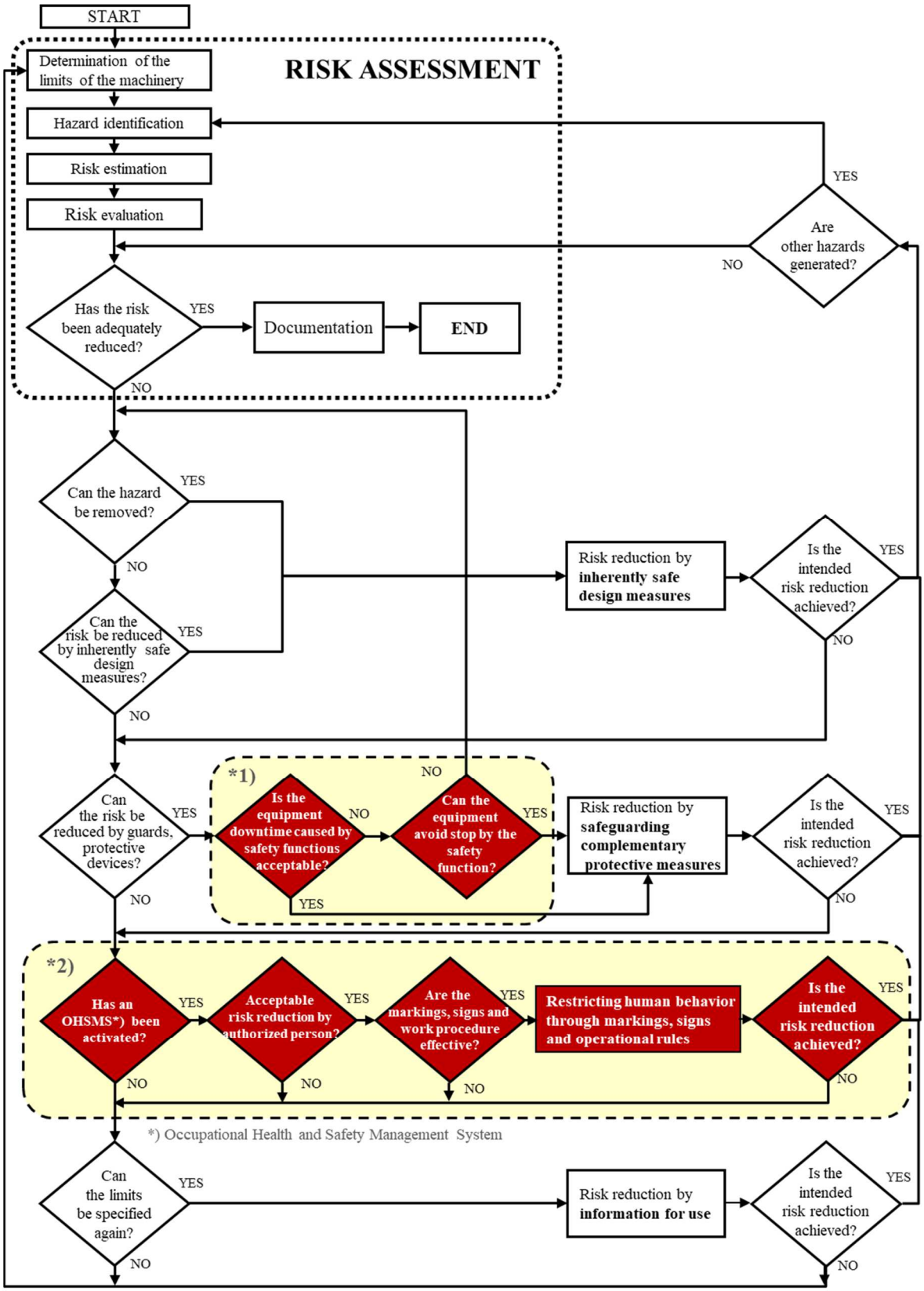

Figure 2. *New schematic representation of risk reduction process including iterative three-step method.*

3.2 Evaluation Index

It is necessary to provide an Evaluation Index for each added flow items to determine YES / NO for each. The following is the example of the evaluation indexes.

***Table 2**. Typical protection measure*

item	evaluation index
Is the equipment downtime caused by safety functions acceptable?	The Effect on Operating Rates of Facilities Number of stops by safety function Frequency of human access to equipment Restart time from stop by safety function
Can the equipment avoid stop by the safety function?	Warning of hazardous situations by indicator lamps and buzzers Warning of hazard by indicator and buzzers installation of hazard avoidance systems

***Table 3**. Typical protection measure*

item	evaluation index
Has an OHSMS*) been activated?	ISO 45001 certification Level of Culture of prevention
Acceptable risk reduction by limiting people?	Decision by user
Are the markings, signs and work procedure effective?	Measuring Effectiveness by Human Behavior Analysis [3]

This evaluation is a risk assessment of the productive aspect, so considering basically only within the scope of normal operations.

3.3 Risk Communication

The determinations of YES/NO for the added processing flow cannot be decided only by the integrator. Information on the user's operation and the installation environment of the facility is necessary, and judgments shall be determined through "risk communication" between the integrator and the user based on this information. Validation of protective measures based on machine safety is used, but for facilities with collaborative workspaces, the equipment operation shall be considered, and it is necessary to validate the productivities. In addition, facilities are close to hazardous sources, so it is necessary to evaluate their usability and stress-free operation, and the effects of anxiety caused by stress from hazardous situations. Risk communication between the integrator and the user is very important to achieve the above.

4 EXAMPLE EVALUATION OF PROTECTIVE MEASURES FOR AMR SYSTEM

In the case of operating AMR in a collaborative workspace with operators, physical isolation from operators is not possible. To avoid collisions with operators, the safety laser scanner as a safety function detects operators in the travel direction and stops AMR to ensure safety.[4]
Figure 4 shows the evaluation of this safety function according to the additional processing flow in *1) of Figure 2. The evaluation details are shown below.

*1) Is the equipment downtime caused by safety functions acceptable? [NO]
AMR stop time affects the operating rate because of frequent operator crossing of the operating zone during work.

*1) Can the equipment avoid stop by the safety function? [YES]
Because of the following reasons
- Installation of an operator evacuation zone around the travel path makes it possible for operators to quickly evacuate, avoid AMR stop by human detection function, and immediately restart AMR after stop.
- AMR's obstacle avoidance function enables running by avoiding operator.

However, the response to the productivity risk is not enough, because operator frequently cross the operating zone, so proceed next to *2).

*2) Has an occupational health and safety management system been activated? [YES]
Because Factory certified according to ISO45001.

*2) Acceptable risk reduction by limiting people? [YES]

The Occupational Health and Safety Management System is activated, and the operator has a high conscious of Occupational Health and Safety.

*2) Are the markings, signs, and work procedure effective? [YES]
Because walkways are clearly marked and separated from operating zone, and pedestrian crossings are set up on the operating zone to ensure reasonable operation.

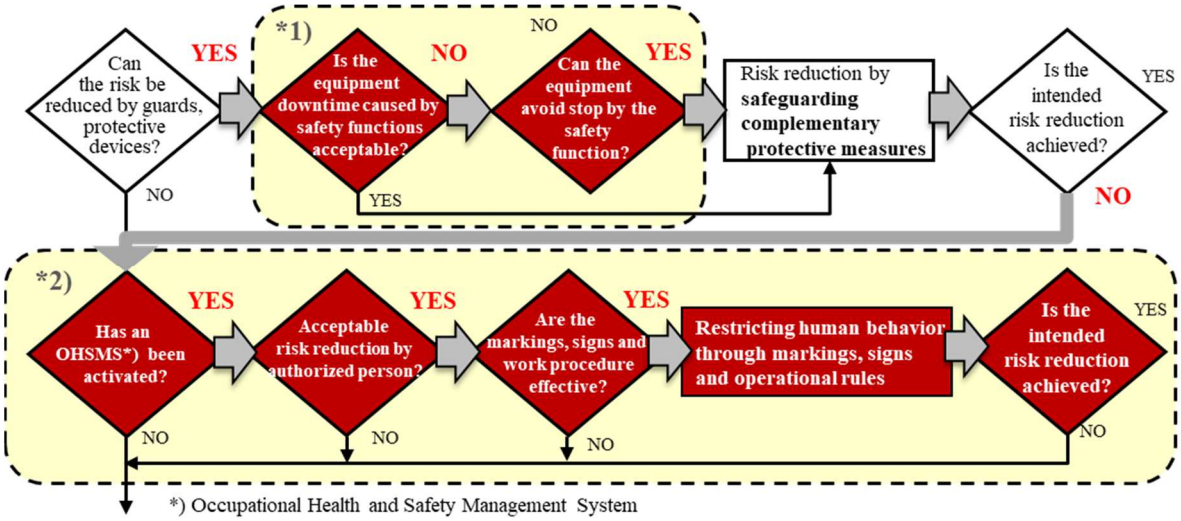

Figure 3. *Example of applying new schematic representation of risk reduction process.*

For effective use of AMR in a collaborative workspace, the AMR stop by operator detection as a safety function shall be installed at first, and then integrator and user shall design the facility layout separating the operator's flow line and AMR travel paths to avoid collisions between the operator and AMR and AMR stop by operator detection.

5 CONCLUSION AND FUTURE PROSPECTS

Safety is essential not only for facilities with collaborative workspaces between man and machine, but for all facilities. In many cases, a risk assessment of the facility is carried out and protective measures are applied to unacceptable risks for making the risks acceptable. However, if the protective measures are mainly " stop" without considering the productive aspect of the facility, problems are likely to occur in the productive aspect of the facility, such as the operation rate, when the user starts using the facility.
To solve this issue, we developed a new process to embed productivity assessments into the selection of protection measures and to design facilities for both safety and productivity. Risk communication between the integrator and the user is crucial for this process to be effective. In addition, risk communication requires the integrator and user to agree on residual risks and countermeasures.
Such risk communication shall be effectively integrated into the design process. In addition, we will continue to study the effectiveness of behavior analysis in measuring the effects of actions to avoid approaching hazards and to prevent stop by safety functions, which have not been clearly evaluated until now.

6 REFERENCES

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