MiR100, MiR200 & MiRHook

Risk Analysis

Technical Documentation

Risk analysis

Release date: 12.07.2019

MOBILE INDUSTRIAL ROBOTS

1 Content

2 Introduction

This document describes scenarios with MiR100, MiR200 and MiRHook that require special attention. First, an introduction to the terminology, assumptions, safety- and awareness indicators. This is followed by a section describing normal use case scenarios.

Each scenario is divided into phases. The phases are described in chronological order.

For each residual risk, the compensating safety features are highlighted, and based on this a conclusion is made on the significance of the residual risk.

Please note that all scenarios are illustrated with MiR200 and MiRHook, but they apply equally for MiR100 and MiRHook.

This document does not provide an exhaustive list of scenarios in which MiR100, MiR200, MiRHook can be used with a reduced safety level of the safety system. However, it describes the most common scenarios for the intended use. The scenarios provided in this document can also be used as a template for making risk analysis of similar scenarios during the commissioning phase.

3 Terminology

- **Awareness indicator**: Light and/or acoustic signals, see section 4.
- **Charging station**: Unit connected to a factory power outlet which enables a robot to autonomously charge its batteries.
- **Docking**: Precision maneuvering to a relative marker.
- **Entry position**: Coordinate on the robot's map that must be reached before initiating a docking sequence.
- **Goal position**: Coordinate on the robot's map that must be reached to finish a docking sequence.
- **Relative marker**: Object with specific physical dimensions and shape used for precision positioning of the robot. Examples are pallet rack, charging station, V-, VL- and L-marker.
- **Operating hazard zone**: Marked area according to standard EN 1525:1997 clause A.3.2. No obstacles other than those specified by each scenario can be placed inside this zone.
- **MiRHook** (MiRHook100 and MiRHook200): Top module that enables MiR100 and MiR200 to tow a cart.
- **Cart**: A cart commissioned to be moved by MiRHook.
- **PLd**: Performance level d as defined by ISO 13849-1.
- **Not a safety function**: A function that is not safety rated.
- **Protective field**: Area in which protective stop is automatically triggered if a person or object enters the area.
- **Tolerance zone**: The safety laser scanner measures the distance to a diffuse reflection and causes a tolerance to the measurement. In most situations, including during tests, the safety laser scanner will detect a person within the tolerance zone.
- **Relative move**: When driving using a relative move the robot relies only on wheel encoders for navigation, and the robot will only move in the specified direction, for example straight forward.

- **Software collision avoidance**: Software using safety scanner data to detect persons or obstacles to avoid these or stop the robot before protective stop is triggered. This works regardless of whether protective fields are active or not but filters out expected obstacles such as a charging stations or pallet racks. The software collision avoidance is not safety rated.
- **Normal driving position**: The speed in normal driving position is 1.5 m/s for MiR100 and 1.1 m/s for MiR200. In the description of the phases, the normal driving speed for MiR100 is shown first, and the speed of MiR200 is shown in parenthesis (1.5 (1.1)).
- **Driving in reverse**: The speed when driving in reverse is shown as negative.

4 Assumptions

- Throughout this document it is assumed that the products are used within the specifications of the robot and top module.
- That the guidelines of correct commissioning have been followed according to the product manuals and the commissioning documentation, see Appendix A. Commissioning will include the following but is not limited to:
    - Protective field adjusts to the size of the towing cart.
    - Protective field adjusts to the increased breaking distance due to the towing cart.
- That carts are commissioned correctly to be towed by MiRHook.
- When towing a cart MiR100 and MiR200 will never drive in reverse, the only exception is when loading and unloading a cart.
- When the robot drives into an enclosure it is assumed that the passage into the enclosure is not part of an escape route.

5 Safety components overview

5.1 Safety laser sensors

- Two safety lasers sensors (PId) are placed at diagonal corners. The safety laser sensors are placed 20 cm from the ground.
- They create a 360° protective field.
- The size of the protective fields depends on robot speed and driving direction. See the specifications of the robot.
  The protective fields of MiR100 and MiR200 will never be turned off. However, the protective fields will adjust to the speed of the robot.

Figure 1 Protective fields of MiR100 and MiR200 when driving forward.

Figure 2 Protective fields of MiR100 and MiR200 when driving in reverse.

5.2 Emergency stops

- There is an emergency stop button placed on top of the robot or MiRHook. The emergency button is within reach from all sides of the robot.

5.3 Awareness Indicators

- Light signals:
  The robot has LED lights on each side of the robot.
  During commissioning the robot must be commissioned to give appropriate light signals when operating in hazard zones.
- Acoustic signals:
  One speaker placed inside the robot.
  Acoustical warnings must be addressed during commissioning.

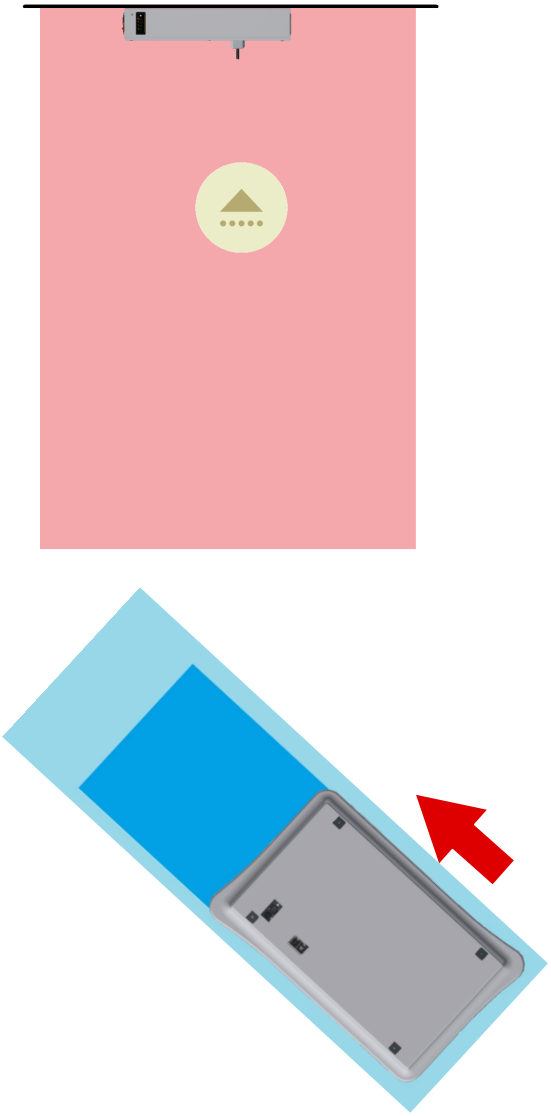
6 Use Cases and Risk Identifications

Use cases		Risks	No.
Dock to charging station	Docking to MiRCharge	Risk of crushing	1
	Docking to MiRCharge	Risk of crushing	2
	Docking to MiRCharge	Risk of crushing	3
	Localization failure	Risk of crushing	4
Entering and exciting enclosures	Entering/exciting enclosure	Risk of crushing	5
	Entering/exciting enclosure	Risk of crushing	6
Attaching to a cart	Alignment to cart	Risk of crushing	7
	Attaching to cart	Risk of crushing	8
	Attaching to cart	Risk of crushing	9
	Attaching to cart	Risk of crushing	10
Towing cart	Towing cart	Risk of crushing	11
	Towing cart	Risk of crushing	12
Parking cart in reverse	Unloading cart	Risk of crushing	13
	Localization failure	Risk of crushing	14
Driving with MiRHook	Driving with a MiRHook	Risk of crushing	15
	Driving with a MiRHook	Risk of crushing	16

7 Safety Design and Residual Risks

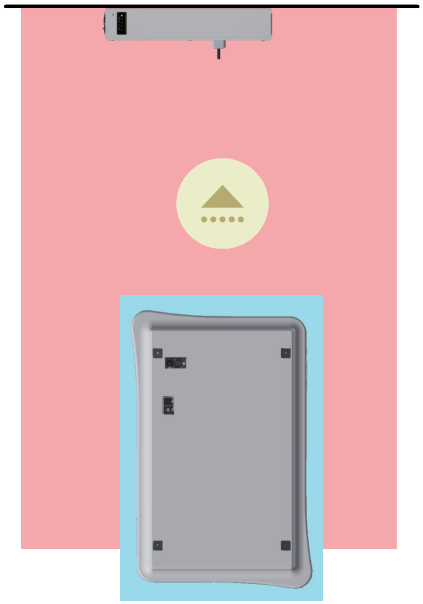
7.1 Docking to charging station

Phase 1: Approaching entry position



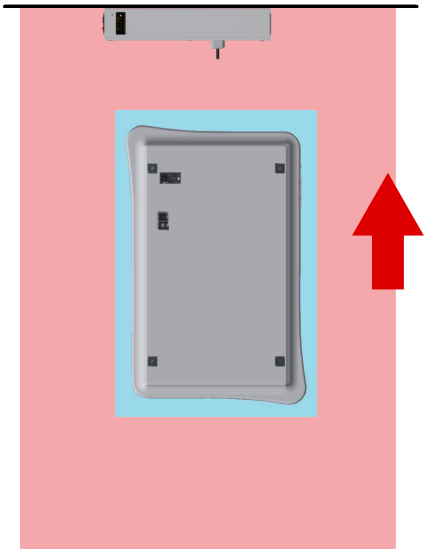
Maximum speed [m/s]	1.5 (1.1)
Awareness indicator	No
Operating hazard zone	No

Phase 2: Marker detection



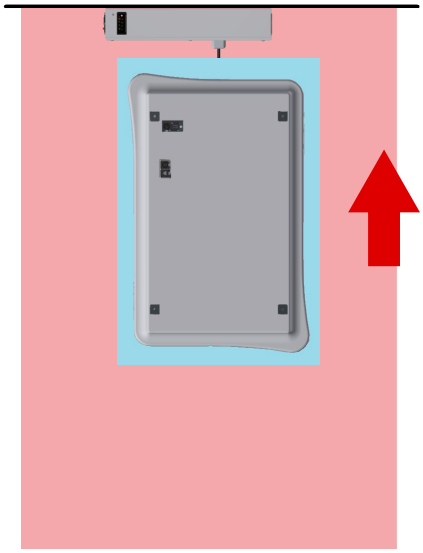
Maximum speed [m/s]	0
Awareness indicator	No
Operating hazard zone	No

Phase 3: Approaching docking station



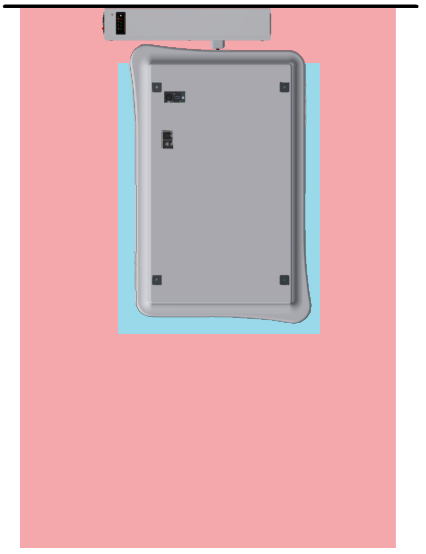
Maximum speed [m/s]	0.1
Awareness indicator	Yes
Operating hazard zone	Yes

Phase 4: Docking



Maximum speed [m/s]	0.1
Awareness indicator	Yes
Operating hazard zone	Yes

Phase 5: Charging. Final position reached



Maximum speed [m/s]	0
Awareness indicator	No
Operating hazard zone	Yes

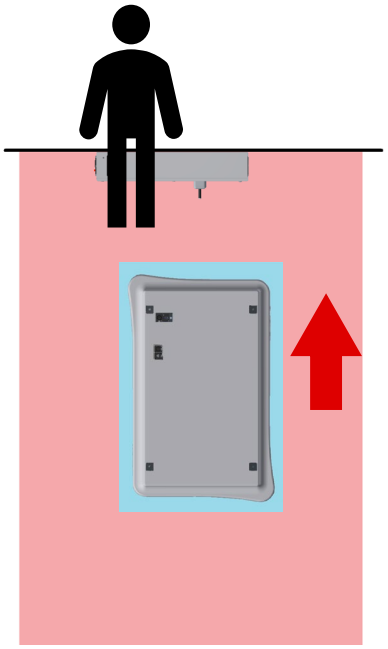
Residual risks

1. A person is standing between the charging station and the robot while the robot is docking to the charging station → Risk of being crushed.

   But:

   - Speed reduced to 0.1 m/s (not a safety function)
   - Software collision avoidance (not a safety function) will detect the person and stop the robot
   - Markings on the floor indicate an operating hazard zone
   - The severity is considered low, due to low impact of the robot

   Conclusion: Low residual risk

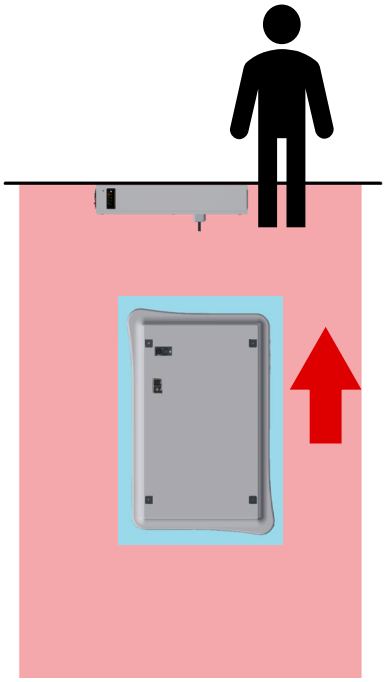


2. A person is staying close to the charging station and robot while the robot is docking (phase 4). → Risk of being crushed.

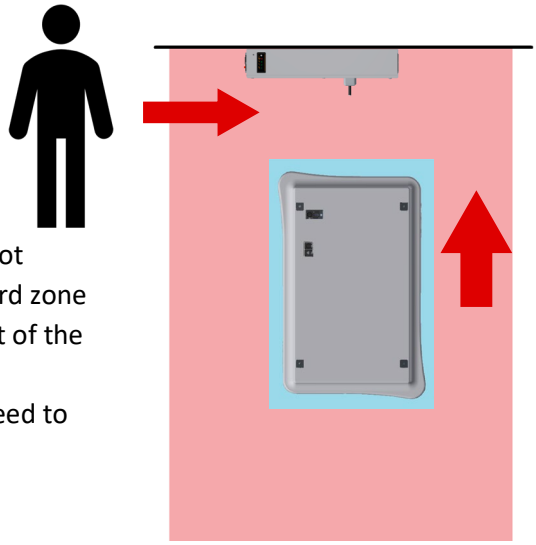
   But:

   - Speed reduced to 0.1 m/s (not a safety function)
   - Software collision avoidance (not a safety function) will detect the person and stop the robot
   - Markings on the floor indicate an operating hazard zone
   - The severity is considered low, due to low impact of the robot

   Conclusion: Residual risk extremely low.



3. A person enters during docking → Risk of being crushed.

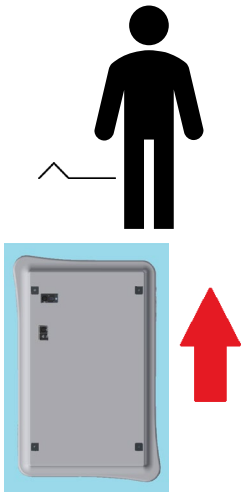


But:

- Speed reduced to 0.1 m/s (not a safety function)
- Software collision avoidance (not a safety function) will detect the person and stop the robot
- Markings on the floor indicate an operating hazard zone
- The severity is considered low, due to low impact of the robot
- Very improbable behavior → Staff and visitors need to be trained

Conclusion: Residual risk low.

4. Localization fault: The robot is not well localized and the robot docks to a marker/object different than the desired charging station, and a person is staying between the marker/object and robot → Risk of being crushed.



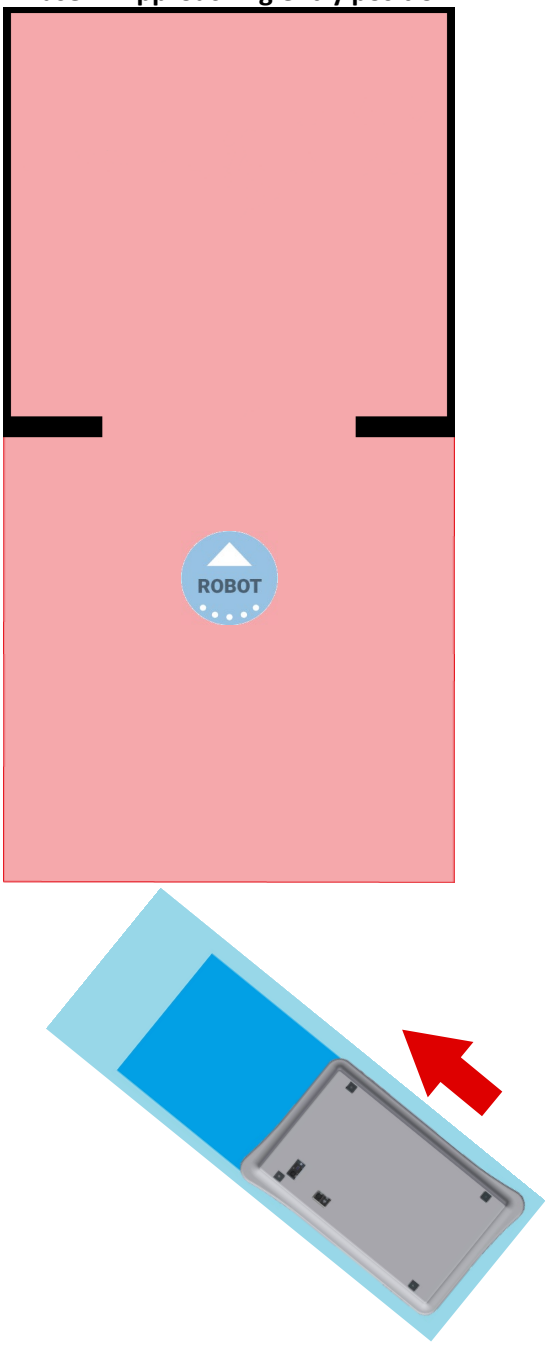
But:

- Localization fault is improbable
- The robot must detect a shape similar to the characteristic shape of a charging station before initiating docking sequence
- Software collision avoidance (not safety function) will detect the person and stop the robot

Conclusion: Residual risk extremely low.

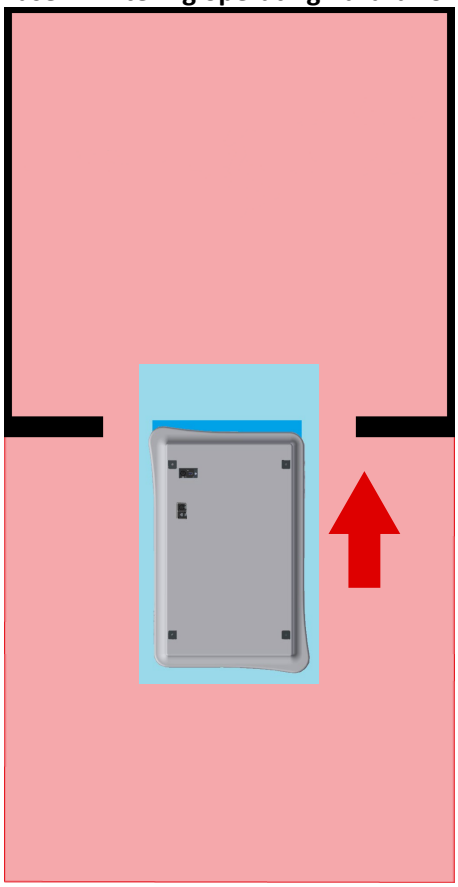
7.2 Entering and exiting enclosure

Phase 1: Approaching entry position



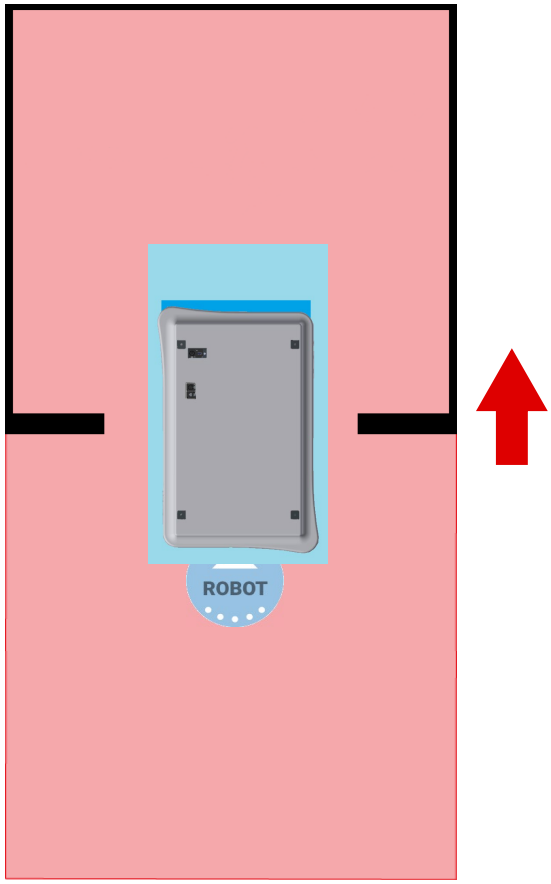
Maximum speed [m/s]	1.5 (1.1)
Awareness indicator	No
Operating hazard zone	No

Phase 2: Entering operating hazard zone



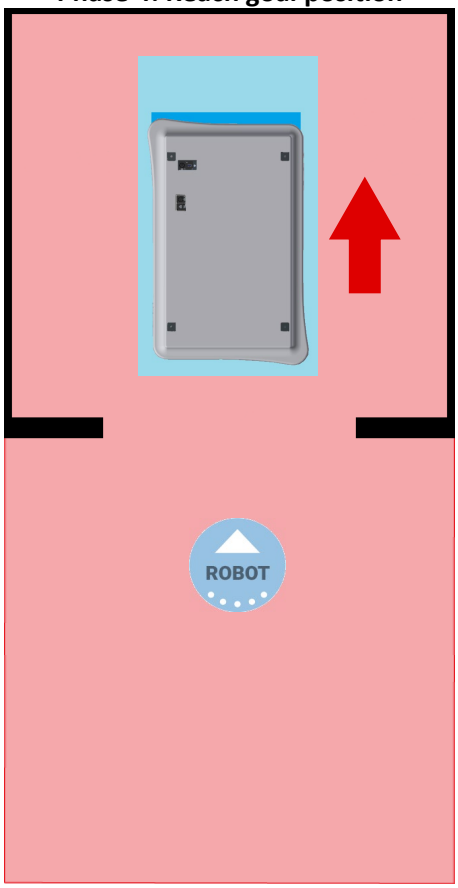
Maximum speed [m/s]	0.3
Awareness indicator	No
Operating hazard zone	Yes

Phase 3: Enter enclosure



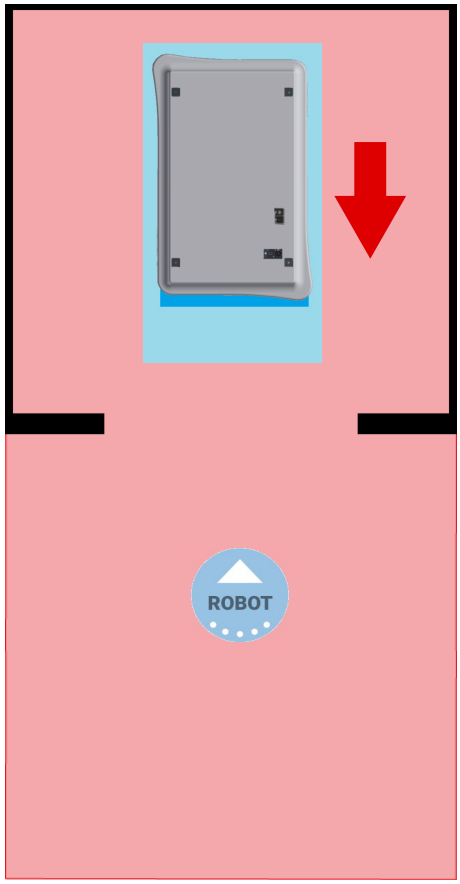
Maximum speed [m/s]	0.3
Awareness indicator	Yes
Operating hazard zone	Yes

Phase 4: Reach goal position



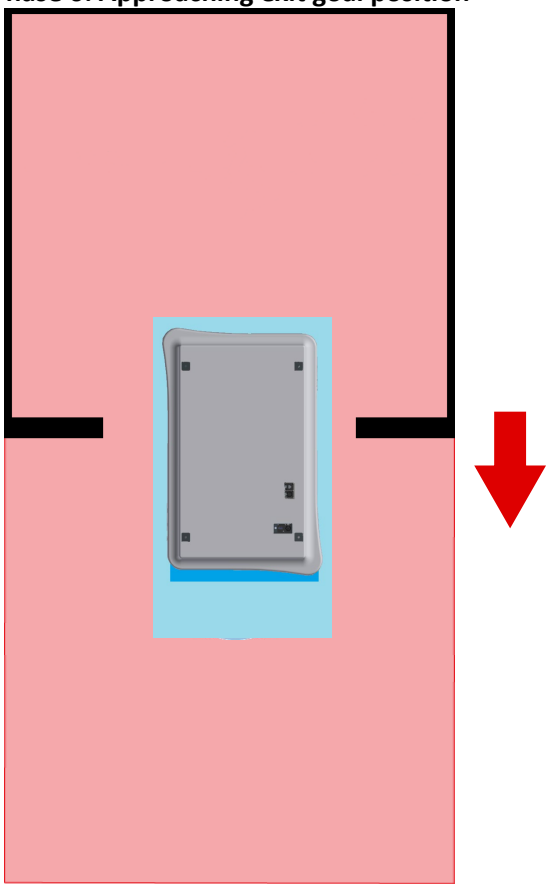
Maximum speed [m/s]	0.3
Awareness indicator	Yes
Operating hazard zone	Yes

Phase 5: Initiate exit move



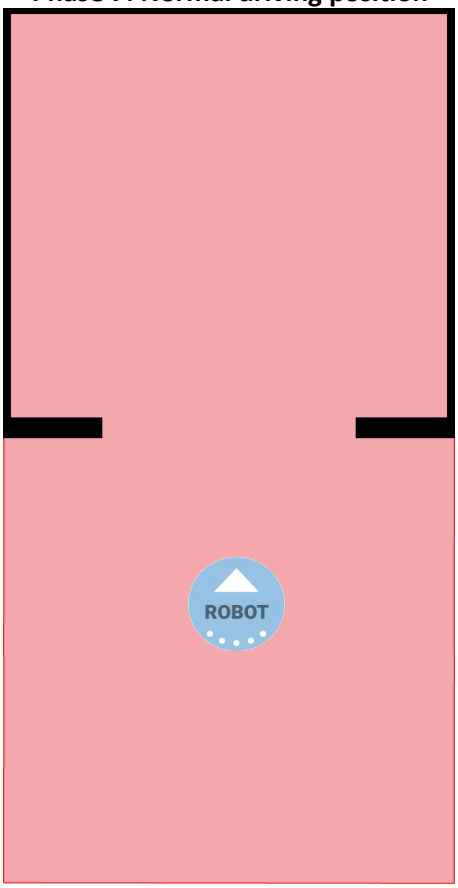
Maximum speed [m/s]	0.3
Awareness indicator	Yes
Operating hazard zone	Yes

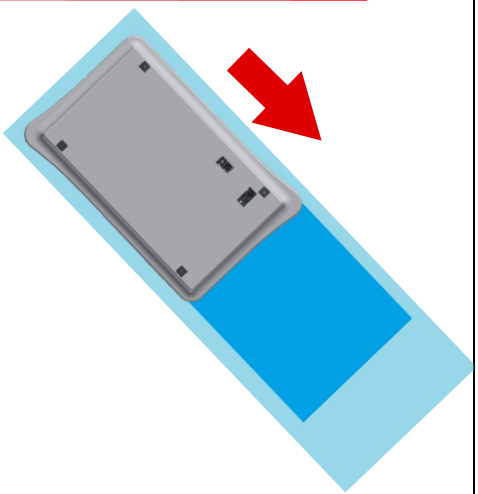
Phase 6: Approaching exit goal position



Maximum speed [m/s]	0.3
Awareness indicator	Yes
Operating hazard zone	Yes

Phase 7: Normal driving position





Maximum speed [m/s]	1.5 (1.1)
Awareness indicator	No
Operating hazard zone	No

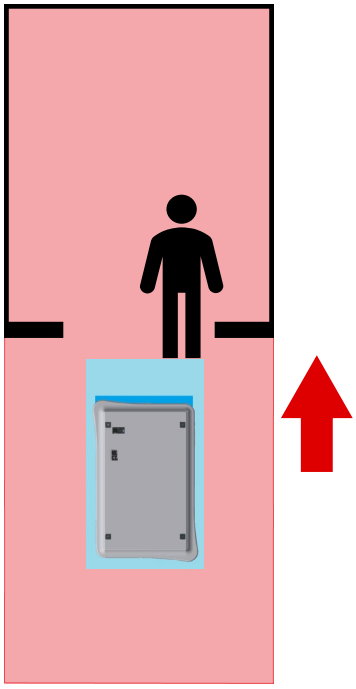
Residual risks

5. Person standing in entry of the passage when the robot drives through (phase 3 and phase 6). Lack of escape zone. → Risk of being crushed or sheared between the door and the robot.

   But:

   - Protective field will trigger protective stop if the person is staying in the area
   - Software collision avoidance (not a safety function) will detect the person and stop the robot
   - Markings on the floor indicate an operating hazard zone

   Conclusion: Residual risk low.

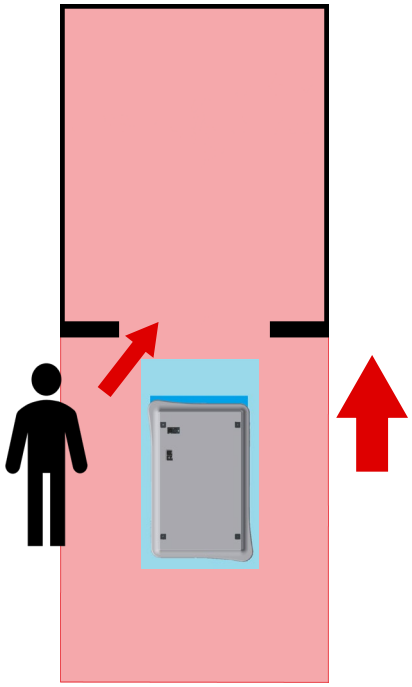


6. Person enter entry passage when the robot drives through (phase 3 and phase 6). → Risk of being crushed.

   But:

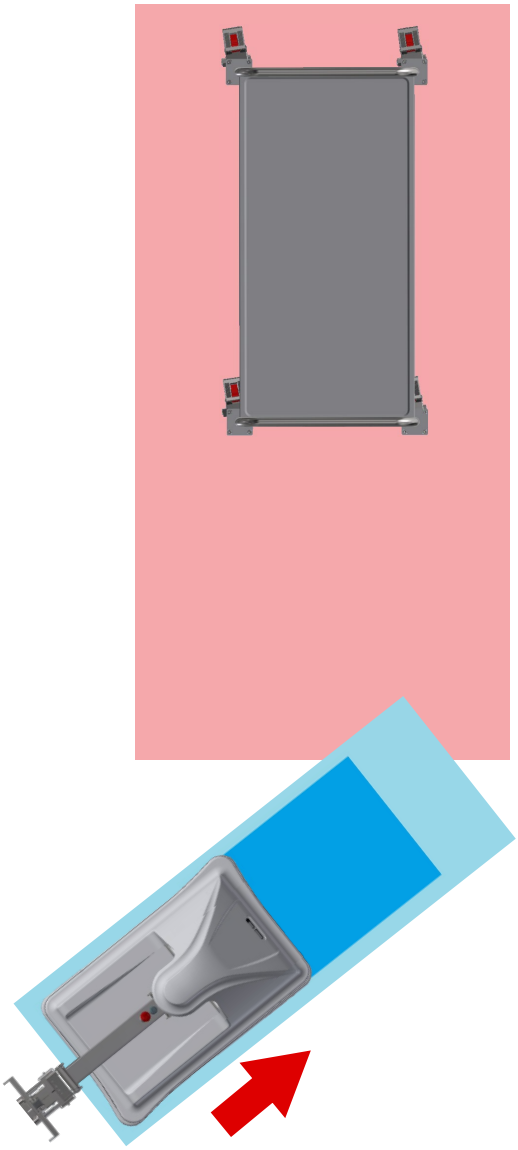
   - Protective field will trigger protective stop if the person is in the area
   - Markings on the floor indicate an operating hazard zone
   - Very improbable behavior. → Staff and visitors need to be trained

   Conclusion: Residual risk extremely low.



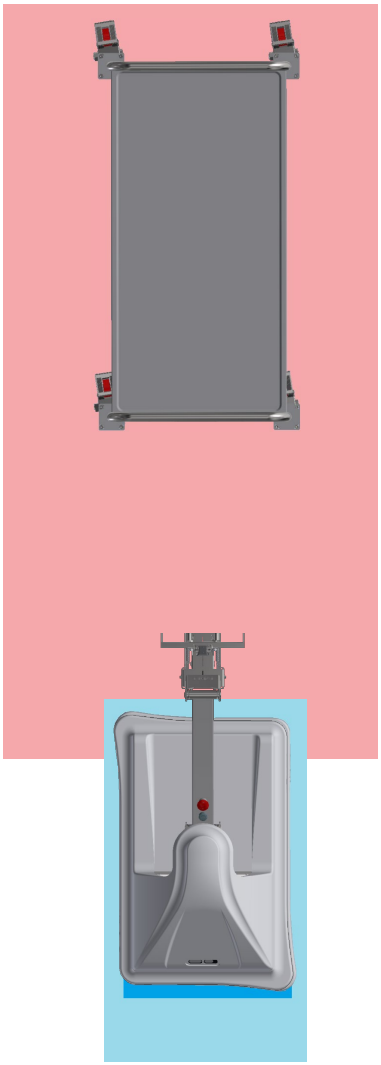
7.3 Picking up cart

Phase 1: Approaching cart. Locating long range

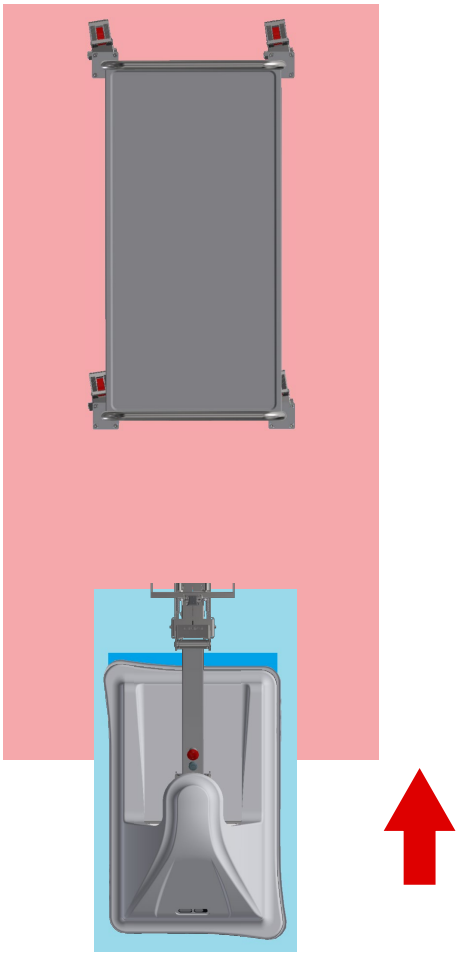
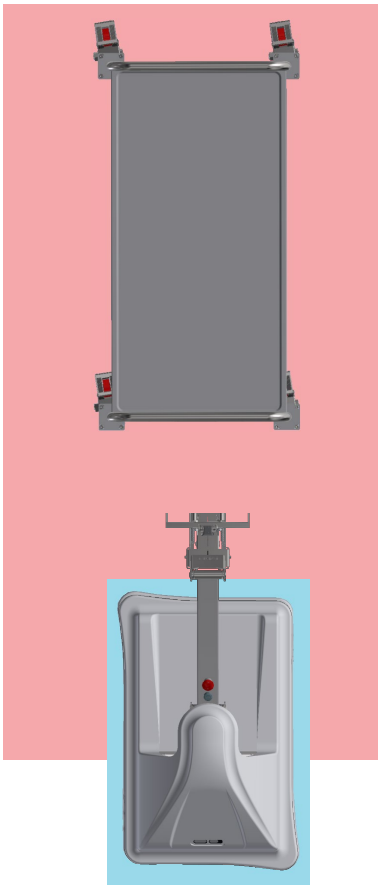


Maximum speed [m/s]	1.5 (1.1)
Awareness indicator	No
Operating hazard zone	No

Phase 2: Setting search height



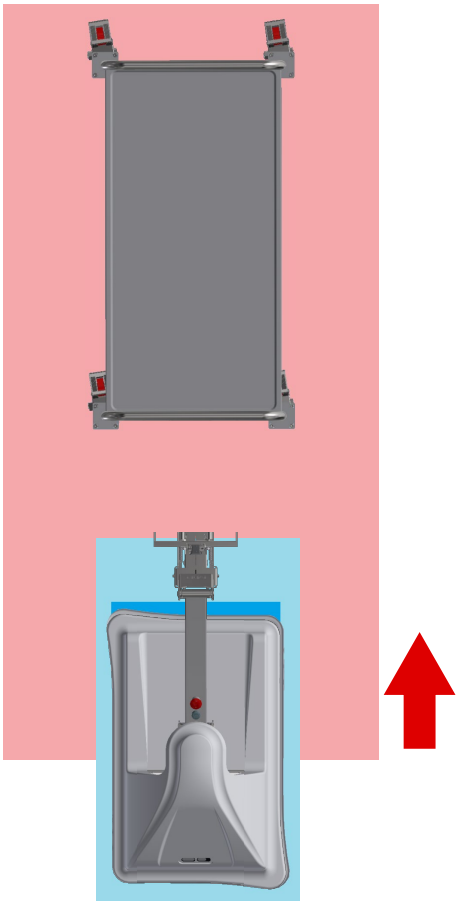
Maximum speed [m/s]	0
Awareness indicator	Yes
Operating hazard zone	No

Phase 3: Long range docking	Phase 4: Setting entry height. Locating short range
	

Maximum speed [m/s]	-0.3
Awareness indicator	Yes
Operating hazard zone	No

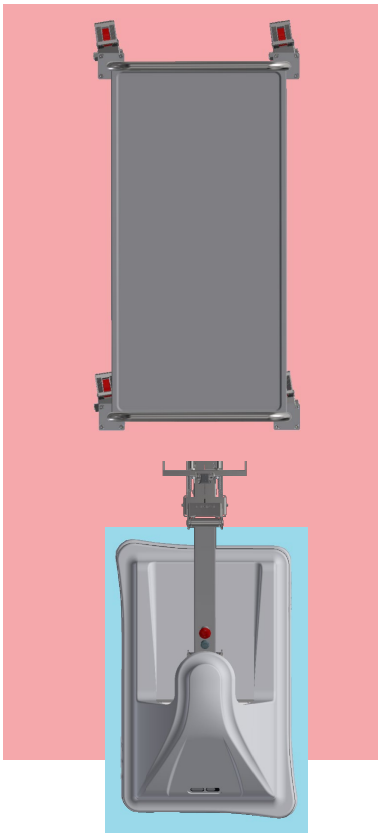
Maximum speed [m/s]	0
Awareness indicator	Yes
Operating hazard zone	No

Phase 5: Short range docking

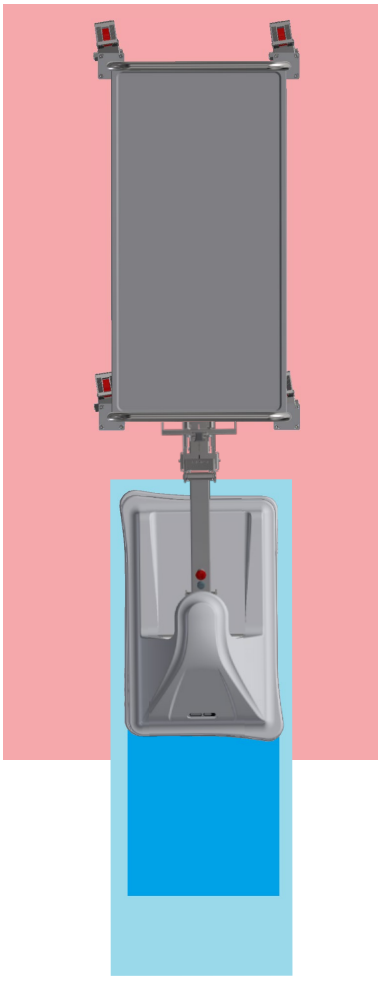


Maximum speed [m/s]	-0.3
Awareness indicator	Yes
Operating hazard zone	No

Phase 6: Setting lock height



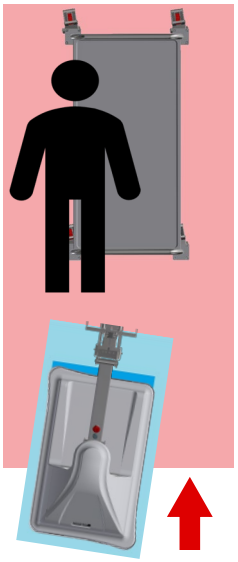
Maximum speed [m/s]	0
Awareness indicator	Yes
Operating hazard zone	No

Phase 7: Locking to cart	Phase 8: Normal driving position
	

Maximum speed [m/s]	-0.3
Awareness indicator	Yes
Operating hazard zone	No

Maximum speed [m/s]	1.5 (1.1)
Awareness indicator	Yes
Operating hazard zone	No

Residual risks

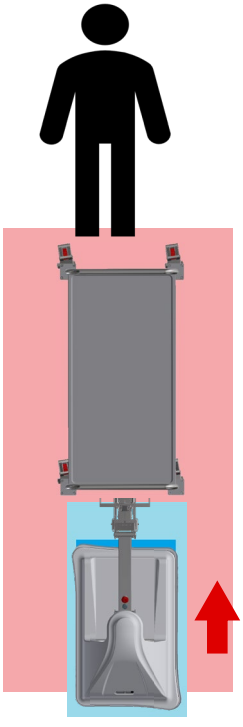


7. Person standing between robot and cart when the robot adjusts its pick-up angle. Alignment is done without collision check. → Risk of being crushed.

   But:

   - Speed is reduced to 0.3 m/s (not a safety function)
   - Awareness indicators when driving in reverse will warn the person
   - Markings on the floor indicate an operating hazard zone

   Conclusion: Residual risk low.



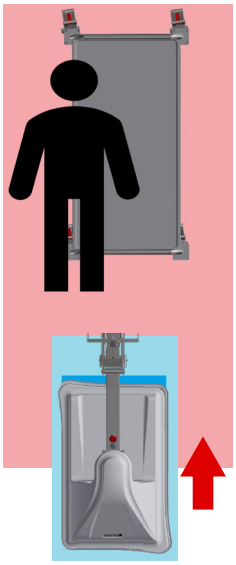
8. A person is standing behind the cart. The robot drives in reverse towards the cart (phase 4). The robot drives too far and pushes the cart. → Risk of being crushed.

   But:

   - Speed is reduced to -0.3 m/s (not a safety function)
   - Awareness indicators when driving in reverse will warn the person
   - Markings on the floor indicate an operating hazard zone

   Conclusion: Residual risk low.

9. A person is standing in front of the cart while the robot is driving in reverse towards the cart (phase 4). → Risk of being crushed.



   But:

   - Awareness indicators when driving in reverse will warn the person.
   - Speed is reduced to -0.3 m/s when the robot is 14 cm from the cart (not a safety function).
   - Software collision avoidance (not a safety function) will detect the person and stop the robot.
   - Markings on the floor indicate an operating hazard zone.
   - Risk only if the person does not move.

   Conclusion: Residual risk low.

10. A person is standing near the robot and the cart. The MiRHook closes around the lower bar of the cart. → Risk of fingers getting crushed and sheared.

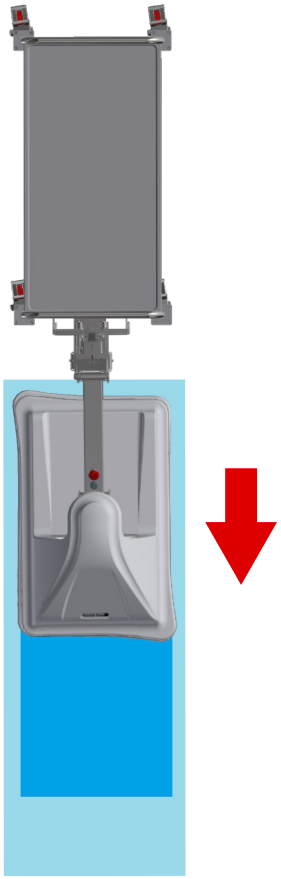
    But:

    - Awareness indicators when driving in reverse will warn the person
    - The zone will be marked as an operating hazard zone
    - MiRHook is marked with warning labels

    Conclusion: Residual risk low.

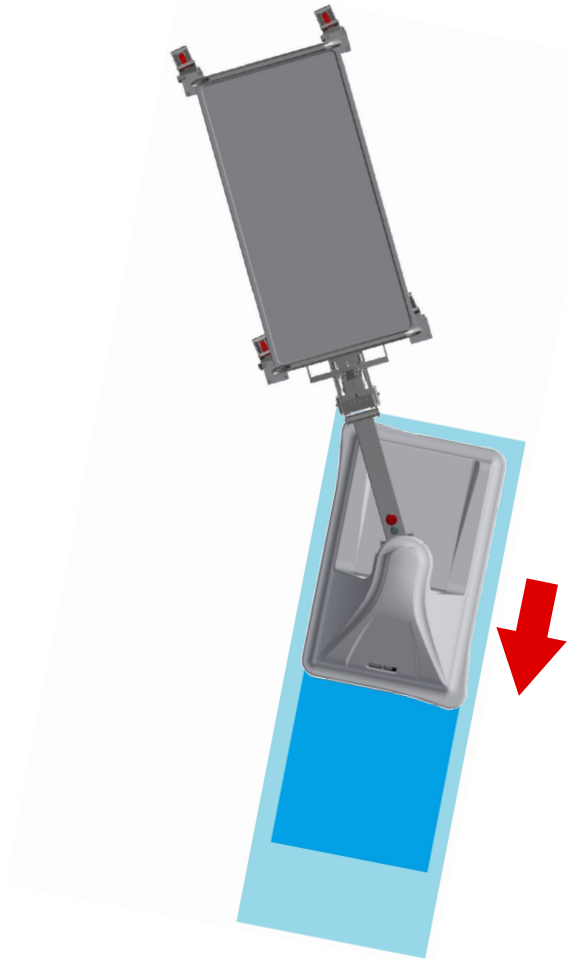
7.4 Towing cart

Phase 1: Driving forward



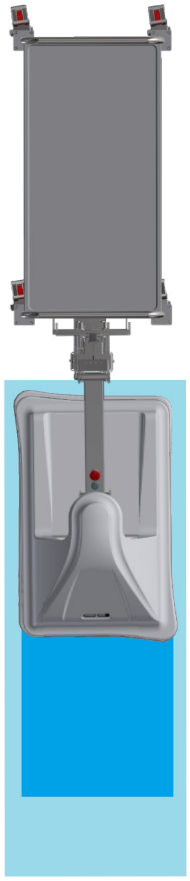
Maximum speed [m/s]	1.5 (1.1)
Awareness indicator	No
Operating hazard zone	No

Phase 2: Turning left or right



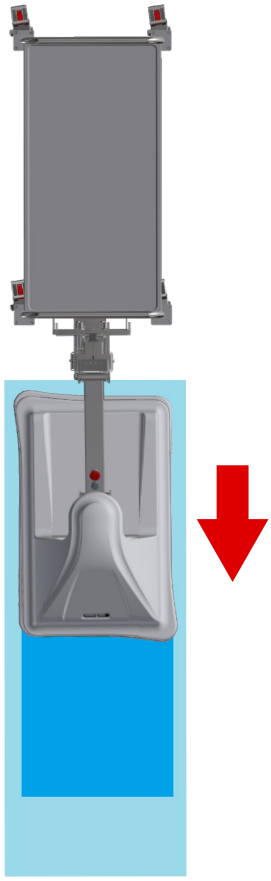
Maximum speed [m/s]	1.5 (1.1)
Awareness indicator	No
Operating hazard zone	No

Phase 3: Stopping



Maximum speed [m/s]	0
Awareness indicator	No
Operating hazard zone	No

Phase 3: Starting.



Maximum speed [m/s]	1.5 (1.1)
Awareness indicator	No
Operating hazard zone	No

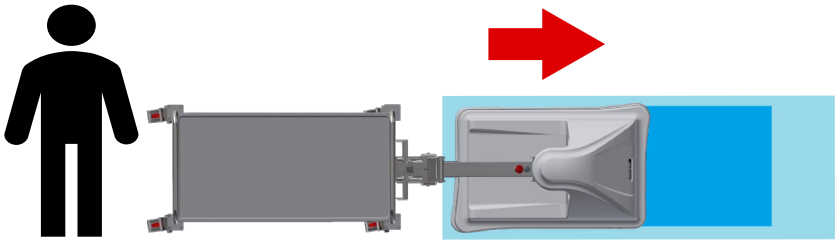
Residual risks

11. The MiRHook does not close correctly around the lower bar of the cart (phase 1). The MiRHook loses the grip of the cart when the robot is driving, special attention must be given when driving on a slope. → Risk of being crushed.

    But:

    - Software (not a safety function) detects gripping force

    Conclusion: Residual risk low.

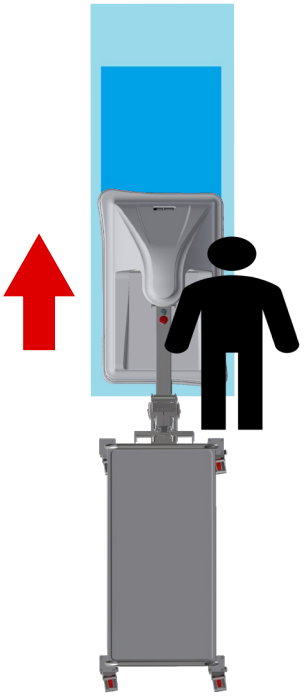


12. The gripper is closed around the lower bar of the cart (phase 6). A person is standing between the cart and the robot. The robot starts accelerating forward. → Risk of being crushed.

    But:

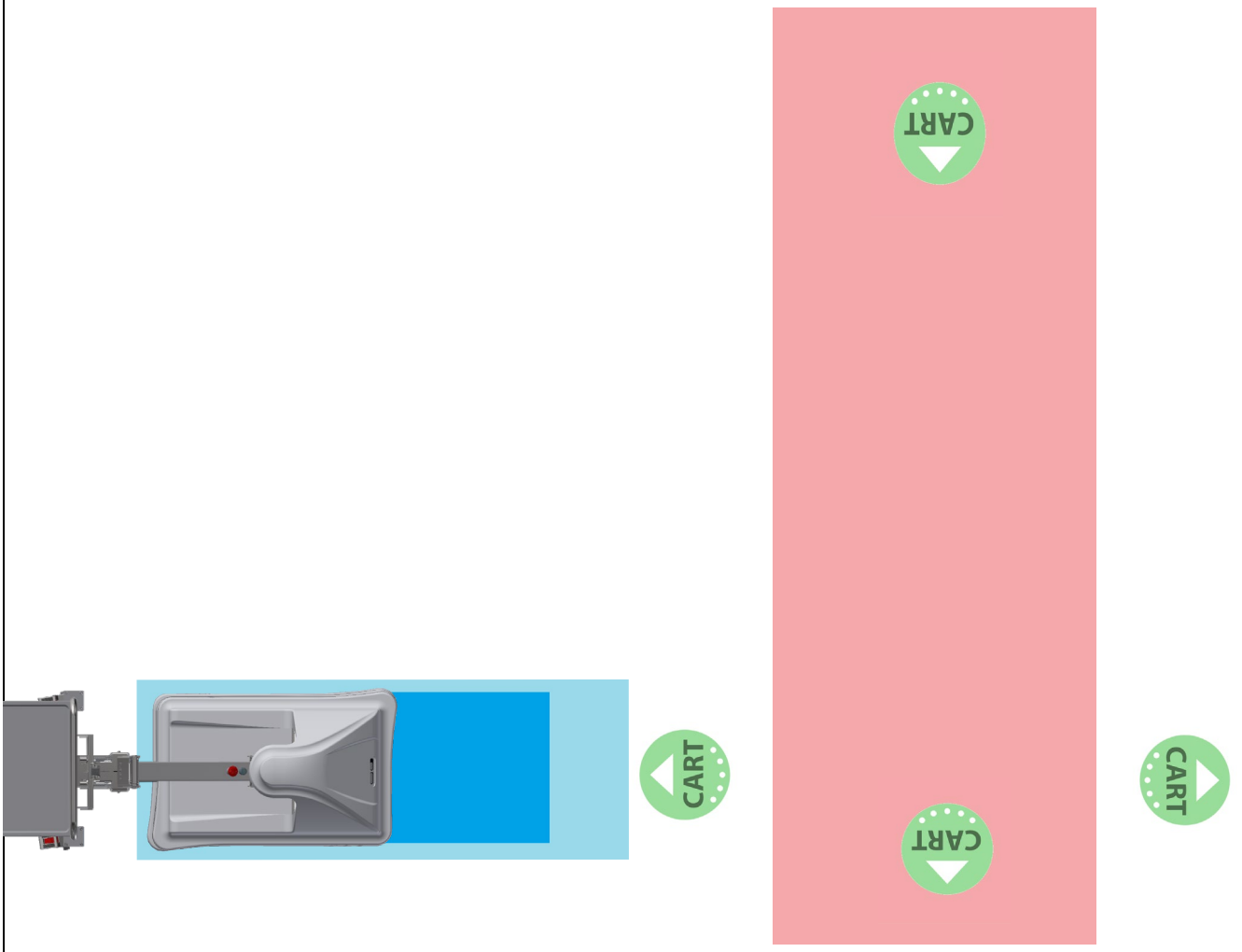
    - Software collision avoidance (not a safety function) will detect the person and stop the robot. Software collision avoidance will only detect the person if the person is closer than 0.20 m from the cart.

    Conclusion: Residual risk low.



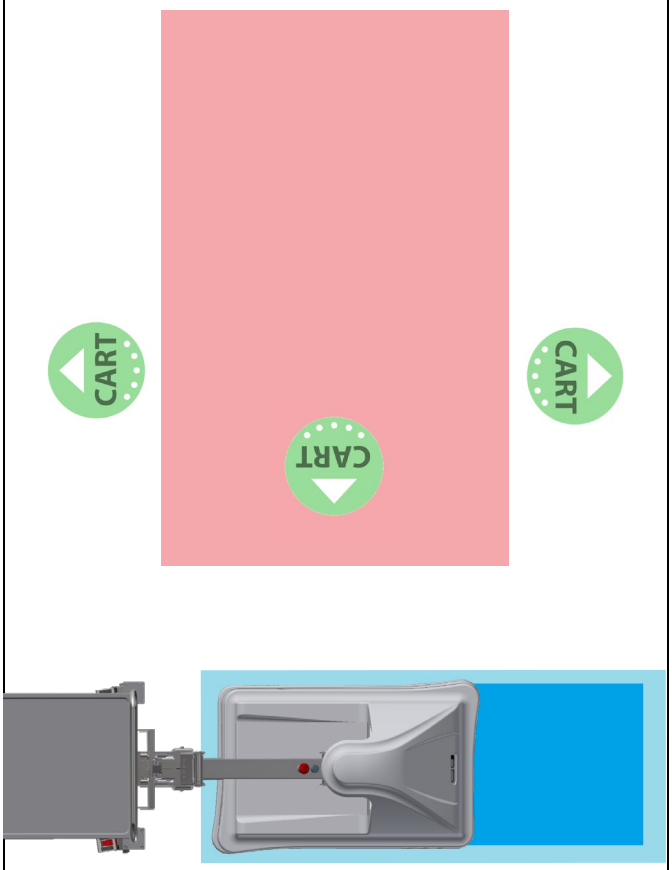
7.5 Parking cart in reverse

Phase 1: Approaching cart entering position



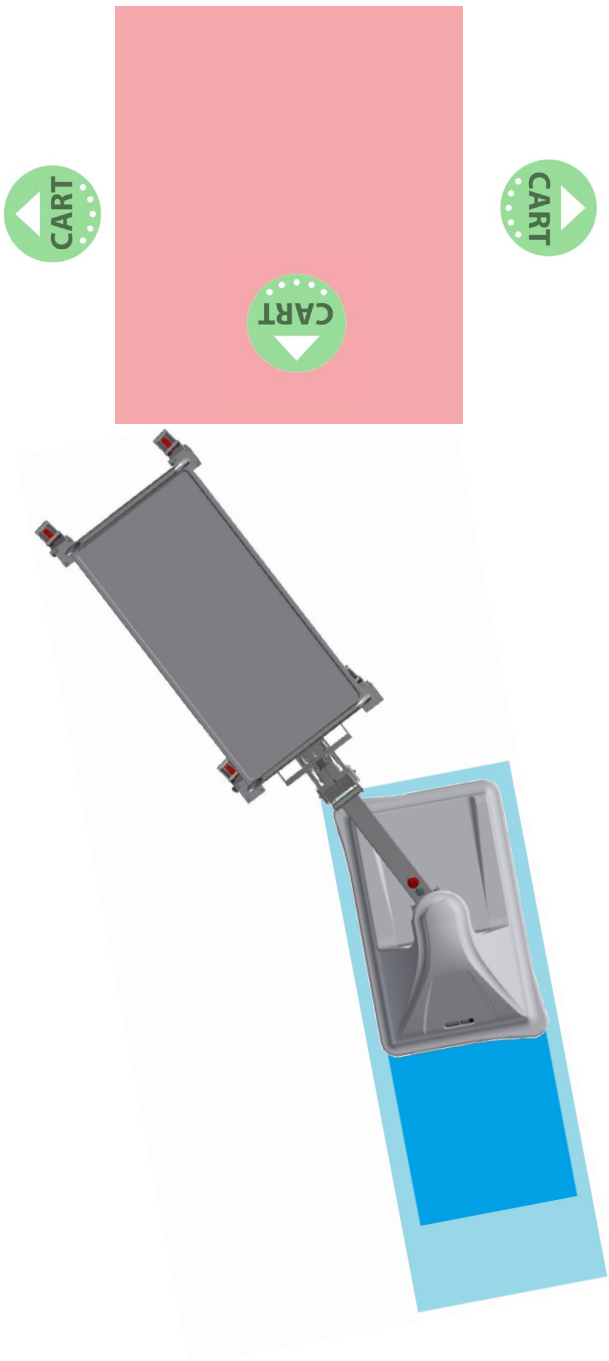
Maximum speed [m/s]	1.5 (1.1)
Awareness indicator	No
Operating hazard zone	No

Phase 2: Reaching entering position. Checking area

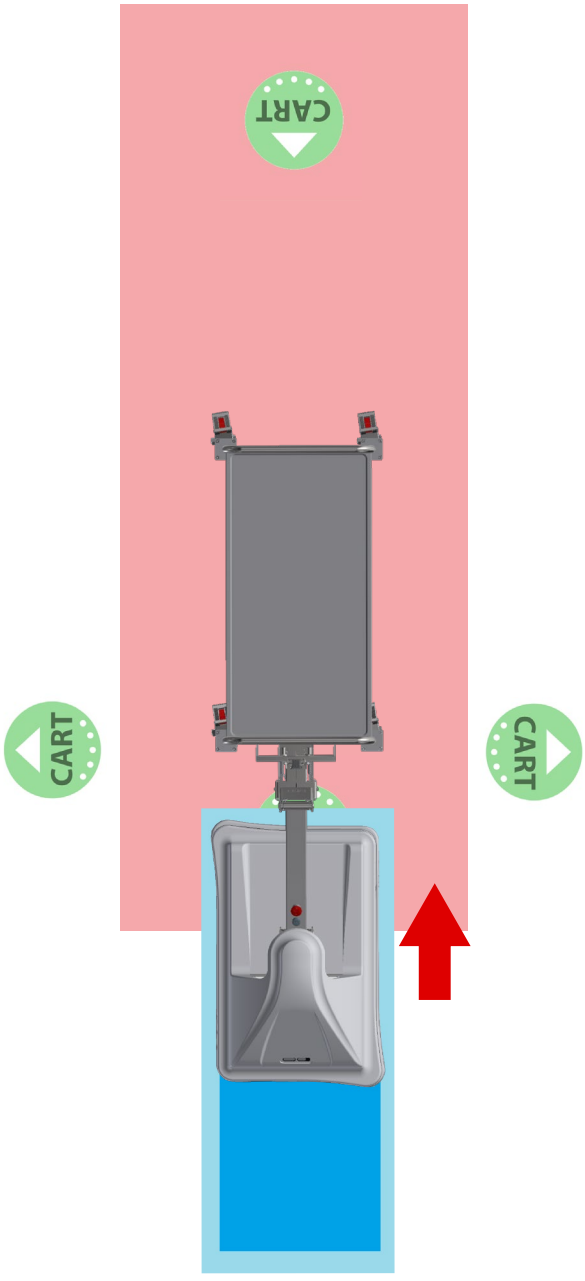
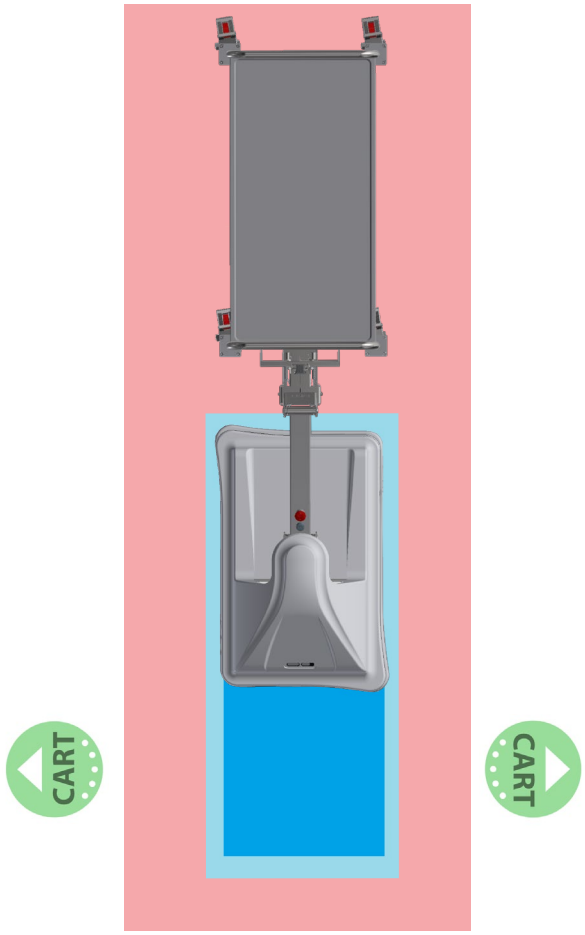


Maximum speed [m/s]	0
Awareness indicator	No
Operating hazard zone	No

Phase 3: Driving forward to initiate parking



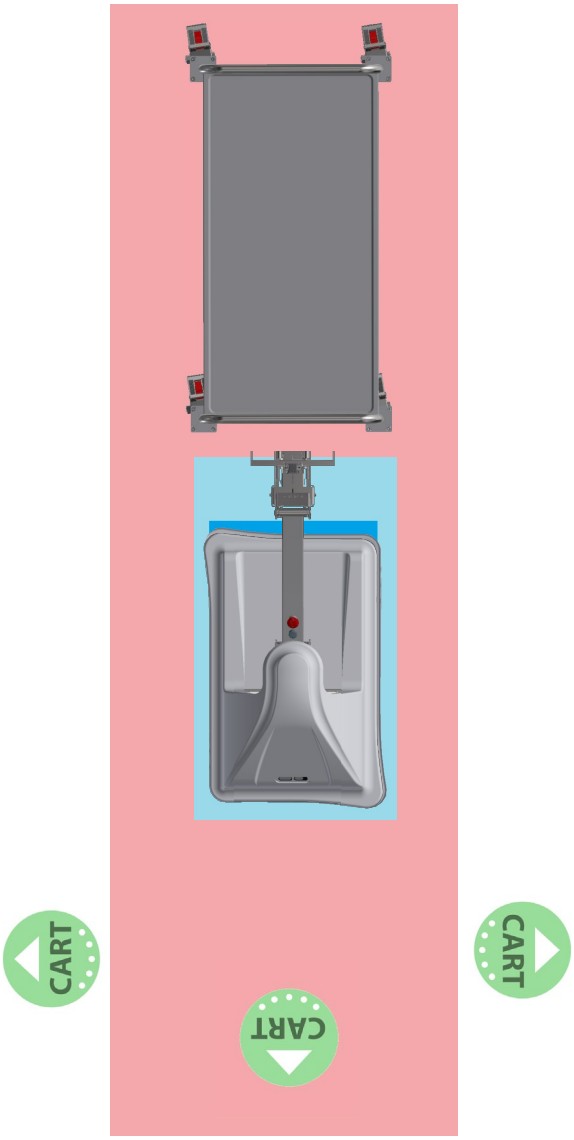
Maximum speed [m/s]	1.5 (1.1)
Awareness indicator	No
Operating hazard zone	No

Phase 4: Driving in reverse towards parking position	Phase 5: Goal position
	

Maximum speed [m/s]	-0.3
Awareness indicator	Yes
Operating hazard zone	Yes

Maximum speed [m/s]	0
Awareness indicator	Yes
Operating hazard zone	Yes

Phase 6: Releasing cart and driving forward



Maximum speed [m/s]	0.2
Awareness indicator	Yes
Operating hazard zone	Yes

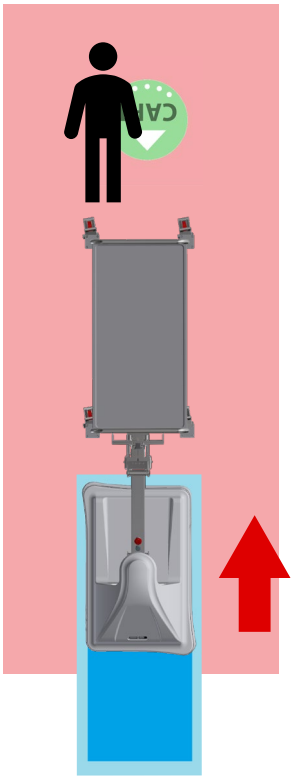
Residual risks

13. A person is standing in the parking zone (phase 4). → Risk of being crushed.

    But:

    - Awareness indicators in phase 4
    - Markings on the floor indicate an operating hazard zone
    - Speed is limited to -0.3 m/s when the robot is driving in reverse to park a cart (not a safety function)
    - The person must take this position in phase 3 or software must fail to see him
    - Only a risk if person does not move.

    Conclusion: Residual risk low.

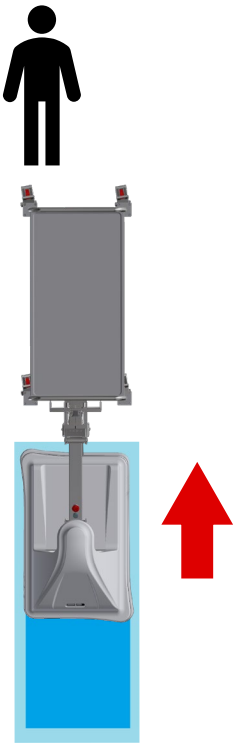


14. Localization fault: The robot is not well localized, and the robot parks the cart in a different area. A person is staying in the parking area. → Risk of being crushed.

    But:

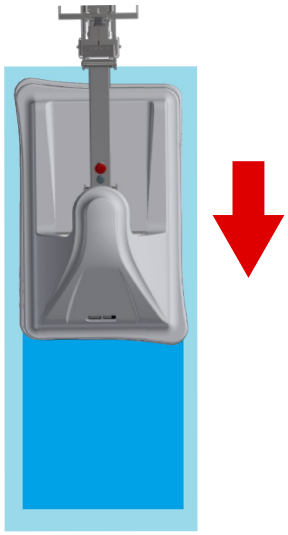
    - Localization fault is improbable
    - Software collision avoidance (not safety function) will detect the person (phase 2) and stop the robot
    - Potentially a lack of escape zone

    Conclusion: Residual risk extremely low.



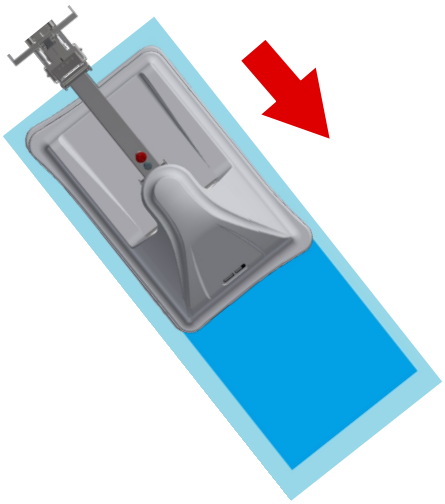
7.6 Driving with MiRHook without a cart

Phase 1: Driving forward



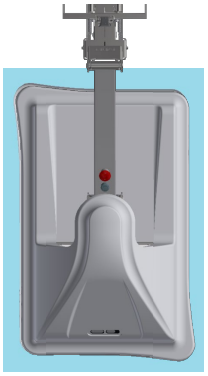
Maximum speed [m/s]	1.5 (1.1)
Awareness indicator	No
Operating hazard zone	No

Phase 2: Turning left or right



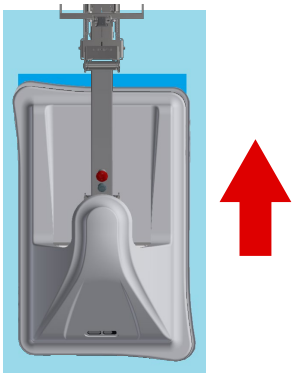
Maximum speed [m/s]	1.5 (1.1)
Awareness indicator	No
Operating hazard zone	No

Phase 3: Stopping



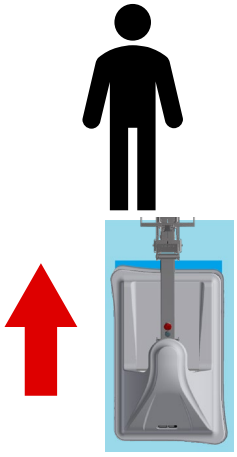
Maximum speed [m/s]	0
Awareness indicator	No
Operating hazard zone	No

Phase 4: Driving in reverse



Maximum speed [m/s]	-0.3
Awareness indicator	No
Operating hazard zone	No

Residual risks

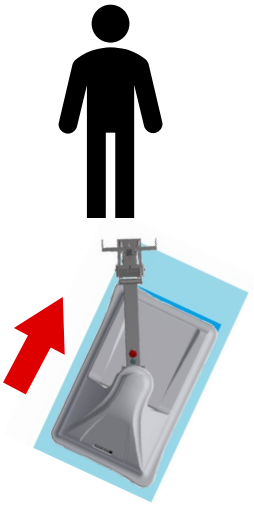


15. The robot is driving in reverse (phase 4). The protective field of the robot is not extended with the MiRHook. A person is standing in the path of the robot. → Risk of being crushed.

    But:

    - Software collision avoidance (not a safety function) will detect the person and stop the robot

    Conclusion: Residual risk low.



16. The MiRHook is released in the Robot interface and a person is standing nearby. → Risk of being crushed.

    But:

    - Software collision avoidance (not a safety function) will detect the person and stop the robot
    - Personnel with access to the Robot interface will be trained to use the interface
    - Releasing the MiRHook is a manual operation

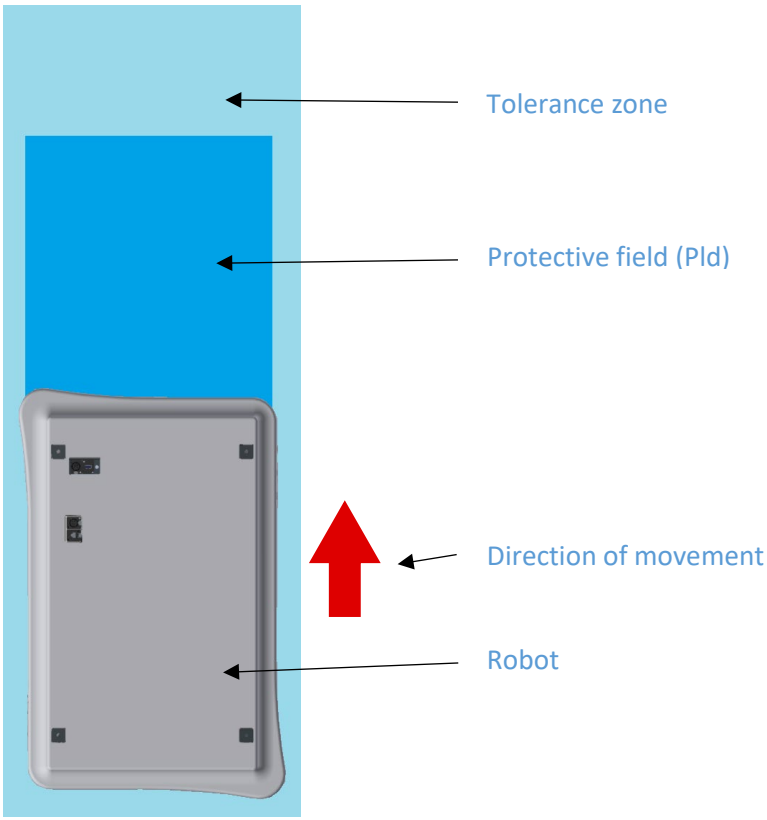
    Conclusion: Residual risk extremely low.

8 Appendix A: Resources

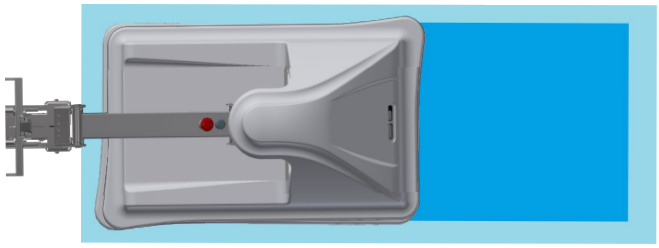
- MiR100 Robot: MiR100 User Guide rev. 3.0
- MiR200 Robot: MiR200 User Guide rev. 2.0
- MiRCharge: MiRCharge Technical Documentation rev. 1.4
- MIRHook: MiRHook Operating Guide rev. 1.9
- Commissioning: Commissioning Documentation rev. 1.0

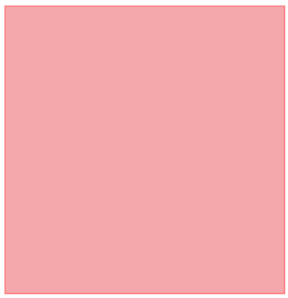
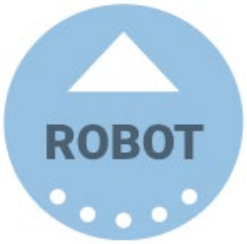
9 Appendix B: Illustrations Documentation

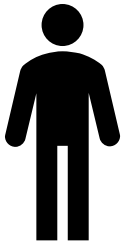
1. Robot
2. Protective field (Pld)
3. Tolerance zone
4. Direction of movement



5. Robot with MiRHook



6. Operating hazard zone	
7. Charging station	
8. Robot position	 
9. Cart position	
10. Cart	

11. Person	

10 Changelog

Version	Date	Changes
0.1	04.07.2019	Document created