TUTORIAL: How to set up a radar system for end-of-line loading and unloading bays

Safety Function: Restart Prevention

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1. Introduction

The purpose of this document is to describe how to install safety radars belonging to **SRE 200 series** in order to detect the presence of operators inside end-of-line loading or unloading bays, in combination with a safety light curtain (AOPD) for detecting the access into the dangerous area. The use of the radar technology for the Restart Prevention safety function should allow the automatic restart without the necessity of getting off the loading machinery, e.g. a forklift, to perform a manual restart.

A generic example of a bay area is shown in the following picture. More than one layout will be analyzed.

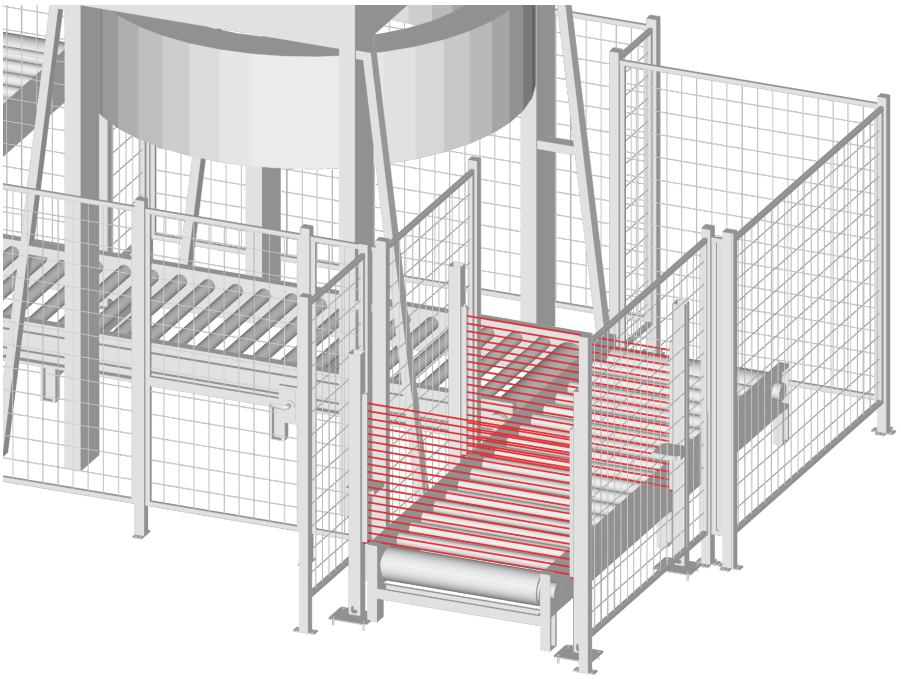


Figure 1. The image shows an example of an end-of-line cell.

2. General principles

2.1 Radar concept and model-type

The first step in providing a solution is to define the number and the type of sensors needed to fulfill the requirements and properly protect the dangerous area. In order to achieve this goal, it is necessary to understand how the radar technology works and how the detection field can be shaped for each model-type.

The sensor is an FMCW (Frequency Modulated Continuous Wave) radar device based on a proprietary detection algorithm. It is a multi-target sensor that sends pulses and receives information, analyzing the reflection of the nearest moving target that it encounters within each detection field.

The sensor can detect the current distance and the angle of each moving target and report the nearest one for each configured detection field.

Each sensor has its own fieldset, which corresponds to the structure of the field of view.

In the case of model-type S201A (Figure 2), the detection field is a symmetric 3D shape similar to a cone, as shown in the image below. The central red line represents the plane of symmetry between the left and right sides of the field of view.

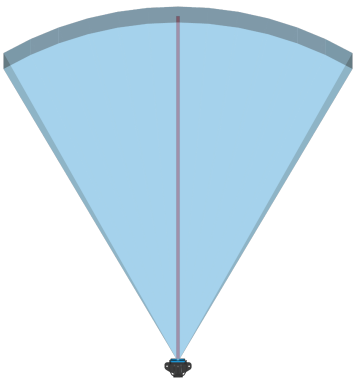


Figure 2. The image shows the model-type S201A with a symmetric 3D shape.

On the contrary, an S201A-W sensor has a more advanced field of view. Indeed, its detection fields can be set either with a classic shape (Figure 3) or a corridor one (Figure 4). Moreover, both shapes can be configured even asymmetrically.

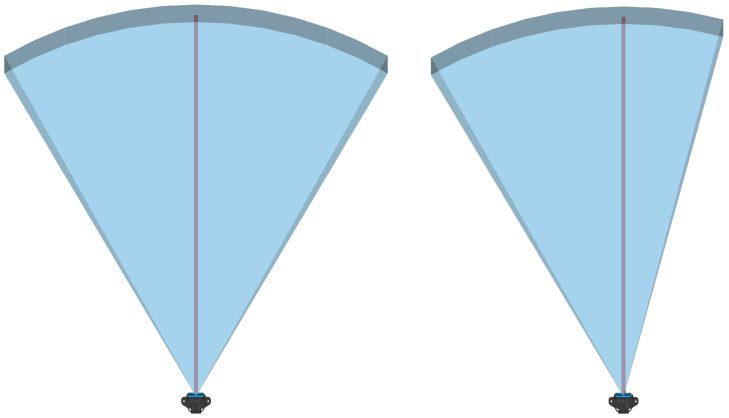


Figure 3. The image shows the model-type S201A-W with a classic field of view: on the left the symmetric cone, on the right the asymmetric cone.

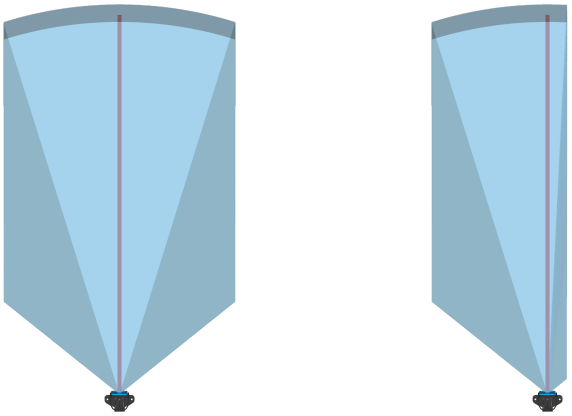


Figure 4. The image shows the model-type S201A-W with a corridor field of view: on the left symmetric corridor, on the right asymmetric corridor.

Finally, the following images show the field of view comparison between an S201A-W (Figure 5) and an S203A-W (Figure 6). As can be seen the main difference is the vertical angular coverage: 20° for S201A-W and 12° for S203A-W.

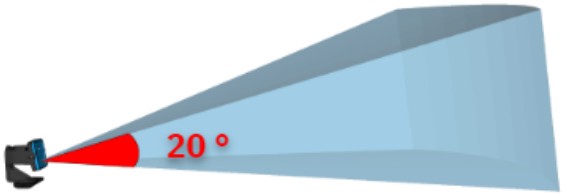


Figure 5. The image shows the vertical angular coverage of 20° of model-type S201A and S201A-W.

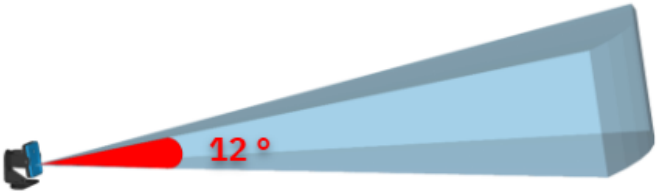


Figure 6. The image shows the vertical angular coverage of 12° of model-type S203A-W.

Summing up, it is possible to affirm that:

- The radar is a motion detection sensor with a volumetric field of view. Therefore any moving object or moving part of a machinery must be kept out of the detection fields.
- The detection distance and the horizontal angular coverage can be adjusted using the configuration tool Inxpect Safety.
- The vertical angular coverage is fixed and depends on the radar model-type.

Overall, there are no formulas to standardize either the number of necessary sensors or their positioning. The goal is to cover the whole area, without leaving any blind spots in which the operator could stay without being detected. Raised positions (like on top of a conveyor) or between pallets must be covered by the sensors whenever they are considered by the risk assessment.

Furthermore, it is good practice to prevent possible reflections of the radar signal which could lead to monitoring unwanted areas outside of the cell. This is the case when the detection field of a radar is set to a long distance and nearby the sensor (in front of it or even at a generic angle within the configured angular coverage of the detection field) a static object is present.

The reflections affect the system anytime a detection field is configured with a detection distance greater than the distance to the reflecting object. Indeed, the reflection itself could scatter the signal behind the sensor outside the area that should be covered.

In the event of sensors installed in a high position looking downward, the height above the ground and the inclination are also important to avoid detecting moving objects outside the monitored area.

Finally, in case of a bay with more than one pallet it is important to take into account the possibility to have an operator between two loading units. In that case it could be necessary to have sensors from the top since there could be blind spots using just bottom sensors.

2.2 Muting function

The muting function is an additional safety-related function that inhibits the sensing capability of the sensor on which it is activated. It can be activated for a specific sensor or for a group of sensors. This results in keeping the ON-state of the OSSD or the safety Fieldbus even when moving targets are in the field of view of sensors.

When the muting function is enabled, its effective activation on one or more sensors occurs only as soon as the conditions permit. Specifically, when all the detection fields involved are free and the restart timeout has expired for all of them. In addition, there must be no other diagnostic errors or fault signals for those sensors (for more details see the technical documentation).

In the following, some insights into this function are discussed.

***Problem**: without using the Muting function, as soon as the components inside the palletizing cell move, the sensors are going to trip an alarm: as a result the system will stop due to an incorrect setting.*

In fact, the system should stop only when the barrier is intercepted by an operator or a forklift and the operator is moving inside the cell, but not during the normal operation within the cell.

To solve this problem it is necessary to use a signal that activates and deactivates the muting of a certain group of sensors.

Muting deactivation:

As soon as a light curtain is interrupted, the sensors must exit from muting.

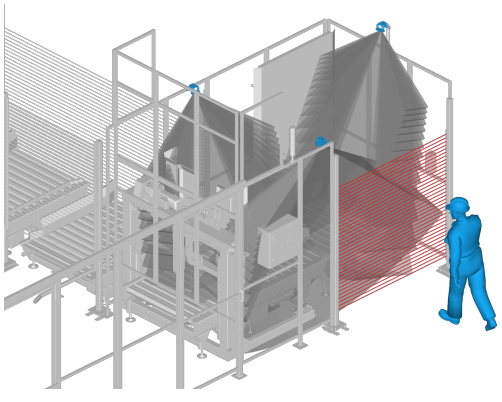


***Figure 7.** Cell during normal operation. Radar sensors are muted.*

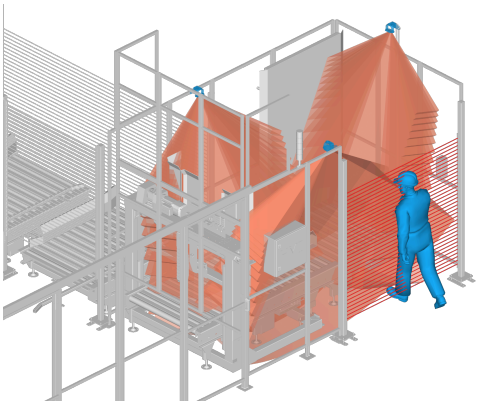


***Figure 8.** Operator invades the light curtain. Radar sensors exit from muting and start monitoring the area.*

Muting activation:

In order to re-activate the muting, both of the following conditions must be verified at the same time:
1- The light curtains are free from obstacles and are not intercepted.
2- All the detection fields configured for all the radars in Restart Prevention mode are free and the restart timeout has expired for all of them.

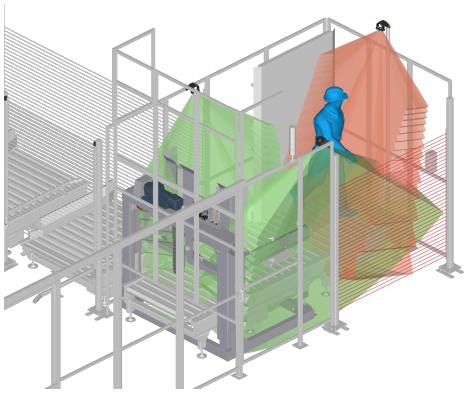


Figure 9. *One sensor is still detecting the operator. The cell cannot be restarted.*

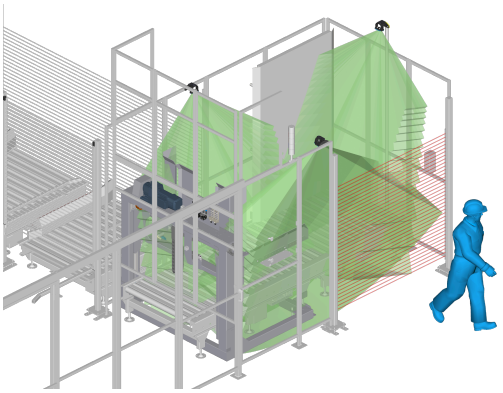


Figure 10. *All the sensors are free and the restart timeout has expired for all of them, the light curtain is not intercepted.*
The cell can be manually restarted or it can automatically restart the process.

Warning: *adopting a wrong logic in muting re-activation could lead to dangerous situations and compromise the safety of the area.*

3. General working logic

While the specific arrangement and quantity of sensors vary across different scenarios, the underlying logic and the ultimate goal remain consistent: to automatically restart the cell once it has been confirmed that the dangerous area is unoccupied by people.

As previously detailed, a certain number of light curtains monitor the access to the area, while the radar technology is employed in conjunction with them to ensure that the dangerous area is clear of personnel or moving forklifts/AGVs thanks to its volumetric field of view.

During the working cycle, the light curtains form a protective barrier. The radar sensors, on the other hand, remain muted. If the barrier is interrupted by an operator, a forklift, or any other object, the system immediately switches to a safe mode. The radar sensors are then activated to continuously monitor the area in Restart Prevention mode, ensuring that it is completely clear before allowing any automated processes to restart.

The Restart Prevention function persists as long as motion is detected within the detection zone. In this safety mode, the sensor can detect micro-movements as small as a few millimeters, including breathing patterns or movements necessary for maintaining balance while standing or crouching.

Whenever the system is configured to allow the automatic restart of the machinery, the following conditions must be verified at the same time in order to certify that the area is free:

1- The light curtains are free from obstacles and are not intercepted.

2- All the detection fields configured for all the radars in Restart Prevention mode are free and the restart timeout has expired for all of them.

When both of the previous points are verified at the same time, the radar sensors can switch back to a muted condition and the area can be considered free.

4. Example cases

The following paragraphs describe multiple use cases with different layouts, along with examples of sensor placement to enable the automatic restart of the machinery through **Restart Prevention** safety function.

4.1 Installation with radar at conveyor height

In this section, the solution with the radar sensors installed at the corners nearby the conveyor is presented. This is a typical installation when there are few centimeters (20-30 cm) between conveyor and physical or optical barriers and there is a single pallet moved by the conveyor belt.

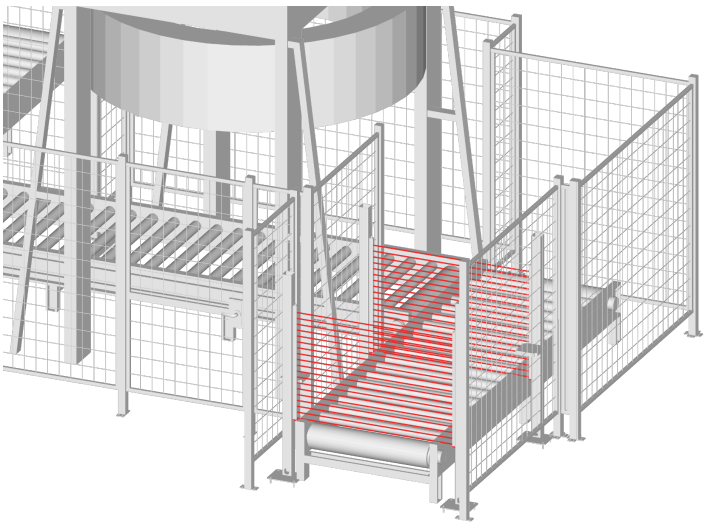


Figure 11. Layout of an end-of-line cell.

Sensors are muted during load transport operations and are activated after detecting access to the dangerous area.

Below it is possible to see a layout example of the described case.

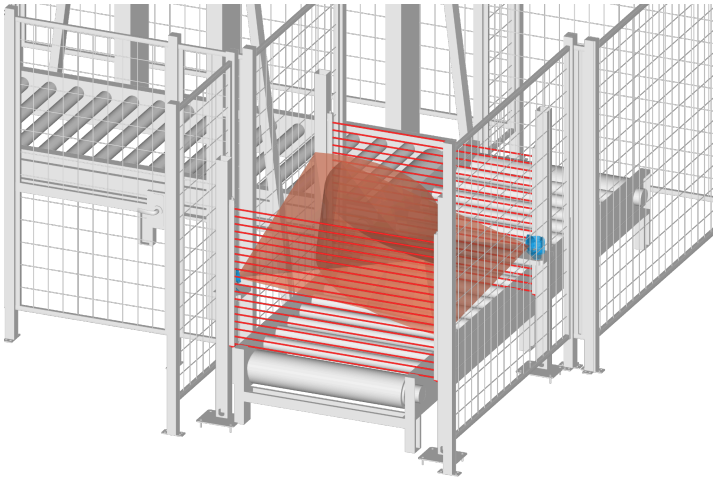


Figure 12. Layout of an end-of-line cell with two sensors installed.

As can be seen, the two sensors (model S201A-W) are installed in opposite corners of the cell with a PAN rotation of 45° and an inclination (TILT angle) of 10° upwards.

Typically the sensors are placed 25 cm higher than the conveyor. This height allows to detect the operator walking on top of it.

4.2 Installation with radar in a high position looking downward

The second case study refers to a similar layout but a different sensors placement. The proposed solution must also be capable of automating the restart of the machinery inside a palletizing cell following the loading of the pallet using a forklift. The radar system should monitor the zone for operator clearance before autonomously restarting the cell.

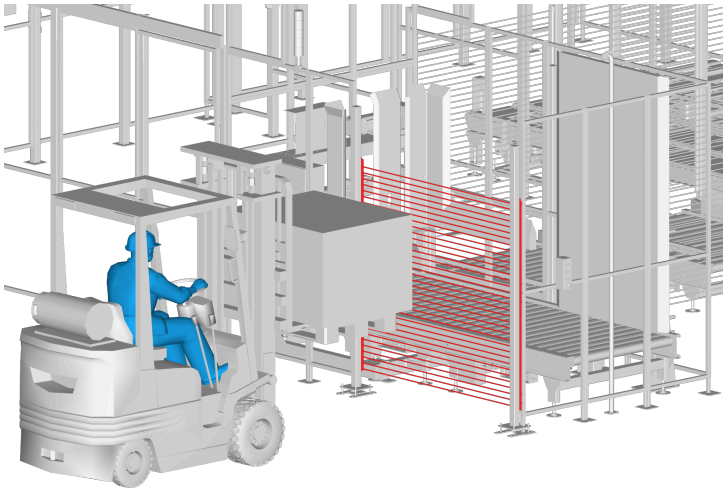


Figure 13. Layout 3D of a loading cell with a forklift entering the area.

The solution employs three radars to detect the presence of an operator within the bay (Figure 14). Unlike the first scenario, the sensors are installed overhead to avoid obstructing the forklift access and to minimize external reflections.

The devices can be mounted on the fences bordering the cell or on purpose-built structures. To this end, it should be verified that the structures on which the sensors are installed are free of vibration, in order to avoid any additional delay in the restart time.

Radar sensors are muted during normal operations within the cell. When the optical barrier at the entrance is interrupted, for example for loading pallets, the movements within the cell stop and the sensors begin monitoring the area (Figure 15). After a minimum timeout of 4 s during which the radars detect no micro-movements, the area is considered safe and the consent is given for restart.

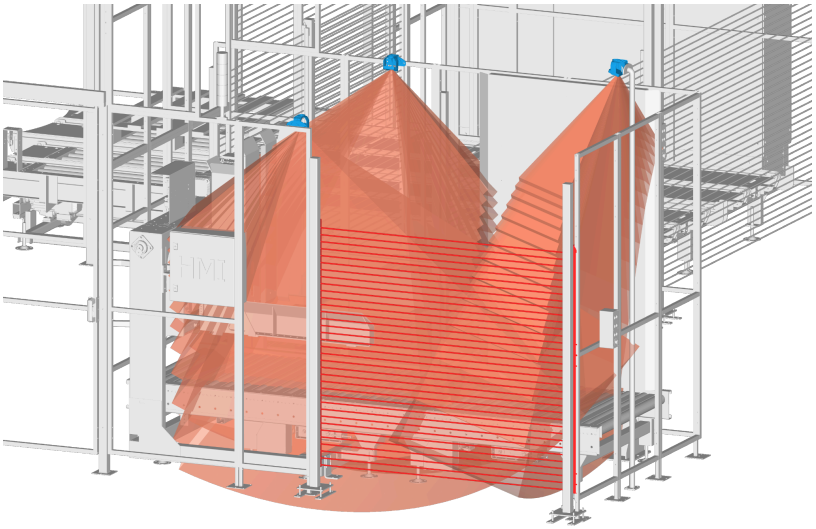


Figure 14. The image shows the sensor positioning in the loading cell: three sensors are used.

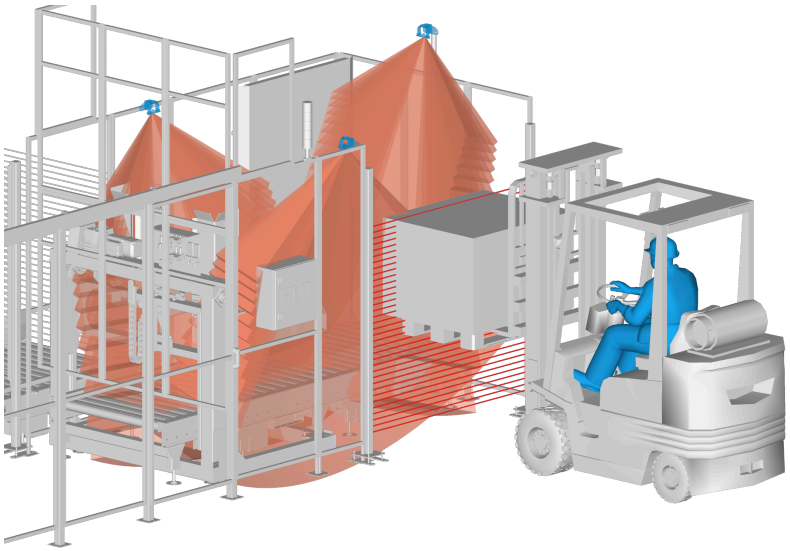


Figure 15. Forklift crossing the light curtain of the cell activating the radar safety system.

4.3 Mixed case with either bottom and top radar

Finally, a mixed case is presented. The solution described involves the use of 5 radar sensors for the detection of operators in the area. The sensors are installed in the corners of the area. In this example the bay is composed of two parallel conveyors and a person could stand in the space between two pallets. It should be noted that each object on top of the conveyors could create one or more "dead zones" where an operator might be undetected. This aspect must be considered in radar placement.

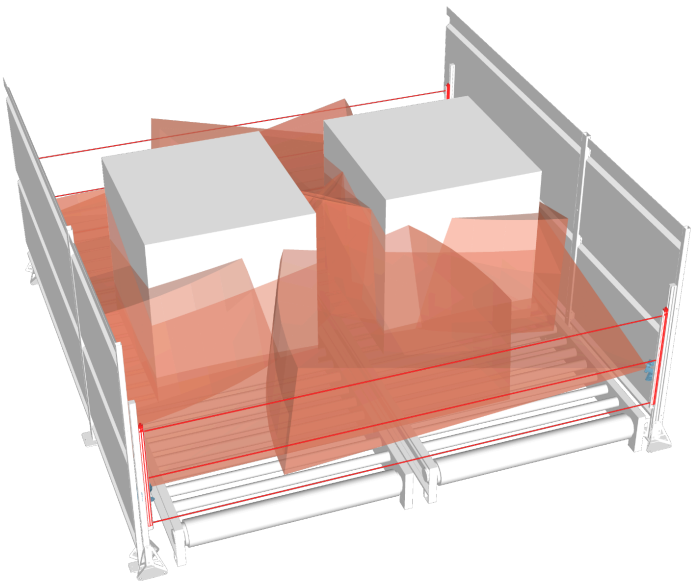


Figure 16. Layout of a cell with two parallel conveyors.

In the event that the scenario depicted in the previous picture occurs, it becomes necessary to add a radar sensor, strategically positioned to ensure complete coverage of the area. The radar in question is mounted on an overhead structure, similar to the one illustrated in Figure 18, and is tasked with monitoring the gap between the two pallets.

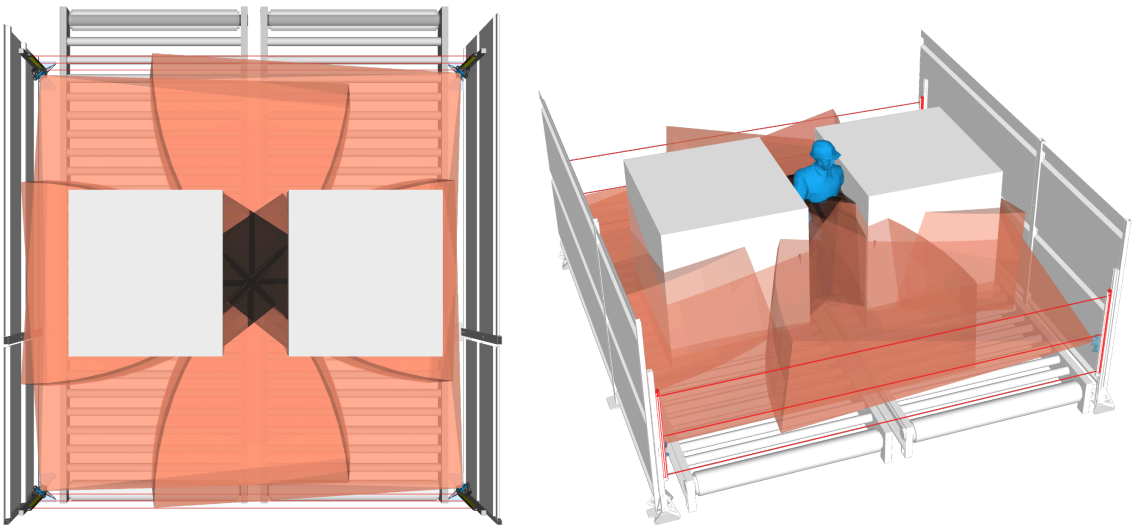


Figure 17. Layout of a cell with two parallel conveyors. On the left a top view, on the right a perspective one. On both can be noted the presence of a possible dead zone using only four radars in the corners of the cell.

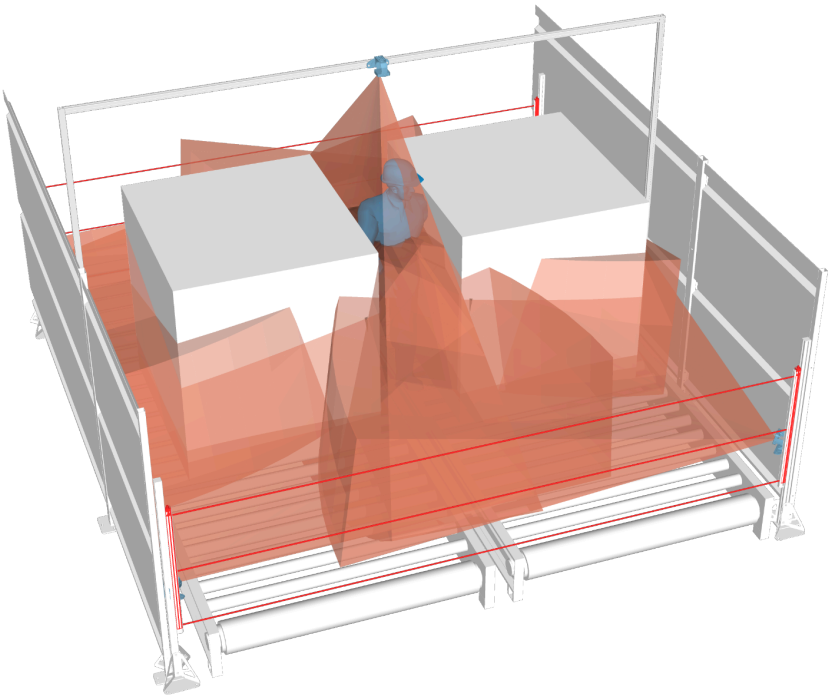


Figure 18. The image shows the four bottom radars at the corners and the fifth radar mounted on an overhead structure for monitoring the gap between the two pallets.

It is essential that the structure is vibration-free, since vibrations could keep the system in an ongoing alarm condition or add delays in the restart process.

5. Software settings

To configure the system, the Inxpect Safety software is needed. Make sure that the software version is compatible with the firmware of the control unit. Please check the file "*System Release Changelog*" downloadable from the Inxpect website under *Support > Inxpect Tools (tools.inxpect.com)*.

As an alternative (recommended), download the latest version of the Inxpect Safety application directly from the Inxpect Tools web page. The latest version of the software is compatible even with older control unit firmware. This eliminates the need to check for specific version compatibility.

In the following chapters, the installation of the radar sensors in a high position looking downward is going to be analyzed.

5.1 Layout and safety working modes

For an optimal system configuration, import a 2D layout into the '*Configuration*' page. This will allow to visually assess the position of the sensors and to validate the solution more easily. Please remember to adjust the scale of the layout to match the real-world dimensions using the scaling functions within the software.

The image below shows the top view of the cell and sensor number 1 positioned and configured with 1 detection field (red = D.F. #1). The advanced detection field shape is set to corridor mode with an asymmetric field.

Detection field #1 is set to "*Access detection and restart prevention*" safety working mode. This means that, when an operator enters the red zone, the safety function switches from Access Detection to Restart Prevention, allowing the sensor to detect even micro-movements, such as breathing patterns or micro-oscillation of the human body.

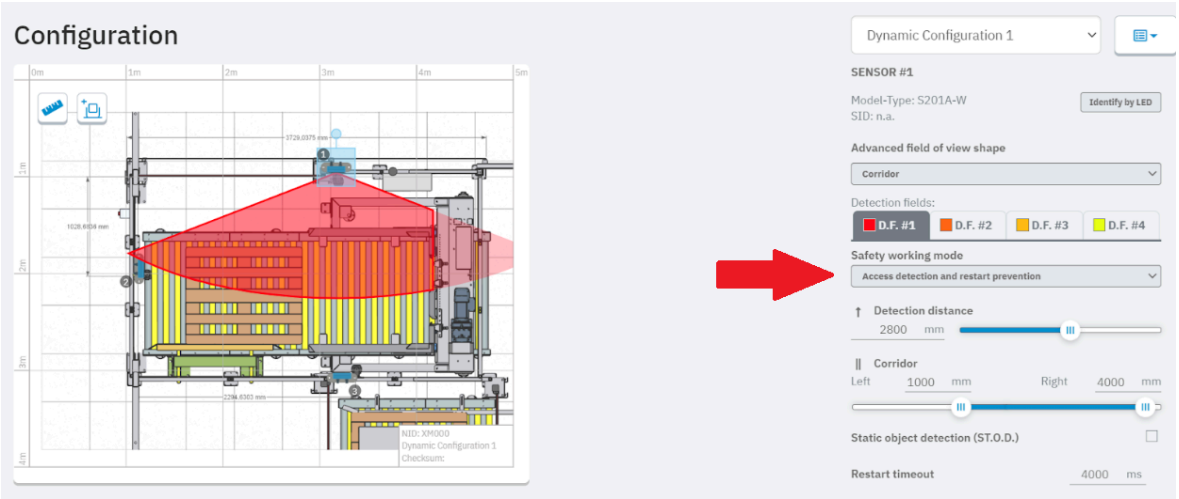


Figure 19. Inxpect Safety: Configuration page.

In order to add the other sensors for the Restart Prevention, please click with the mouse on the button , then place the sensors on the defined positions and set the detection distances.

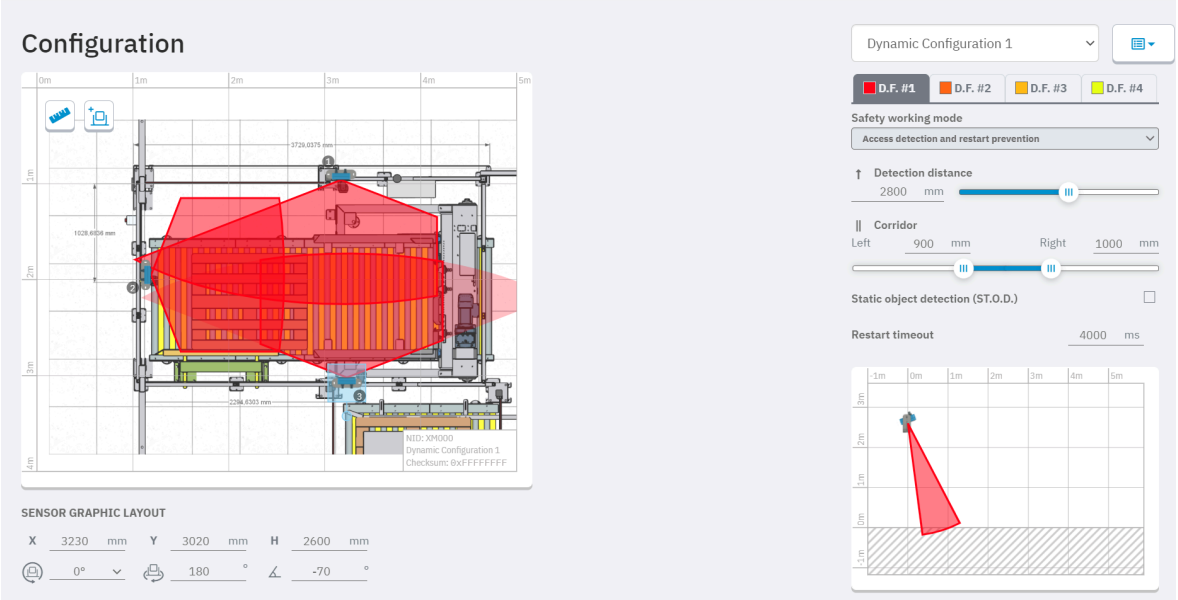


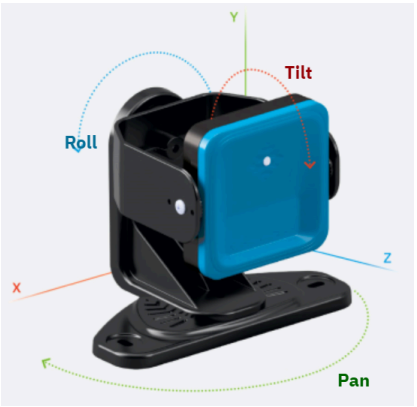
Figure 20. Inxpect Safety: Configuration page with Sensor Graphic Layout.

Each of the three sensors is configured with a single detection field and a safety working mode of "*Access detection and restart prevention*".

To ensure effective restart prevention, it is crucial to detect even stationary operators. Therefore, the "*Access detection and restart prevention*" safety mode is mandatory.

Note: All radars are positioned overhead at a height of approximately 2.6 meters from the ground. The 2D visualization may not fully represent the coverage area, particularly in the corners. A 3D model can be used to confirm the complete coverage. During the coverage validation process, it is essential to verify that all the possible operator positions are detected.

As additional information, in the **sensor graphic layout** section of the Configuration page the x/y coordinates can be inserted, as well as the height from the ground of the sensor and its rotation with respect to the three axes. This information is not used for the configuration itself but is important in order to have a complete and conformed report (generated at the end of the APPLY CHANGES) containing all the actual information.



Tilt angle: rotation of the sensor around the x-axis

Pan angle: rotation of the sensor around the y-axis

Roll angle: rotation of the sensor around the z-axis

Figure 21. Sensor rotation around the x-, y-, and z-axes.

5.2 Detection fields and digital outputs

In order to provide the correct signals to stop the machinery, the safety outputs of the control unit must be linked to the Detection Fields.

Since a single safety zone (the red one, D.F. #1)is used, a dual-channel safety output is sufficient.

To achieve this, two OSSDs should be linked to ***Detection Field #1*** of all the sensors. This pairing is referred to as ***Detection Signal #1***.

Note: *Detection Signal 'X' is linked to Detection Field 'X' for all sensors, not just a specific one. To pinpoint the exact sensor triggering an alarm, a Fieldbus communication (e.g. PROFIsafe) is required.*

Refer to the image below for the OSSD assignment details.

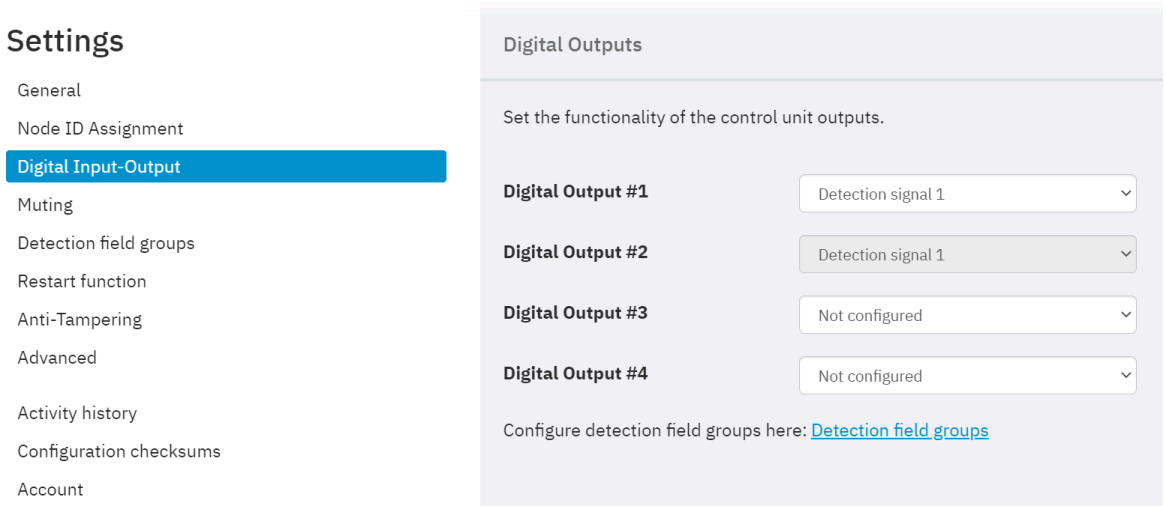


Figure 22. Inxpect Safety: Settings page with Digital Outputs.

5.3 Muting and inputs

For this scenario, the light curtains should remain continuously active to detect the access of an operator or a forklift.

The radar sensors should be activated only when an entry occurs. During regular operations, they should be in “muting” mode to prevent possible false alarms triggered by the movements of the object within the area.

To ensure correct operation, the muting function must be configured appropriately. Specifically, all the sensors should be assigned to the same muting group.

Access the “***Settings > Muting***” menu to configure this feature, as illustrated in the image below.

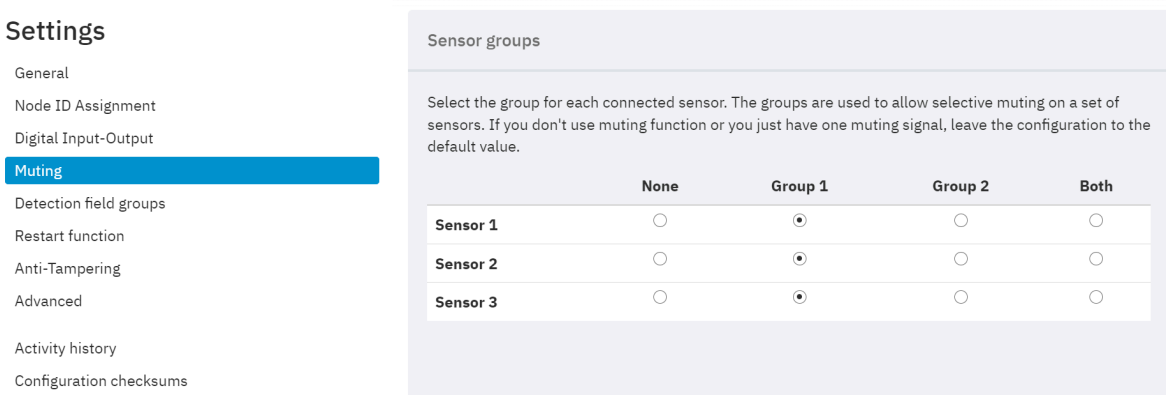


Figure 23. Inxpect Safety: Settings page with Muting options.

The muting signal will be handled with ***Digital Input #1.***

Access the "***Settings > Digital Input-Output***" menu to configure this feature, as illustrated in the image below.

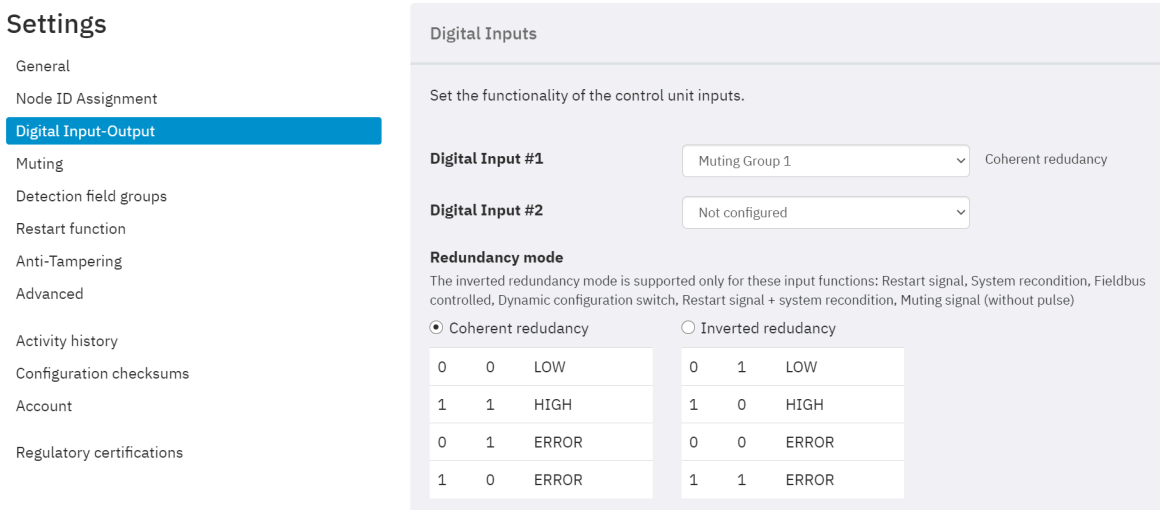


Figure 24. Inxpect Safety: Settings page with Digital Inputs.

Note: the *Digital Input #1* is a safe input (double channel). The muting is activated when both channels of the input are at 24 Vdc.

WARNING: *the muting signal needs to be managed paying attention to dangerous situations and respecting the two conditions explained in the chapter 2.2 Muting function and General working logic.*

If and only if ***(Detection Signal #1 = 1) and (Light Curtain Signal = 1) then*** *Area is Free* ***then Muting enabled***

(Detection Signal #1 = 1) and (Light Curtain Signal = 0) then *Operator or forklift intercept the barrier* ***then Muting disabled***

(Detection Signal #1 = 0) and (Light Curtain Signal = 0) then *Barrier intercepted and operator/forklift inside the cell* ***then Muting disabled***

(Detection Signal #1 = 0) and (Light Curtain Signal = 1) then *Operator inside the cell* ***then Muting disabled***

Logical Muting conditions

Detection Signal #1	***Light Curtain Signal***	***Muting***	***Cell occupancy***
1	***1***	*enabled*	*Area is Free*
1	***0***	*disabled*	*Operator or forklift intercept the barrier*
0	***0***	*disabled*	*Barrier intercepted and operator/forklift inside the cell*
0	***1***	*disabled*	*Operator inside the cell*

Table 1. Table showing the logical muting conditions.

5.4 Configure the Restart Prevention

The use of the radar technology for Restart Prevention aims to automate the restart process, thereby preventing operators from having to leave their machinery, like a forklift, to manually restart the system.

To set the automatic restart, in the Inxpect Safety application go to "***Settings > Restart function"*** and select Automatic.

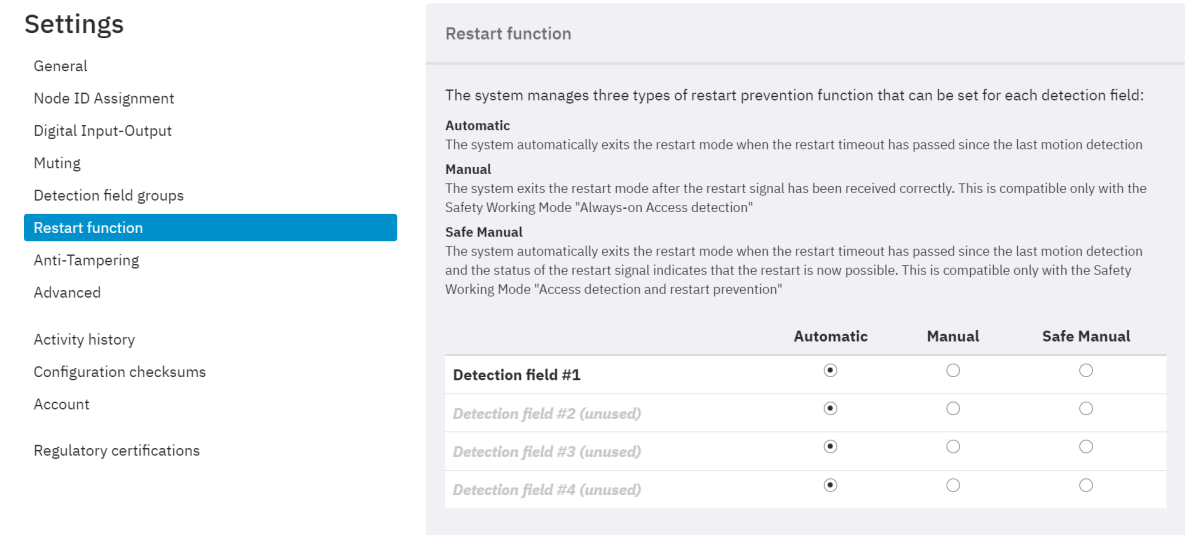


Figure 25. Inxpect Safety: Settings page with Restart function options.

6. PROFIsafe communication (optional)

If the Safety PLC supports the PROFIsafe protocol, Digital Inputs & Outputs become redundant. Please remove any configured I/O and utilize PROFIsafe for PLC communication.

Note: *If physical inputs are unnecessary, ensure their configuration is deleted.*

Consult the 'PROFIsafe Reference Guide' on the Inxpect Tools web page for detailed information on the PROFIsafe protocol.

The safe data from the first Safe Module, 'Configuration and Status Module', is going to be used.

The following example (Network 1) describes the sensor muting configuration. The muting is directly linked with the behavior of the light curtain and Detection Field #1. When DF#1 and the light curtain signal are both high, the cell is empty and sensor muting can be enabled.

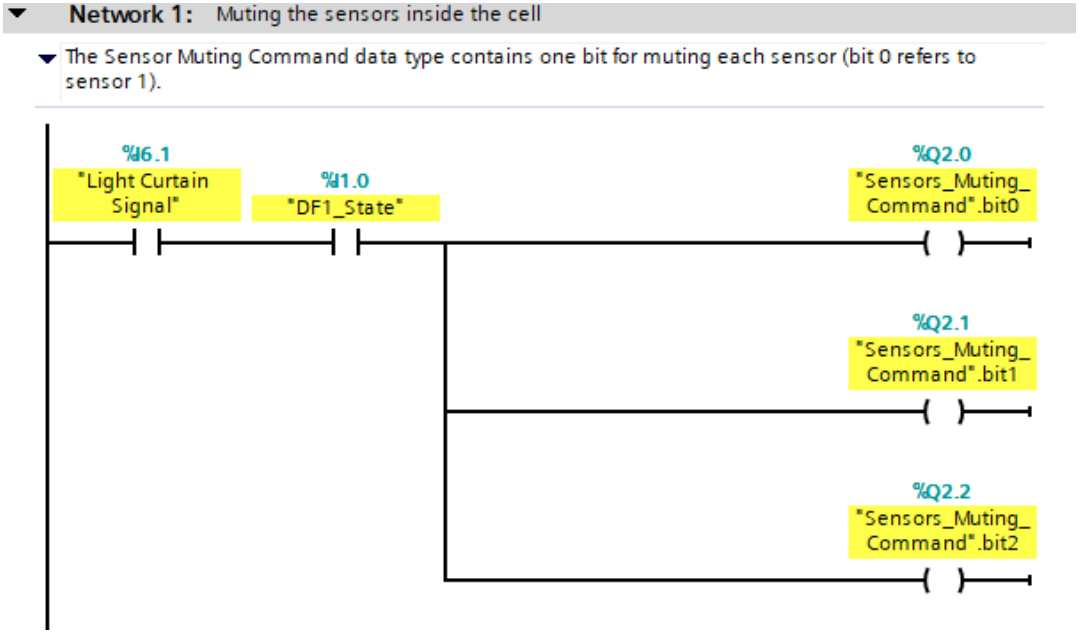


Figure 26. PLC programming: logical connection for muting function.

Network 2 shows how to stop the cell. If either the light curtain or DF#1 is activated (low level) the cell should be stopped and, for example, a RED light could be turned on. Similarly, any diagnostic errors within the safety system should trigger an immediate cell stop.

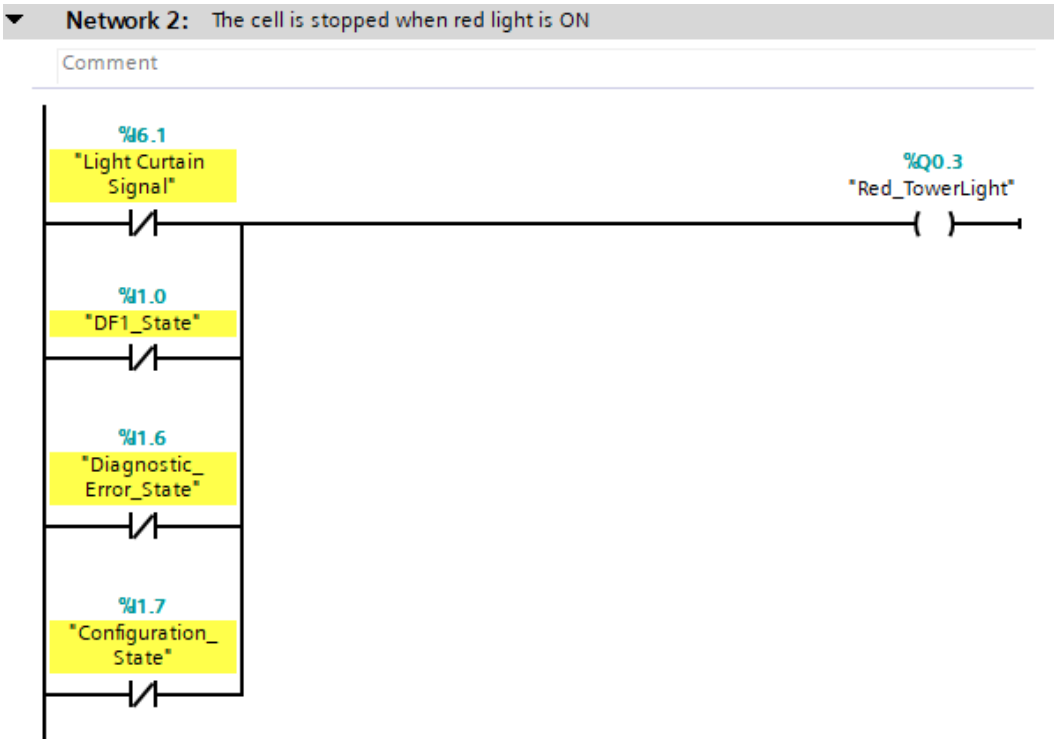


Figure 27. PLC programming: logical connection for stopping the cell.

In Network 3, an example of automated cell restarting is shown. All the conditions of the sequence must be at a high level for the cell to restart automatically.

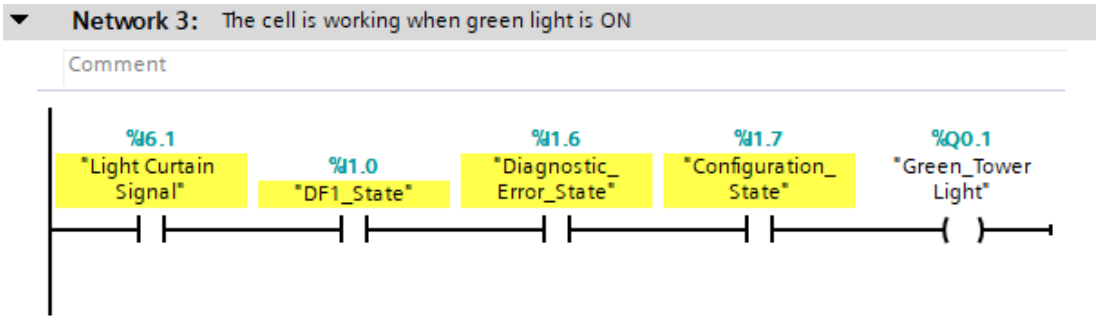


Figure 28. PLC programming: logical connection for cell restart.