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Making the Invisible Visible for Off-Highway Machinery by Conveying Extended Reality Technologies

DELIVERABLE 2.1 – USE CASE SPECIFICATION

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Executive summary

In this project, use cases are defined as descriptions of how a person who uses a process, or a system will accomplish an objective. These use cases outline a system's behaviour from a user's point of view as it responds to a request and is represented as a sequence of steps.

In this document, the work performed so far in Task 2.1 will be summarized. It will present the first versions of the use case specifications. At the first stage, the use cases are described are they currently are with the existing machines used within the demonstrations. In the second sage, XR extensions are identified that will be added/investigated for the solutions and how they would be added to the identified use cases and their scenarios. This will then demonstrate how the different situations unfold with the aid of XR interaction.

The three different use cases (snow grooming, logistics and construction) defined within the THEIA^{XR} project are introduced and described in detail in this document. For each use case, a dedicated chapter (Section 0 to Section 5) within the deliverable is available. There we also describing the utilization of user stories to describe especially operator's role in the process. User Stories are centred on the result and the benefit of the thing you're describing, whereas Use Cases can be more granular, and describe how your system will act. We also listed potential issues which we found during this phase. In section 4 we are concluding results of this deliverable.

This document provides a solid basis to accomplish the proper requirement specification and technical analysis of the applications investigated during the duration of the project. A second, and final, updated version of this deliverable is due in Month 19 of the project and will include the final definition of the use cases. This will be based on the experiences gained and developments performed within the first half of the project.

List of contents

List of figures

List of Tables

1 Introduction

This document specifies the domain–specific use cases within the THEIA^{XR} project. Three different domains associated pilot systems were selected from the field of off-highway and logistics mobile machinery. These three heterogeneous use cases post in part similar and differing requirements on information presentation to the machine operators. The expert-driven use case analysis, reported in this deliverable examines the individual potential value of applying eXtended Reality technologies for presenting data in a new, advanced, and intuitive manner to the human operator. Analysis highlights several critical operation situations. Based on the decomposition of operator workflows and information requirements, the added value and quality of data representation and interaction in extended reality means is discussed in the context of increasing the human-machine collaboration. Selected domain-specific machine types, operation situations and environmental conditions are shortly described in this document and in what kind of environment they are working.

In this document selected operation situations (use cases) are described in detail based on data collection with a formalized questionnaire to collect domain-specific knowledge on within the several domain experts in the consortium. The questionnaire focuses on involved machine and production processes, associated tasks, involved stakeholder, machine functionalities, information, and environmental constraints. The collected data is used to identify and further specify the potential of implementing of XR technologies in human-machine interaction by means of improved information availability, increased usability and suitability to existing task flows and system constraints. In the context of assessed task-based information requirements. The use case specifications are basis for WP3, 4 and 6. Additionally, collected domain and use-case specific operation challenges are discussed, revealing differences regarding feedback and control requirements for cabin-based and teleoperation environments but highlight strong similarities regarding environmental detection, implementation of data from digital terrain and object modelling. Findings provide a basis for the applicability of the solutions in potential other domains.

In the snow groomer use cases the main objective is to supply to the operator the needed information in the best possible and digestible way and to find a solution to drive with sensor and visualization assistance in a complete “white out” (no view to the environment possible). The use case addresses a human mobile machinery interaction task in a very challenging environment, with most often limited visibility to the human operator. The use case considers the operator sitting in a snow groomer cabin and it will contribute ultimately to remote controlled or supervised operation of future snow groomers, whereby the human operator is interacting with the machine from a remote location.

In logistics use case main objective is to support the operator to have a better perception of the task at hand and its context as it can vary from task to task. Also, how digital experience can help in this. Sub-objectives are:

(1) Defining most suitable set of combination of controls to ideal for precision, performance, and ergonomics.
(2) To validate factors in working environment which could be helping operators to concentrate better on their work, and
(3) Defining factors which are affecting desirability of the job.

In construction use cases, the main objective is to provide interfaces to the operator for handling digital design models and their implementation in an efficient and safe way. As a result, different feedback and interaction modalities are evaluated and compared in realistic test environments. Overall, an HMI-concept for operators of highly automated excavators based on mixed-reality technology will be developed.

This document gives a brief introduction into the methodology of data assessment, documentation, and evaluation (chapter 2), followed by a detailed documentation of use case descriptions (system description, actor description, use case analysis, use case diagrams and derived user stories (chapters 3, 4 and 5) and a conclusion of this deliverable (chapter 6).

2 Methodology

2.1 Use case data collection

While conventional human-machine interfaces (HMI) rely on visual terminal-based UI and direct environment monitoring, Extended Reality-technologies offer novel forms of information presentation. Utilizing XR multimodal and augmenting information presentation techniques offers the potential to implement digitally enhanced information spaces more intuitively and effectively embedded into the operator's information perception and processing workflows in machine operation. To use XR technology where it is needed, we conducted an analysis of user workflows within the given use-cases to investigate information requirements and operation specific constraints. As a result, we derived user stories that list prioritized information requirements for involved stakeholders.

To collect related domain-specific information we used a template that was developed by the OEM partners, refined by human-machine interaction experts within the project consortium. For each domain we collected data on at least three different operation scenarios covering typical tasks, machine setups and environmental conditions with a focus on problematic operation situations.

We used the template to collect data on involved machines, involved stakeholders, task goal, success criteria, frequency of occurrence in daily work shifts, pre and post task conditions, basic and alternative workflows and a hypothetical XR enriched workflow. This data was used to collect HMI related challenges and problems with a focus on beneficial XR techniques. The template documents workflows as a sequence of information retrieval, use and human-machine-environment interaction activities highlighting operators' information dependencies within the selected scenarios.

Result was documented in UML use case-diagrams that visualize operators' interactions with the machine HMI. Further User stories were used to extract information requirements that formulate direct requirements for potential integration of XR technology.

These results will be used in the following work packages. In WP 4 useful implementation areas and conditions for XR technologies within the use cases will be retrieved and specified. In WP3 suitable involvement methods for information presentation co-design will be derived and in WP 5 suitable XR technologies will be focused based on these findings.

The assessed workflow descriptions, use-case diagram and user stories enabled a holistic and comparable elaboration of information and interaction requirements for user interfaces with a focus on extending techniques and technologies.

2.2 Use Case Diagram notation

In the Unified Modelling Language (UML), a use case diagram can summarize the details of your system's users (also known as actors) and their interactions with the system. To build one, you'll use a set of specialized symbols and connectors which are depicted in the following Figure 1.

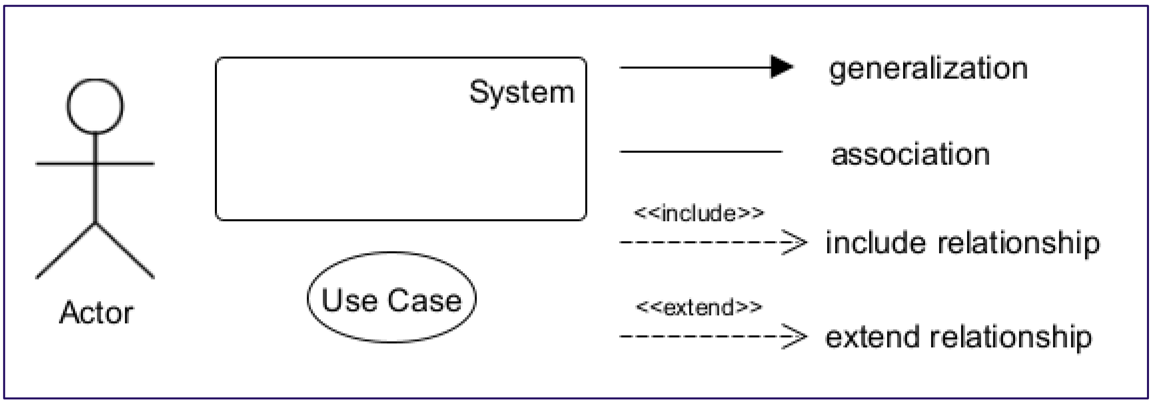

Figure 1: Use Case Diagram notation

2.3 User Stories

As a result of the use case analysis, the user stories document a prioritized list of information requirements across use cases. It allows a cross domain comparison of requirements indicating areas of conjoined HMI requirements that con supported with similar XR solutions.

These compact insights will be used in WP 4 to further detail information characteristics and the development of XR user interfaces and in WP 5 to explore suitable XR technology implementations that will merge into interactive XR use-case demonstrators that showcase beneficial effects of XR for operators.

3 Use case 1 - Snowgrooming

3.1 Description of the system

Generally, snow grooming is the process to prepare, build and maintain any kind of slope or road out of snow. A snowgroomer (Figure 2) is a tracked vehicle, which is equipped with an operator cabin, a blade, a tiller and optionally with a winch. The blade on the front is used for dozing the snow, shaping slope contours, and pre-processing the snow. The tracks allow the snowgroomer to drive on snowy and icy surface, so they give traction and stability to the snowgroomer. With the tiller in the back, you finally process the snow so that in the end you get a long-lasting snow surface. The winch on the top is used for operations in steep terrain.

Figure 2 Snowgroomer during operation ©PRINOTH

Mainly the work needs to be performed outside and on every weather condition during winter months. A skiing day starts in the morning, this requires work to be performed mostly during night.

State of the art technology allow the operator to control and interact with the vehicle in CAN-controlled systems and give permanent feedback on the chosen settings and status of vehicle sub-systems, such as engine, tiller, and winch.

As trend for efficiency, digital systems like telemetric based fleet management and snow measurement (Figure 3) are getting more and more common in ski resorts. Specially the knowledge of the amount of snow and where to bring it is key for a successful slope management. The system use GNSS in combination with RTK technology for identifying the position of the vehicle to an accuracy of 2-3 cm. This position is compared to a predefined terrain model, which can be based on the ground scan of the area or a computer-generated target geometry on the slope or snow terrain park. The offset below the vehicle represents the amount of snow.

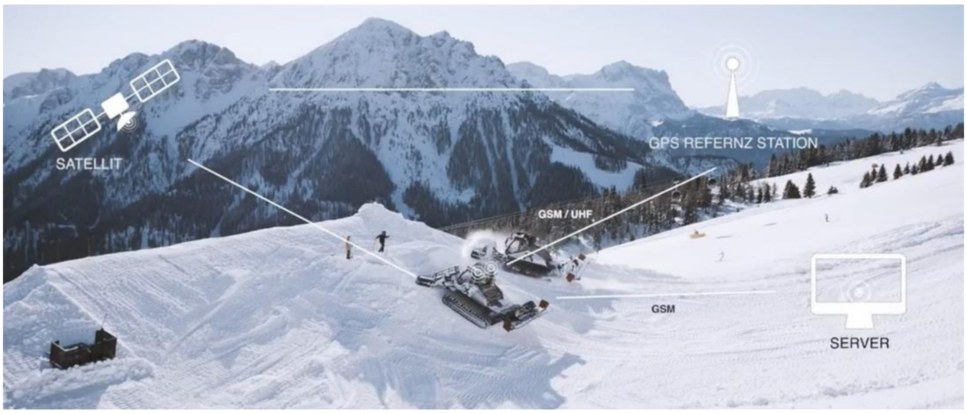

Figure 3 Principle of GNSS RTK snow measurement ©PRINOTH

To bring the operator in the position to act proactive, a measurement not only under the vehicle but also underneath the blade is key. So, he can identify based on a color-coded heat map of the last recorded snow height data decide how to work with the snow and distribute it accordingly.

Within the snowgroomer use-case we considered three scenarios:

- Build slope matching target surface,
- obstacles detection, and
- zero sight navigation

The following tables report on the collected data on involved agents, workflows, and user stories.

3.2 Names and descriptions of the actors

The operation of snow groomers relies on several agents. Table 1 gives an overview about the involved human and technological agents.

Name of the actor	Description
An operator	operates a snowgroomer and all its accessories.
A chief of operation	is responsible for the fleet and snow management within a ski resort. He/she decides onto the work target.
A surface creator	provides a graphical 3D model, which consists of available terrain information and requirements.
A predefined obstacle	is a known static object in the operating area of the snowgroomer.
An unexpected obstacle	is a dynamic object (f. ex. a skier) that can occur within the area of operation.
A snow measurement system	is capturing the actual exact position (via GNSS + RTK) of a snowgroomer on a slope. Combining the collected data with the existing data from the terrain scan, the actual snow depth can be calculated.
An object detection system	is analysing the surrounding and detecting obstacles within its scanning radius.

Table 1: Names and descriptions of the actors UC1

3.3 Snowgroomer use cases

3.3.1 Use Case 1.1

The use case „Build Slope Matching Target Surface" (Table 1) describes which activities are required from which actor to create a surface that corresponds to the target surface. First, the chief of operation must define his requirements on the target surface and align with the surface creator. Out of the defined requirement (e.g., Snowpark) the surface creator designs the georeferenced target surface and uploads it to the snow measurement system within a snowgroomer. This snow measurement system compares the measured actual surface with the target and shows via UI (Figure 4) the difference to the operator. Finally, the operator has to execute actions to reach the target surface. The use case is depicted as a use case diagram in Figure 7.

Use case name	build slope matching target surface
Use case number	1.1
Summary description	Visualization of needed information and actions to reach target surface
Status	V1
Stakeholders/actors (primary actor bolded)	**1. Operator**
	2. chief of operation
	3. surface creator
	4. snow measurement system
Use case goal	finished slope matches target surface
Frequency of occurrence	daily
Preconditions	1. target surface inc. tolerance and actualization based on snow situation
	2. snow depth system (e.g. GNSS + RTK, area summer scan, kinematic sensors)
	3. actual slope condition (e.g. stereo camera, LIDAR)
	4. Guideline principles for grooming (uphill, downhill, side hill, max height in 1 operation step, windrow…)
	5. HMI system
Post-Condition(s)	target surface matched and recorded
Basic flow	1. start-up system
	2. positioning and tracking of vehicle
	3. vehicle enters area with target surface
	4. analysis of delta from actual to target surface
	5. execution by operator to reach target
	6. record result / new actual surface
	7. share new actual surface with other vehicles and to cloud
	8. vehicle exit area
Alternative flow(s)	2a. localization not possible
	3a. No target surface specified
	3b. Area boundaries invalid
	4a. System defect
	4b. No actual surface data available
	5a. Delta above guideline principles

	5b. Operator / system over / under compensates
	7a. No connection for data sharing
Exceptions	-
Success Criteria	Operator is informed about fulfilment rate
	Operator is willing to fulfil and to follow instructions from system
Challenges and Problems	How to visualize the information
	Not to be distractive to the operator

Table 2: Snowgroomer Use Case 1.1 Build slope matching target surface

XR Flow - How situation unfolds with XR interaction

Advanced flow	1. start up system
	2. positioning and tracking of vehicle
	3. vehicle enters area with target surface
	4. indicate to operator that system is activated (XR or trad.)
	5. analysis of delta from actual to target surface
	6. use XR-technology to visualize actual and target surface
	7. use XR-technology to inform about deviations and action required to reach target along expected trajectory • Use kinematic feedback to attract the operator toward the ideal height and angle of the blade • The operator is not constrained to the ideal profile, he/she can adapt but an active movement against the kinematic feedback is needed • The kinematic feedback adapts to the control mode chosen by the operator (front blade, etc)
	8. execution by operator / system
	9. record result / new actual surface and operator / system action
	10. share new actual surface with other vehicles and to cloud (XR-technology)
	11. inform about fulfilment rate (XR in the snow groomer, office PC...)
	12. indication vehicle exit area (XR or trad.)
Alternative flow(s)	2a. localization not possible
	3a. No target surface specified
	3b. Area boundaries invalid
	4a. System malfunction indicate to operator
	5a. System defect
	5b. No actual surface data available
	6a. Additional control axes can be allocated for more intuitive operation (e.g. substitution for buttons)
	7a. Delta above guideline principles
	8a. Operator / system over-/ undercompensates
	10a. No connection for data sharing
	11a visualization fulfilment rate outside specified tolerance

Table 3: XR Flow for Snowgroomer Use case 1.1

Figure 4 Snowgroomer interface touch screen for snow measurement ©PRINOTH

Figure 5 Touch screen showing a 3D park model target surface ©PRINOTH

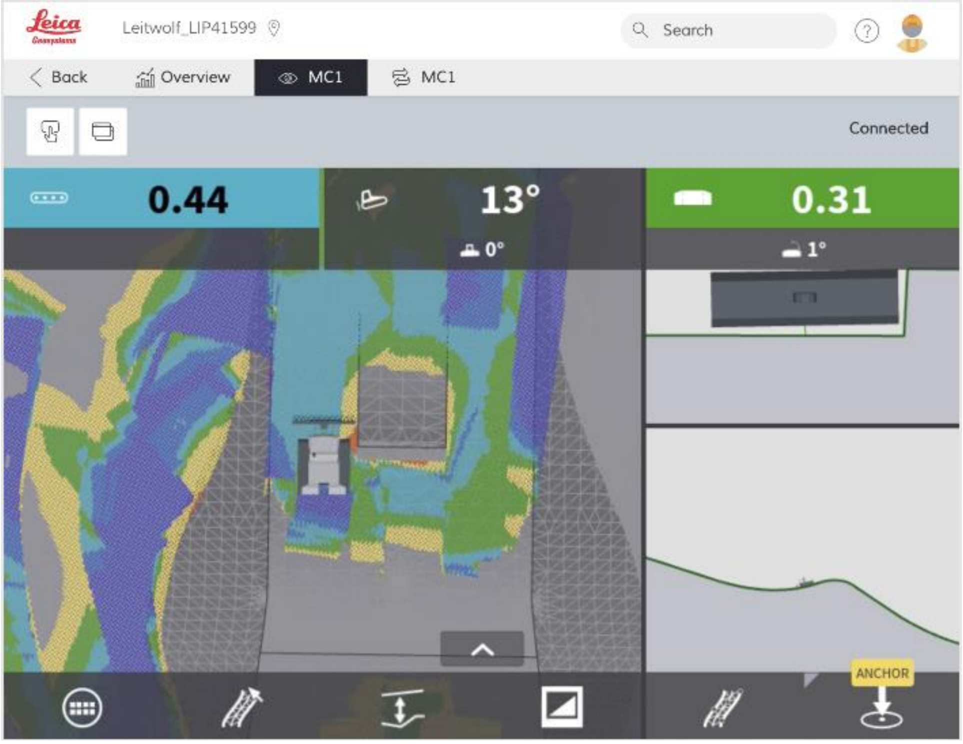

Figure 6 Touch screen showing top, side and blade view ©PRINOTH

3.3.2 Use Case 1.2

The use case "Obstacles Detection" (Table 4) describes the required activities to avoid collisions during operation. The full visibility to the surrounding of a snowgroomer is not realizable by design. Assistant systems like cameras help the operator to widen the field of visibility. Even using all systems to the best of their ability, collisions still occur. In the working area of a snowgroomer there are static obstacle that are known (e.g., snow gun, pillar, pit, crevasse...) and there appear unexpected dynamic obstacles (e.g., skier). The object detection system detects known and unexpected objects and informs/warn the operator in case of a potential risk. The operator permanently observes the surrounding and checks the inputs from the system. In most of the cases with this information the operator sets corrective actions to avoid a collision. The use case is depicted as a use case diagram in Figure 9.

Use case name	obstacles detection
Use case number	1.2
Summary description	Inform about obstacles that are met during operation - predefined or unexpected (e.g., skiers, animals, trees, rocks, buildings, other vehicles on the slope, winch cable, snow pile...)
Status	V1
Stakeholders/actors (primary actor bolded)	1. **Operator**
	2. surface creator
	3. predefined or unexpected obstacles
	4. chief of operation
	5. object detection system
Use case goal	Inform the human operator about obstacles
Frequency of occurrence	permanent
Preconditions	1. virtual ski area representation (slopes inc. snow height info, boundaries, buildings, obstacles, height and width limitation, anchor points...)

	2. GNSS, better with RTK
	3. obstacle detection system
	4. guideline principles for grooming (uphill, downhill, side hill, max height in 1 operation step, windrow…)
	5. HMI system
Post-Condition(s)	Early warning in case of detection to avoid collision
Basic flow	1. start-up system
	2. positioning and tracking of vehicle
	3. active connection to cloud or other vehicles to get/share actual (static) surrounding information
	4. obstacle detection system active
	5. warning to operator in case of obstacle or boundary proximity
	6. execution by operator / system
Alternative flow(s)	4a. Warning to operator if system failure
Exceptions	-
Success Criteria	Detection and visualization of obstacles
Challenges and Problems	Travel speed (relevant for reaction time)
	Not to be distractive to the operator
	How to inform about the information
	Moving obstacles might continue moving, also after detection.
	No detection because of snow or ice

Table 4: Use Case 1.2: Obstacles detection

XR Flow - How situation unfolds with XR interaction

Advanced flow	1. startup system
	2. positioning and tracking of vehicle
	3. active connection to cloud or other vehicles to get/share actual (static) surrounding information
	4. obstacle detection system active
	5. visualize surrounding including real time obstacles to operator (XR technology)
	6. warning to operator in case of obstacle or boundary proximity
	7. execution by operator / system
	8. record action and surrounding data
	9. share recorded data with other vehicles and cloud (XR or trad.)
Alternative flow(s)	4a. Warning to operator if system failure
	7a. New concept for controlling direction / speed with force-feedback joystick

Table 5: XR Flow for Use case 1.2

Figure 7 Potential scenario of a snowgroomer operator view using XR-technology ©PRINOTH

3.3.3 Use Case 1.3

The environmental condition influences the snowgrooming operation. In the worst case it causes a complete “White out” (no view to the environment possible). The operator still needs to perform his activities without bringing him or any other in dangerous situation. The use case “Zero Sight Navigation” describes the required activities in this critical situation. This use case presupposes use case 1.1 and 1.2. as functional and implemented. The systems need to perform also with no direct view. The operator needs to fully trust the input of the system and set the required action accordingly. The use case is depicted as a use case diagram in Figure 10.

Use case name	zero sight navigation
Use case number	1.3
Summary description	navigation under no-sight condition
Status	V1
Stakeholders/actors (primary actor bolded)	1. **Operator**
	2. surface creator (PRINOTH CONNECT TEAM)
	3. chief of operation
	4. unexpected object (living or dead)
	5. object detection system
Use case goal	system supplies navigation and surrounding information to compensate zero sight situation
Frequency of occurrence	depending on weather situation
Preconditions	1. virtual ski area representation (slopes inc. snow height info, boundaries, buildings, obstacles, height and width limitation, anchor points…)
	2. GNSS, better with RTK
	3. Zero sight obstacle detection system
	4. guideline principles for grooming (uphill, downhill, side hill, max height in 1 operation step, windrow…)

	5. HMI system
Post-Condition(s)	vehicle reaches desired end position without collision and the most appropriate way uploading of registered data
Basic flow	1. start-up system
	2. positioning and tracking of vehicle
	3. active connection to cloud or other vehicles to get/share actual surrounding information
	4. obstacle detection system active
	5. vehicle enters area with zero sight
	6. warning to operator in case of obstacle or boundary proximity
	7. execution by operator / system
Alternative flow(s)	2a. vehicle tracked without GNSS (based on to vehicle driving parameter, IMU….)
Exceptions	-
Success Criteria	Provide enough information to the operator to navigate under no-sight condition
Challenges and Problems	How to visualize the information distorted by environmental influences (snow, fog, snowstorm...)
	Not to be distractive to the operator
	Full reliability to the system

Table 6: Use Case 1.3: Zero sight navigation

XR Flow - How situation unfolds with XR interaction

Advanced flow	1. startup system
	2. positioning and tracking of vehicle
	3. active connection to cloud or other vehicles to get/share actual surrounding information
Advanced flow Alternative flow(s)	4. obstacle detection system active
	5. vehicle enters area with zero sight
	6. inform about surrounding including real time obstacles to operator (XR-technology)
	7. warning to operator in case of obstacle or boundary proximity (XR-technology)
	8. execution by operator / system
	9. record path and surrounding data
	10. share data with other vehicles and cloud
Alternative flow(s)	2a. vehicle tracked without GNSS (based on to vehicle driving parameter, IMU….)
	8a. New concept for controlling direction/speed with force-feedback joystick

Table 7: XR Flow for Use case 1.3

3.4 Use case diagrams

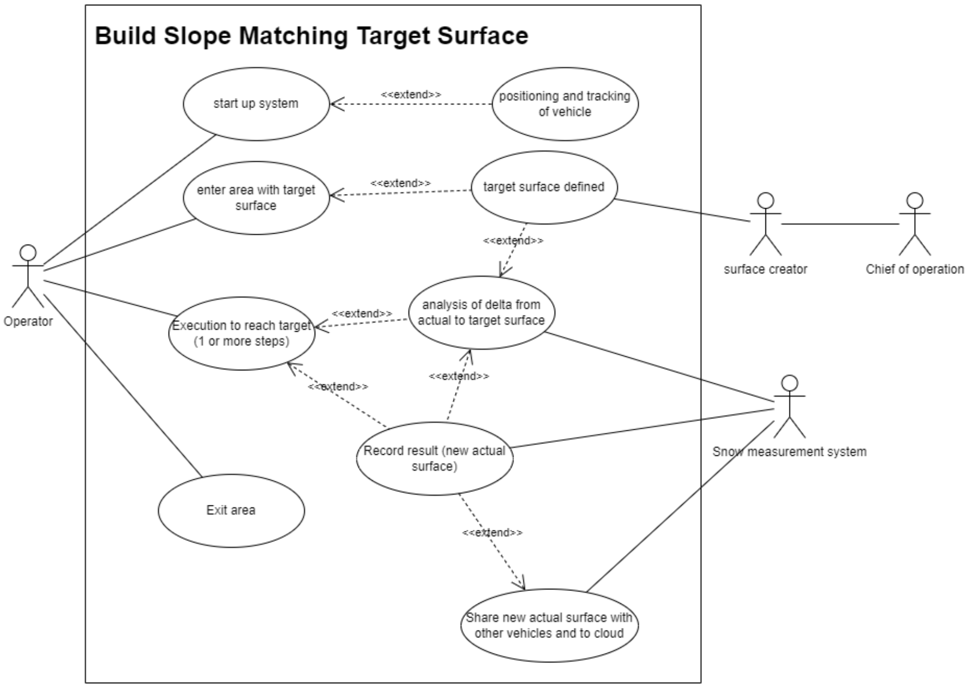

Figure 8 Use-Case Diagram for "Snowgroomer Use Case 1.1 - Build slope matching target surface"

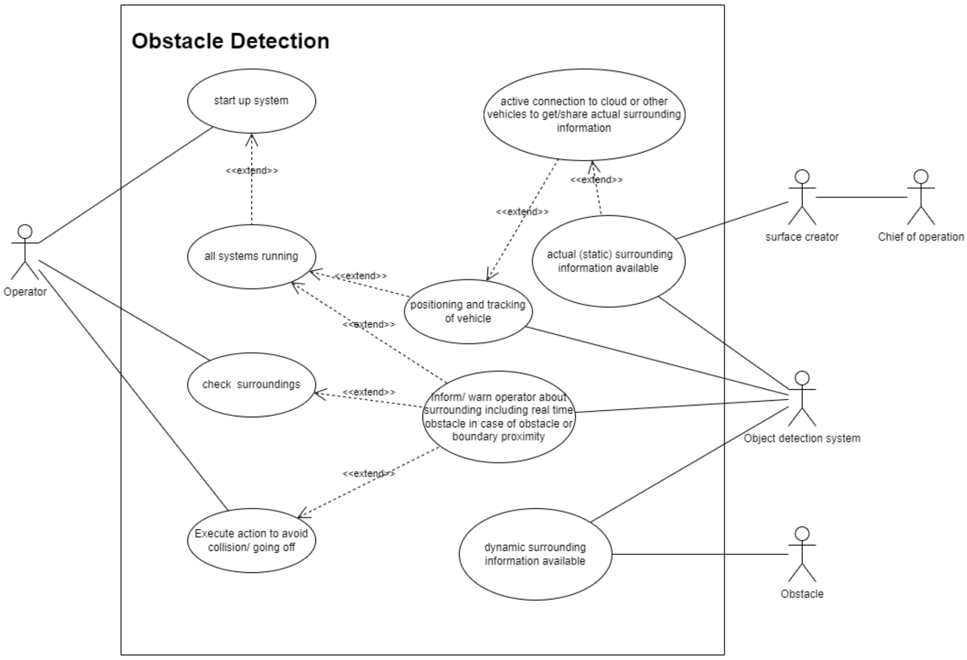

Figure 9 Use- Case Diagram for "Snowgroomer Use Case 1.2 - Obstacle detection"

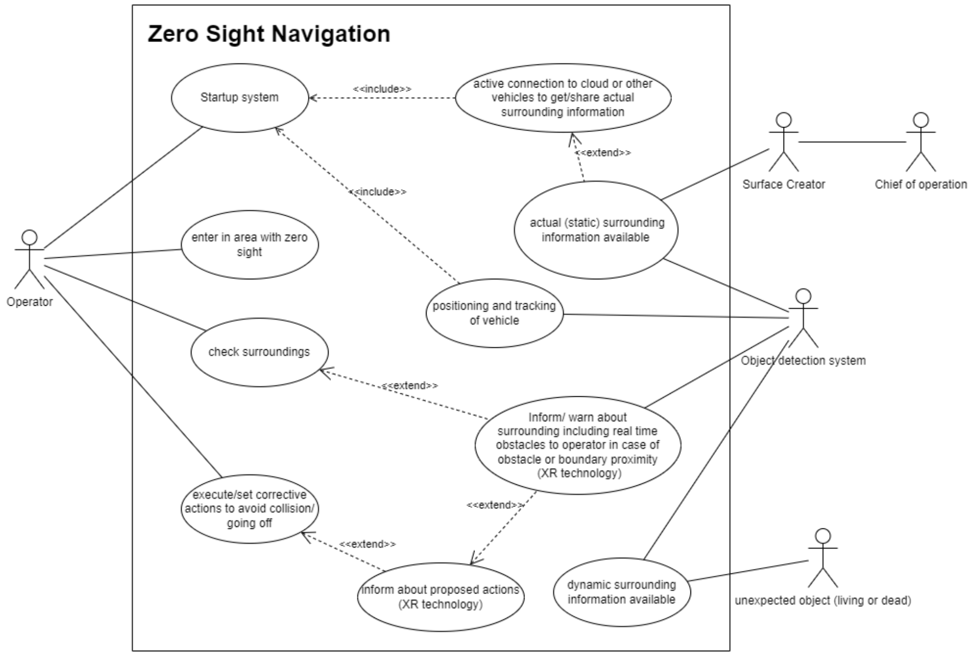

Figure 10 Use- Case Diagram for “Snowgroomer Use Case 1.3 - Zero sight navigation”

3.5 User stories

ID	PRIORITY	AS A [type of user]	I NEED TO [do some task]	SO THAT I CAN [get some result]	STATUS	UC 1.1	UC 1.2	UC 1.3
1.1	Must have	Operator	get a clear indication of the system status	rely on the functionality or understand malfunction	Open	x	x	x
1.2	Must have	Operator	operate the blade, tracks, winch and the tiller according to the topography and the snow condition	get a perfect target slope prepared	Open	x	x	x
1.3	Must have	Operator	control the front blade	smooth/shape the surface	Open	x		
1.4	Must have	Operator	observe the area x meters ahead	plan and set action to achieve my target surface	Open	x		
1.5	Must have	Operator	observe the area x meters ahead	plan and set action to avoid collisions and accidents	Open		x	x
1.6	Must have	Operator	monitor the vehicle traction	set corrective action in speed and steering to prevent stopping and surface damage	Open	x	x	x

1.7	Must have	Operator	know where other vehicles are located	plan and set actions to increase efficiency and to avoid collisions/incidents	Open	x	x	x
1.8	Must have	Operator	know if and where a winch vehicle is anchored	avoid entering in dangerous area	Open	x	x	x
1.9	Should have	Operator	know where mobile snow guns are in functions	avoid collisions with water hoses or cables	Open		x	x

Table 8: User stories for Snowgroomer Use Cases

3.6 Issues

The following issues have been depicted:

- How to visualize the required information to the operator?
- Due to limited view around the vehicle, it is hard to see/detect obstacles around.
- Operator needs to work also in complete “whiteout” with no view.
- With no view it is not possible to detect obstacles with the eyes.

4 Use case 2 – Logistics

4.1 Description of the system

4.1.1 Reachstacker (RS)

A reachstacker is a container-handling machine / container lifter / container crane like a crane but at the end of the boom it has a spreader and this way it can lift 20´- 40´ empty and full containers from 10 to 45 tons up to 6 containers high in the first row. It can even load and unload containers in the second and in the third row. With the rotating spreader the driver can put the container in the right position. Reach stackers can be adapted for any lifting operations in ports, terminals, and stevedoring operations such as container handling.

As reachstackers offer a more efficient and economical solution than any other type of container-handling machine and don't take up too much space, they are widely in operation in many ports and container terminals. Modern reach stackers have an elevating cabin to improve the visibility of the driver.

A special type of reachstacker is the intermodal reachstacker / combi reachstacker. In comparison to the other type of reachstackers it has four extra arms fitted to the spreader called piggy-back. With this extra attachment and with its long wheelbase it can lift and lower laden containers together with the trailer from/onto wagons / railcars on the second rail lift.

Figure 11 Kalmar reachstacker ©KALMAR

4.1.2 Remote control (RC)

Remote operations can improve overall operator performance primarily by extending visibility with multiple camera views. Cameras can be zoomed in on the container and big angles all around the machine can be seen. It helps operators to do the work more efficiently as well as enhance safety.

Remote operations also serve to improve the working environment for equipment operators by physically removing them from the machines into the safety and comfort of a control room. The control room also enables a more versatile workplace. If some tasks could be automated, one operator can even operate many machines efficiently from one desk.

There are several benefits to using a remote-controlled container-handling machine, including:

- Improved Safety: With a remote-controlled container-handling machine, operators can control the equipment from a safe distance, reducing the risk of injury or accidents.
- Increased Efficiency: fewer people, reducing labour costs and increasing productivity when automatic features are available, can operate Remote-controlled container handling machines.
- Flexibility: Remote-controlled container handling machines can be operated from a variety of locations, allowing operators to work in different areas and access hard-to-reach spaces.
- Reduced Downtime: Remote controlled cargo handling machines can be easily serviced and maintained because of advanced (predictive) monitoring system, reducing downtime and increasing overall equipment reliability.

Within the logistics use-case we considered the following scenarios:

- Remote controlled reachstacker (RS): Job order to pick from the stack,
- Remote controlled RS: Job order to place to the stack,
- Remote controlled RS: Job order to pick from the ground,
- Remote controlled RS: Job order to place on the ground,
- Remote controlled RS: Job order to pick from the trailer, and
- Remote controlled RS: Job order to place to the trailer

The following tables report on the collected data on involved agents, workflows and user stories.

Figure 12: Kalmar Remote Control Desk ©KALMAR

4.2 Names and descriptions of the actors

Name of the actor	Description
An operator	controls the machine with Remote-Control (RC) desk.
Reachstackers	move containers.
A remote control desk	includes all needed controls and equipment which are needed to operate reachstackers remotely.
Sensors	collect needed measurements for the operator and for the automation system.
Infrastructure	includes components for wireless communication, safety, maintenance, and security.

Table 9: Names and descriptions of the actors UC2

4.3 Logistics use cases

4.3.1 Use Case 2.1

The use case „Remote controlled RS: Job order to pick from the stack" (Table 10)describes which activities are required from which actor to pick sea container from the yard stack where there is adjacent containers around the target container. First, the Terminal Operating System (TOS) sends planned pick job order to the free remote control desk and remote operator chooses the job from the screen and starts to execute the job. The automation system has already driven the machine near the target position and RC operator's job is to drive the machine over target position, lower the boom and pick the container and lift it above safe height. The job must be done without collisions against adjacent containers and landing of the spreader should be done smoothly. The user interface and control systems should assist operators to execute the job correctly. The use case is depicted as a use case diagram in Figure 20.

Use case name	Remote controlled RS: Job order to pick from the stack
Use case number	UC2.1
Summary description	The remote operator at RC desk receives the job order, moves RS over the target slot, and picks the container from the stack.
Status	V2
Stakeholders/actors (primary actor bolded)	**1. Remote operator**
	2. Terminal operating system (TOS)
	3. Container position indicator (CPI)
Relevant characteristics (of primary actor)	1. Experienced in remote control of cargo handling machines
	2. Container handling knowledge
	3. Expertise in port operations
Use case goal	To pick container without collisions
Frequency of occurrence	Regularly
Preconditions	1. Valid job order is received from TOS.
	2. Remote operator is available
	3. Machine is ready for operation
Post-Condition(s)	Container is above safe height and not touching adjacent containers

	Transportation move
Basic flow	1. Remote operator at RC desk receives job order from TOS.
	2. Remote operator moves RS to position appointed by job order, moves spreader with the help of CPI over target slot and changes spreader size according to TOS job order.
	3. Remote operator lifts the container and CPI sends lift message to system. System delivers lift message to TOS.
Alternative flow(s)	1. Operation with over-high folding legs
Exceptions	Damaged container can't be picked
Success criteria	Container picked without damages
Challenges and problems	Harsh weather conditions (fog, snow, wind etc.), stability issues, surface quality of ground

Table 10: Use Case 2.1: Remote controlled RS: Job order to pick from the stack

Figure 13: Reachstacker picking container from stack ©KALMAR

XR Flow - How situation unfolds with XR interaction

XR supported workflow	1. Shows TOC job order via AR/XR in video feed. E.g. also highlights container location
	2. Show to user spreader corner in video overlay via AR/XR. This will support user to understand if the spreader is correctly located in relation to container underneath and adjacent containers.
	3. Bird view from spreader and container or 3D view of them to support RS operator to lift container without collision. XR-supported safety warning if someone (human or machine is arriving close to working area. Multi-modal support:
	3.1. Also, haptics feedback to support lifting Augment the operator interface with force-feedback Apply repulsion force on potential collisions; the repulsion force must be adapted based on the incoming speed to compensate inertia Implement attractive force for precise alignment with the target position Implement virtual fixtures to guide the operator along a predefined path after a precise alignment is achieved
	3.2. Also, audio feedback from distance and location before collision
	Devices: HMD, Power wall, normal screen, haptic device, 3D audio device

Figure 14: XR Flow for Use case 2.1

4.3.2 Use Case 2.2

The use case „ Remote controlled RS: Job order to place to the stack" (Table 11) describes which activities are required from which actor to place sea container to the yard stack where there is adjacent containers around the target container. First, the Terminal Operating System (TOS) sends planned place job order to the free remote control desk and remote operator chooses the job from the screen and starts to execute the job. The automation system has already driven the machine near the target position and RC operator's job is to drive the machine and container over the target position, lower the container on top of the container below and release the spreader and lift spreader above safe height. The job must be done without collisions against adjacent containers and landing of the container should be done smoothly. The user interface and control systems should assist operator to execute the job correctly. The use case is depicted as a use case diagram in Figure 21.

Use case name	Remote controlled RS: Job order to place to the stack
Use case number	UC2.2
Summary description	The remote operator at RC desk receives the job order, moves RS over the target slot, and places the container on the stack.
Status	V2
Stakeholders/actors (primary actor bolded)	**1. Remote operator**
	2. Terminal operating system (TOS)
	3. Container position indicator (CPI)
Relevant characteristics (of primary actor)	1. Experienced in remote control of cargo handling machines
	2. Container handling knowledge
	3. Expertise in port operations
Use case goal	To place container without collisions
Frequency of occurrence	Regularly

Preconditions	1. Valid job order is received from TOS.
	2. Remote operator is available
	3. Machine is ready for operation
Post-Condition(s)	Container is landed to correct position
	Spreader released and spreader above safe height
	Transportation move
Basic flow	1. Remote operator at RC desk receives job order from TOS.
	2. Remote operator moves RS to position appointed by job order, moves spreader and container with the help of CPI over slot and places container according to TOS job order.
	3. Remote operator lowers the container and CPI sends grounded message to system. System delivers lift message to TOS.
Alternative flow(s)	1. Operation with over-high folding legs
Exceptions	Twist locks are stuck.
Success criteria	Container picked without damages
Challenges and problems	Harsh weather conditions (fog, snow, wind etc.), stability issues, surface quality of ground

Table 11: Use Case 2.2: Remote controlled RS: Job order to place to the stack

Figure 15: Reachstacker placing container to the stack ©KALMAR

XR Flow - How situation unfolds with XR interaction

XR supported workflow	1. Shows TOC job order via AR/XR in video feed. E.g. also highlights container location in relation to container underneath and adjacent containers. 2. Show to user spreader corner in video overlay via AR/XR. This will support user to understand if the spreader is correctly located.
	3. Bird view from spreader and container or 3D view of them to support RS operator to lower container to correct position without collision. XR-supported safety warning if someone (human or machine is arriving close to working area. Multi-modal support: 3.1. Also, haptics feedback to support placing container to correct position • Augment the operator interface with force-feedback • Apply repulsion force on potential collisions; the repulsion force must be adapted based on the incoming speed to compensate inertia • Implement attractive force for precise alignment with the target position • Implement virtual fixtures to guide the operator along a predefined path after a precise alignment is achieved
	3.2. Also, audio feedback from distance and location before collision
	Devices: HMD, Power wall, normal screen, haptic device, 3D audio device

Table 12: XR Flow for Use Case 2.2

4.3.3 Use Case 2.3

The use case „Remote controlled RS: Job order to pick from the ground" (Table 10) describes which activities are required from which actor to pick sea container from the yard stack where there is adjacent containers around the target container. First, the Terminal Operating System (TOS) sends planned pick job order to the free remote control desk and remote operator chooses the job from the screen and starts to execute the job. The automation system has already driven the machine near the target position and RC operator's job is to drive the machine and spreader over the target position, lower the boom and pick the container and lift it above safe height. The job must be done without collisions against adjacent containers and landing of the spreader should be done smoothly. The user interface and control systems should assist operator to execute the job correctly. The use case is depicted as a use case diagram in Figure 22.

Use case name	Remote controlled RS: Job order to pick from the ground
Use case number	UC2.3
Summary description	The remote operator at RC desk receives the job order, moves RS over the target slot, and picks the container from the ground.
Status	V2
Stakeholders/actors (primary actor bolded)	1. **Remote operator**
	2. Terminal operating system (TOS)
	3. Container position indicator (CPI)
Relevant characteristics (of primary actor)	1. Experienced in remote control of cargo handling machines
	2. Container handling knowledge
	3. Expertise in port operations
Use case goal	To pick container without collisions
Frequency of occurrence	Regularly

Preconditions	1. Valid job order is received from TOS.
	2. Remote operator is available
	3. Machine is ready for operation
Post-Condition(s)	Container is above safe height and not touching adjacent containers
	Transportation move
Basic flow	1. Remote operator at RC desk receives job order from TOS.
	2. Remote operator moves RS to position appointed by job order, moves spreader with the help of CPI over slot and changes spreader size according to TOS job order.
	3. Remote operator lifts the container and CPI sends lift message to system. System delivers lift message to TOS.
Alternative flow(s)	1. Operation with over-high folding legs
Exceptions	Damaged container can't be picked
Success criteria	Container picked without damages
Challenges and problems	Harsh weather conditions (fog, snow, wind etc.), stability issues, surface quality of ground

Table 13: Use Case 2.3: Remote controlled RS: Job order to pick from the ground

Figure 16: Reachstacker picking container from the ground. ©KALMAR

XR Flow - How situation unfolds with XR interaction

XR supported workflow	1. Shows TOC job order via AR/XR in video feed. E.g. also highlights container location 2. Show to user spreader corner in video overlay via AR/XR. This will support user to understand if the spreader is correctly located in relation to container underneath and adjacent containers.
	3. Bird view from spreader and container or 3D view of them to support RS operator to lift container without collision. XR-supported safety warning if someone (human or machine is arriving close to working area. Multi-modal support: 3.1. Also, haptics feedback to support lifting • Augment the operator interface with force-feedback • Apply repulsion force at predefined height above the ground
	3.2. Also, audio feedback from distance and location before collision
	Devices: HMD, Power wall, normal screen, haptic device, 3D audio device

Table 14: XR Flow for Use Case 2.3

4.3.4 Use Case 2.4

The use case „ Remote controlled RS: Job order to place on the ground" (Table 11) describes which activities are required from which actor to place sea container to the yard stack where there is adjacent containers around the target container. First, the Terminal Operating System (TOS) sends planned place job order to the free remote control desk and remote operator chooses the job from the screen and starts to execute the job. The automation system has already driven the machine near the target position and RC operator's job is to drive the machine and container over the target position (Marked with painted lines on ground), lower the container on ground and release the spreader and lift spreader above safe height. The job must be done without collisions against adjacent containers and landing of the container should be done smoothly to correct position in relation to painted lines. The user interface and control systems should assist operator to execute the job correctly. The use case is depicted as a use case diagram in Figure 23.

Use case name	Remote controlled RS: Job order to place on the ground
Use case number	UC2.4
Summary description	The remote operator at RC desk receives the job order, moves RS over the target slot, and places the container on the ground
Status	V2
Stakeholders/actors (primary actor bolded)	**1. Remote operator**
	2. Terminal operating system (TOS)
	3. Container position indicator (CPI)
Relevant characteristics (of primary actor)	1. Experienced in remote control of cargo handling machines
	2. Container handling knowledge
	3. Expertise in port operations
Use case goal	To place container without collisions
Frequency of occurrence	Regularly
Preconditions	1. Valid job order is received from TOS. Remote operator is available.
	2. Remote operator is available
	3. Machine is ready for operation

Post-Condition(s)	Container is landed to correct position
	Spreader released and spreader above safe height
	Transportation move
Basic flow	1. Remote operator at RC desk receives job order from TOS.
	2. Remote operator moves RS to position appointed by job order, moves spreader and container with the help of CPI over slot and places container according to TOS job order.
	3. Remote operator lowers the container and CPI sends grounded message to system. System delivers lift message to TOS.
Alternative flow(s)	1. Operation with over-high folding legs
Exceptions	Twist locks are stuck
Success criteria	Container picked without damages
Challenges and problems	Harsh weather conditions (fog, snow, wind etc.), stability issues, surface quality of ground

Table 15: Use Case 2.2: Remote controlled RS: Job order to place on the ground

Figure 17: Reachstacker placing container to the ground ©KALMAR

XR Flow - How situation unfolds with XR interaction

XR supported workflow	1. Shows TOC job order via AR/XR in video feed. E.g. also highlights container location 2. Show to user spreader corner in video overlay via AR/XR. This will support user to understand if the spreader is correctly located in relation to adjacent containers or painted lines on ground.
	3. Bird view from spreader and container or 3D view of them to support RS operator to place container to correct position without collision. XR-supported safety warning if someone (human or machine is arriving close to working area. Multi-modal support: 3.1. Also, haptics feedback to support lowering • Augment the operator interface with force-feedback • Apply repulsion force at predefined height above the ground
	3.2. Also, audio feedback from distance and location before collision
	Devices: HMD, Power wall, normal screen, haptic device, 3D audio device

Table 16: XR Flow for Use Case 2.4

4.3.5 Use Case 2.5

The use case „Remote controlled RS: Job order to pick from the trailer” (Table 17) describes which activities are required from which actor to pick sea container from the trailer where the cabin of the terminal tractor is near container target position. First, the Terminal Operating System (TOS) sends planned pick job order to the free remote control desk and remote operator chooses the job from the screen and starts to execute the job. The automation system has already driven the machine near the target position and RC operator’s job is to drive the machine and spreader over the target container, lower the boom and pick the container and lift it above safe height. The job must be done without collisions against terminal tractor structures and so that the trailer is not lifted together with container. This can happen if container locks are not fully open. The user interface and control systems should assist operator to execute the job correctly. The use case is depicted as a use case diagram in Figure 24.

Use case name	Remote controlled RS: Job order to pick from the trailer
Use case number	UC2.5
Summary description	The remote operator at RC desk receives the job order, moves RS over the trailer and correct slot, and picks the container.
Status	V2
Stakeholders/actors (primary actor bolded)	**1. Remote operator**
	2. Terminal operating system (TOS)
	3. Container position indicator (CPI)
Relevant characteristics (of primary actor)	1. Experienced in remote control of cargo handling machines
	2. Container handling knowledge
	3. Expertise in port operations
Use case goal	To pick container without collisions
Frequency of occurrence	Regularly
Preconditions	1. Valid job order is received from TOS.
	2. Remote operator is available
	3. Machine is ready for operation
Post-Condition(s)	Container is above safe height and not touching adjacent containers
	Transportation move
Basic flow	1. Remote operator at RC desk receives job order from TOS.
	2. Remote operator moves RS to position appointed by job order, moves spreader with the help of CPI over target slot and changes spreader size according to TOS job order.
	3. Remote operator lifts the container and CPI sends lift message to system. System delivers lift message to TOS.
Alternative flow(s)	1. Operation with over-high folding legs
Exceptions	Damaged container can't be picked
Success criteria	Container picked without damages
Challenges and problems	Harsh weather conditions (fog, snow, wind etc.), stability issues, surface quality of ground

Table 17: Use Case 2.5: Remote controlled RS: Job order to pick from the trailer

Figure 18: Reachstacker picking container from the trailer ©KALMAR

XR Flow - How situation unfolds with XR interaction

XR supported workflow	1. Shows TOC job order via AR/XR in video feed. E.g. also highlights container location 2. Show to user spreader corner in video overlay via AR/XR. This will support user to understand if the spreader is correctly located.
	3. Bird view from spreader and container or 3D view of them to support RS operator to lift container without collision. XR-supported safety warning if someone (human or machine is arriving close to working area. Multi-modal support: 3.1. Also, haptics feedback to support lifting • Augment the operator interface with force-feedback • Apply repulsion force on potential collisions; the repulsion force must be adapted based on the incoming speed to compensate inertia • Implement attractive force for precise alignment with the target position • Implement virtual fixtures to guide the operator along a predefined path after a precise alignment is achieved
	3.2. Also, audio feedback from distance and location before collision
	Devices: HMD, Power wall, normal screen, haptic device, 3D audio device

Table 18: XR Flow for Use Case 2.5

4.3.6 Use Case 2.6

The use case „Remote controlled RS: Job order to place to the trailer" (Table 17) describes which activities are required from which actor to place sea container to the trailer where the cabin of the terminal tractor is near container target position. First, the Terminal Operating System (TOS) sends planned place job order to the free remote control desk and remote operator chooses the job from the screen and starts to execute the job. The automation system has already driven the machine near the target position and RC operator's job is to drive the machine and container over the target position of the trailer, lower the boom and place the container on trailer on twistlocks, release the spreader and lift the boom above safe height. The job must be done without collisions against terminal tractor structures and so that the trailer is not damaged. The user interface and control systems should assist operator to execute the job correctly. The use case is depicted as a use case diagram in Figure 25.

Use case name	Remote controlled RS: Job order to place to the trailer
Use case number	UC2.6
Summary description	The remote operator at RC desk receives the job order, moves RS over the trailer and correct slot, and places the container.
Status	First draft
Stakeholders/actors (primary actor bolded)	**1. Remote operator**
	2. Terminal operating system (TOS)
	3. Container position indicator (CPI)
Relevant characteristics (of primary actor)	1. Experienced in remote control of cargo handling machines
	2. Container handling knowledge
	3. Expertise in port operations
Use case goal	To place container without collisions
Frequency of occurrence	Regularly
Preconditions	1. Valid job order is received from TOS. Remote operator is available.
	2. Remote operator is available
	3. Machine is ready for operation
Post-Condition(s)	Container is landed to correct position
	Spreader released and spreader above safe height
	Transportation move
Basic flow	1. Remote operator at RC desk receives job order from TOS.
	2. Remote operator moves RS to position appointed by job order, moves spreader and container with the help of CPI over target slot and places container according to TOS job order.
	3. Remote operator lowers the container and CPI sends grounded message to system. System delivers lift message to TOS.
Alternative flow(s)	1. Operation with over-high folding legs
Exceptions	Twist locks are stuck
Success criteria	Container picked without damages
Challenges and problems	Harsh weather conditions (fog, snow, wind etc.), stability issues, surface quality of ground

Table 19: Use Case 2.6: Remote controlled RS: Job order to place to the trailer

Figure 19: Reachstacker placing container to the trailer ©KALMAR

XR Flow - How situation unfolds with XR interaction

XR supported workflow	1. Shows TOC job order via AR/XR in video feed. E.g. also highlights end-location 2. Bird view from spreader and container or 3D view of them to support RS operator to put-down container without collision. User has freedom to choose point of-view from 3D model in XR e.g., left view. XR-supported safety warning if someone (human or machine) is arriving close to working area. Multi-modal support: 2.1. Also, haptics feedback to support lifting • Augment the operator interface with force-feedback • Apply repulsion force on potential collisions; the repulsion force must be adapted based on the incoming speed to compensate inertia • Implement attractive force for precise alignment with the target position • Implement virtual fixtures to guide the operator along a predefined path after a precise alignment is achieved 2.2. Also, audio feedback from distance and location before collision 3. AR or XR view for extra information e.g., distance, speed to put-down of container **Devices:** HMD, Power wall, normal screen, haptic device, 3D audio device

Table 20: XR Flow for Use Case 2.6

4.4 Use case diagrams

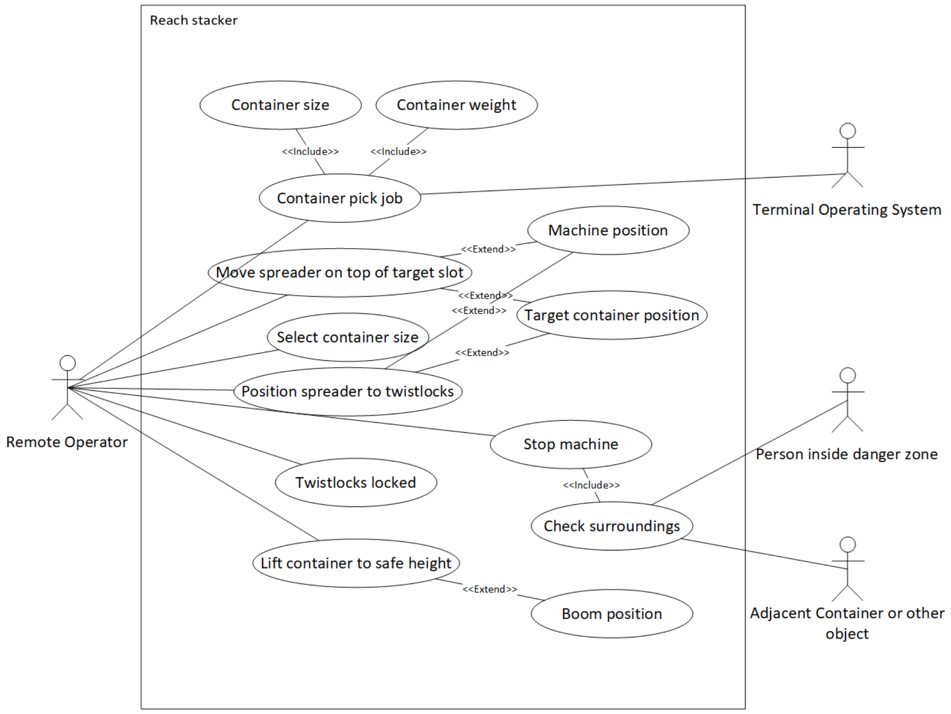

Figure 20 Use-Case Diagram for "Logistics Use Case 2.1 – Pick container from stack"

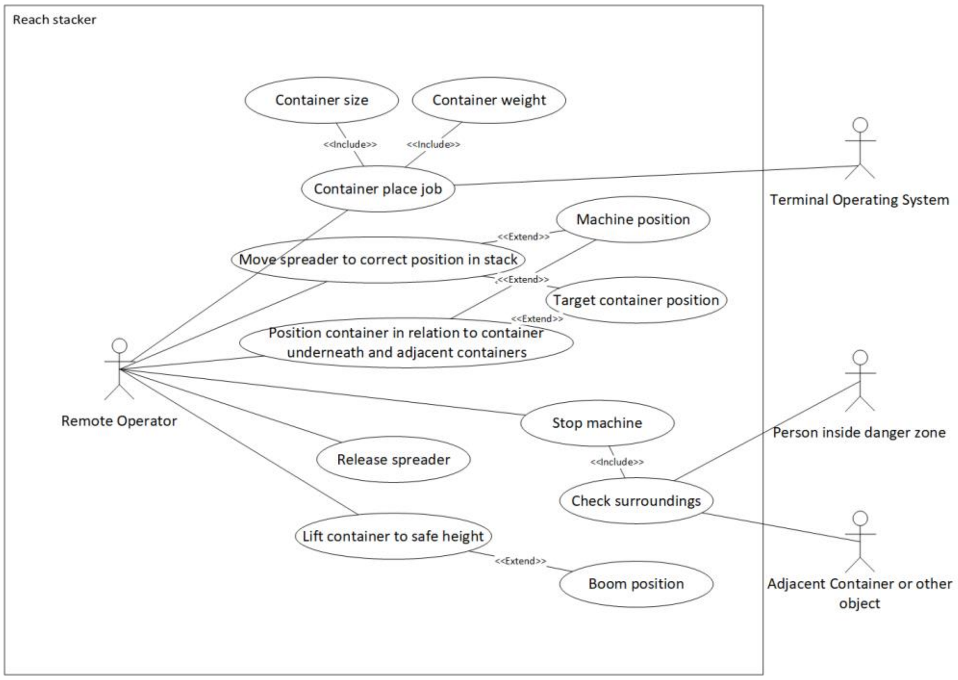

Figure 21 Use-Case Diagram for "Logistics Use Case 2.2 – Place container to stack"

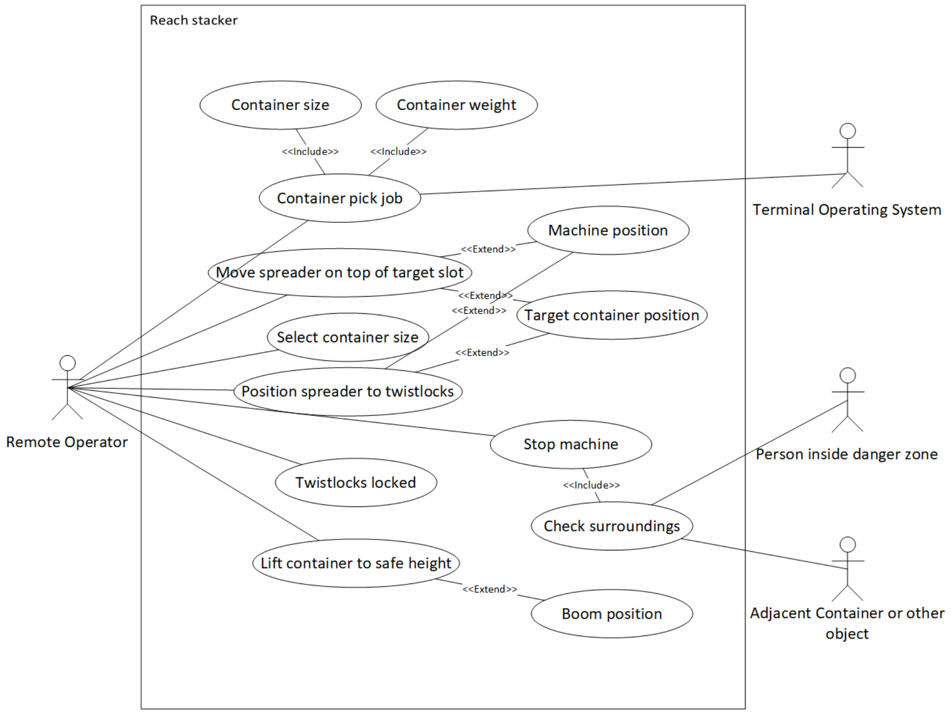

Figure 22 Use-Case Diagram for "Logistics Use Case 2.3 – Pick container from ground"

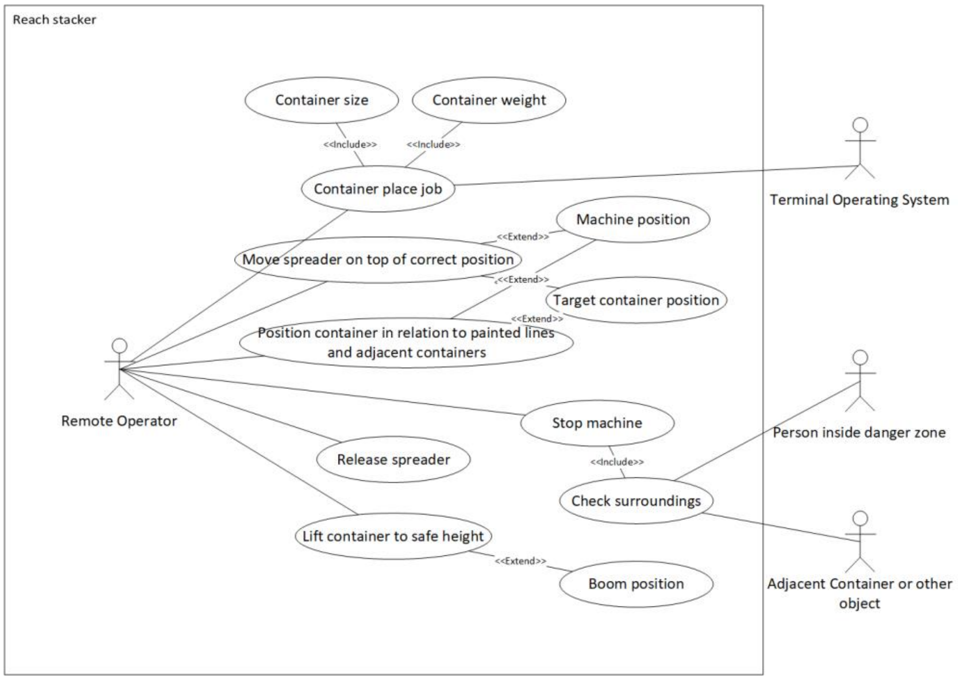

Figure 23 Use-Case Diagram for "Logistics Use Case 2.4 – Place container on ground"

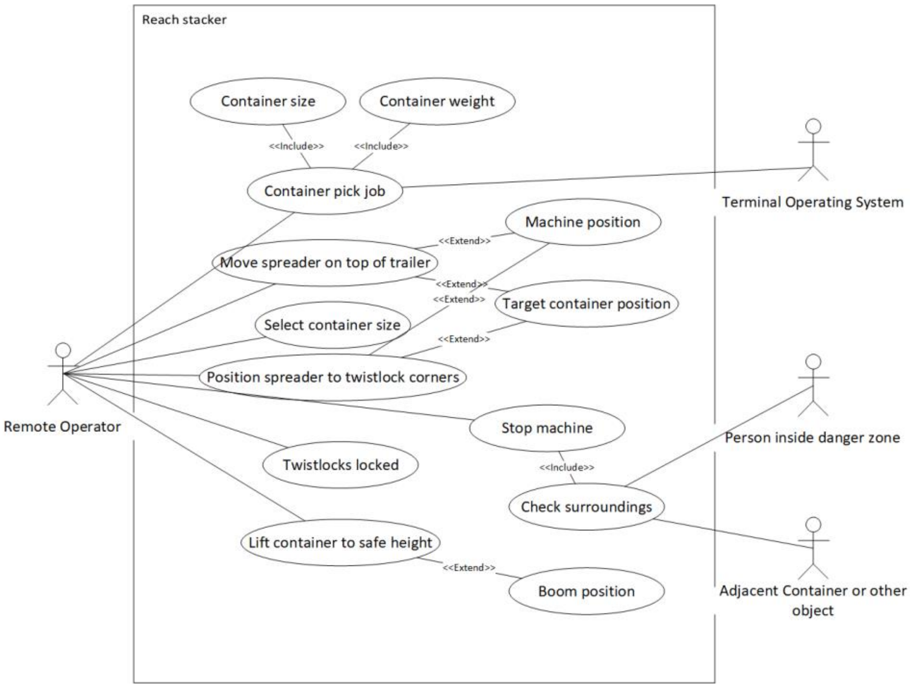

Figure 24 Use-Case Diagram for "Logistics Use Case 2.5 – Pick container from the trailer"

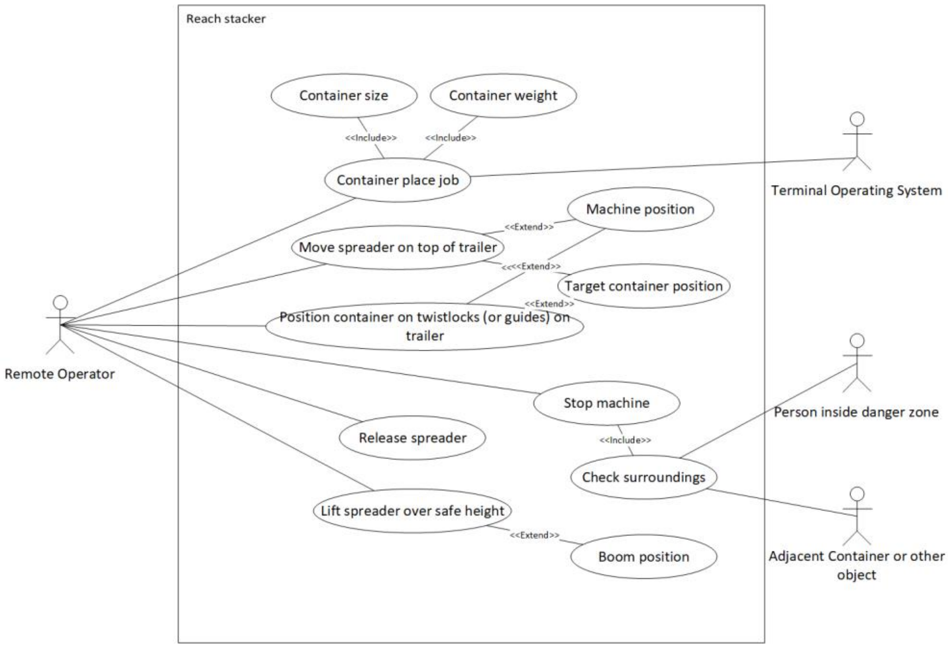

Figure 25 Use-Case Diagram for "Logistics Use Case 2.6 – Place container to the trailer"

4.5 User stories

ID	PRIORITY	AS A [type of user]	I NEED TO [do some task]	SO THAT I CAN [get some result]	STATUS	UC 2.1	UC 2.2	UC 2.3	UC 2.4	UC 2.5	UC 2.6
2.1	Must have	Remote RS Operator	get information about target slot position (X; Y, Tier)	move RS spreader over target slot	Open	x	x	x	x	x	x
2.2	Must have	Remote RS Operator	get information about target container	select the correct size of the spreader and check that I have correct spreader attachment	Open	x		x		x	
2.3	Must have	Remote RS Operator	get closed information from spreader	pick up the container and lift it above safe height	Open	x		x		x	
2.4	Must have	Remote RS Operator	gat landed and twist locks open information from spreader	lift spreader over safe height after container landing	Open		x		x		x
2.5	Must have	Remote RS Operator	get warning if adjacent containers are close to spreader or hanging container	avoid collision	Open		x		x		x
2.6	Must have	Remote RS Operator	get information about distance under spreader / container to container underneath or ground	avoid collision and enable soft landing	Open		x		x		x
2.7	Should have	Remote RS Operator	get information about obstacles near RS	avoid collisions and accidents	Open	x	x	x	x	x	x
2.8	Must have	Remote RS Operator	get information about machine's status and health	to continue operation efficiently without breaks	Open	x	x	x	x	x	x
2.9	Must have	Remote RS Operator	get information about relative position between container/spreader or container/container	to pick up or land container efficiently	Open	x	x	x	x	x	x

Table 21: User Stories for Logistics Use Cases

4.6 Issues

The following issues have been depicted:

- Visibility to target position and container
- Visibility to obstacles around the machine
- Distances between objects
- Trailer twist locks can get stuck

- Material damages
- Safety (persons around the machine and other vehicles)
- Productivity of the remote-controlled system
- Latency and reliability of the communication

5 Use case 3 – Construction

5.1 Description of the system

In the field of construction machinery, the excavator is one of the most common machines with a wide variety of designs. A typical application for an excavator is earthmoving in civil engineering and landscaping. Modern excavators feature a so-called 3D-machine control system, which is a sensor system that measures the kinematic information of the attachment as well as the high-precision position with an RTK-GNSS.

With the help of a 3D-machine-control system and a digital terrain model, the operator can align its working process with the digital design model. This paves the way for the comprehensive implementation of model-based construction (BIM) but may challenge the operators with increased complexity and automation in novel and more dynamic information spaces that require advanced forms of information presentation and interaction. Figure 26 show an excavator with a 3d-machine control system. The two displays inside the cabin show video streams of the surrounding areas and the digital 3D-model of the excavator.

Figure 26 An excavator with a 3D-machine control system and a bird-view camera setup in order to monitor the danger areas close to the machine (© ÜAZ Glauchau, Bau Bildung Sachsen e. V.)

Within the construction use case we considered three scenarios:

- Finish Grading (target surface profile),
- Collision Avoidance (with persons or objects), and
- Infield Design

The following tables report on the collected data on involved agents, workflows and user stories.

5.2 Names and descriptions of the actors

Name of the actor	Description
A machine operator	controls the excavator and the 3D-machine-control system.
A survey assistant	sets reference points in the working area in order to mark the target design.
A person in the danger	standing in the danger area of the excavator and might be hit accidently by the excavator.

Table 22: Name and descriptions of the actors Use Case 3

5.3 Construction use cases

5.3.1 Use Case 3.1

The use case "Finish Grading" describes the activities by the operator which are related to creating a level plane or a slope with high demands on precision. After checking of the general system, the operator has to set the reference height of the desired surface. This can be done either by using a predefined digital design model that is chosen from the UI or by setting the reference height manually in the UI. Afterwards, the operator must check if the model aligns with the real environment. If everything is correct, the operator starts digging to make a rough level pass. Therefore, holes are filled and hills are removed. Finally, the operator performs a finish grading by moving the edge of the bucket according to the final design specification. The use case is depicted as a use case diagram in Figure 27 and is described in the subsequent table.

Use case name	Finish Grading (target surface profile)
Use case number	3.1
Summary description	Making a finish grade with an excavator (plane, ramp)
Status	Medium level of detail
Stakeholders/actors (primary actor bolded)	**1. Operator**
Relevant characteristics (of primary actor)	1. experienced operator, skilled in excavator handling
	2. Mapping between real environment and 3D representation, understanding how 3D control works
	3. Basic knowledge of soil behaviour and civil works
	4. Basic knowledge of environmental factors on soil behaviour (humidity, weather, wind)
Use case goal	1. Create a Finish Grading with a reference height on bare soil
Frequency of occurrence	Regularly
Preconditions/Requirements	1. Irregular soil surface (probably after cleaning of rocks and tree stumps)
	2. A 20t excavator with a bucket.
	3. A 3D machine control system.
Post-Condition(s)	1. The surface is levelled out according to reference height (Accuracy = 5cm)
	2. Final surface profile is logged/measured and documented as a DTM (digital terrain model)
Basic flow	1. Check general machine status und check 3d-machine control system status.
	2. Check target surface profile, determine own position
	3. Set the reference height for the finish plane: a) set height in GNNS System (b) tip with bucket to set height relative to object (e.g. road curb) in environment c) working together with a separate person who surveys road with GNSS-Rover
	3. Develop a grading strategy (where to start, where to move, and how to finish, consider working area boundaries, soil reservoirs or dump areas, logistic areas and paths)
	4. Fill holes and level out bumps by moving soil with the bucket.

	5. Move vehicle to change action radius
	6. Work together and communicate with crawler or truck
	7. Create a uniform plane (level pass) with the teeth of the bucket.
	8. Finish the grading by smoothing out the ground with the bottom plate of the bucket.
Alternative flow(s)	1. There is too much material to reach reference height. Material must be removed.
Exceptions	1. There is a lack of material to reach reference height.
Success Criteria	1. Accuracy
	2. Time/Speed
	3. Gentle use of machine and tool
Challenges and Problems	1. Requires good handling skills especially for linear movements of the bucket.
	2. Requires planning of soil distribution and backfilling.
	3. Requires confident usage of 3D-machine control system.
	4. Spatial imagination to reference virtual model with real references.

Table 23: Use Case 3.1: Finish Grading (target surface profile)

XR Flow - How situation unfolds with XR interaction

Advanced flow	1. Check general machine status und check 3D-machine control system status.
	2. Set the reference height for the finish plane: a) set height in GNNS System (b) tip with bucket to set height relative to object (e.g., road curb) in environment c) working together with a separate person who surveys road with GNSS-Rover
	3. XR: reference height is visualized in alignment with real environment
	4. XR: show delta of target and actual height and boundaries, show where to move material to easily develop a grading strategy
	5. XR: target geometry is mapped on feedback function of physical machine controls
	4 Fill holes and level out bumps by moving soil with the bucket.
	5. Create a uniform plane (level pass) with the teeth of the bucket.
	6. Finish the grading by smoothing out the ground with the bottom plate of the bucket.

Table 24: XR Flow for Construction Use case 3.1

5.3.2 Use Case 3.2

Use case 3.2. is about collision avoidance during everyday working tasks. The excavator has multiple blind spots which results in a risk of hitting persons within these danger zones during operation. The excavator is equipped with a camera monitor system (CMS), which displays video streams of the blind spots on a display inside the cabin. As an extension, the CMS is enhanced with a collision warning systems, which informs the operator about persons in the danger zone. Before critical movements, the operator can check the video streams. The operator can either detect or oversee an obstacle, even after a warning of the collision warning system. The detection of an obstacle results leads to a stopping motion and the operator must contact the person in the danger zone. If the operator oversees the person, the risk of hitting the person is high during a critical movement, e.g., while slewing. The person in the danger zone is responsible for leaving the surrounding of the machine as soon as possible. Although the collision warning system and the CMS are helpful to monitor the surrounding, it might warn to frequently which leads to annoyance of the operator. The use case is depicted as a use case diagram in Figure 28 and is described in the subsequent table.

Use case name	Collision Avoidance (with persons or objects)
Use case number	3.2
Summary description	Ensure that there will be no collision at the rear and at the side of the excavator while slewing.
Status	Medium level of detail
Stakeholders/actors (primary actor bolded)	**1. Operator**
	2. A person standing in the slewing radius
	3. Operators of other vehicles in the area
Relevant characteristics (of primary actor)	1. Basic knowledge about machines dimensions and clearance
	2. General environmental awareness
	3. Familiarity with distorted perspective in mirrors and mirror replacement camera images
	4. Knowledge about safe working on construction sites
Use case goal	Stop Slewing when there is a collision obstacle.
	The person standing in the slewing radius is informed about the excavator's movement and leaves the danger zone
	Collision avoided
Frequency of occurrence	Often
Preconditions/Requirements	1. Operator is working concentrated.
	2. An unexpected slewing motion has to be done.
	3. The excavator has a camera monitor system (CMS) at the right side and at the rear of the machine.
	4. The CMS has a collision warning system (CWS) and actively warns the operator.
Post-Condition(s)	1. The excavator stopped the slewing movement.
	2. Persons in the way have left the danger zone
Basic flow	1. The operator starts the machine and checks that it is ready for use.
	2. The operator drives to the working position.
	3. The operator starts the working procedure (e.g., trenching)
	4. The operator digs in the centre line and swings 45° to the left for unloading. This procedure is continued.
	5. The operator wants to swing to the right (e.g., to change the attachment)
	6. The operator checks the rear and side of the machine before slewing via CMS.
	7. The operator detects the person within the danger area.
	8. The operator does not initiate the slewing movement and informs the person to move out of the way
Alternative flow(s)	1. The operator performs the slewing movement without previous check of the blind spots.

	2. The operator checks the CMS but does not see the person in the danger zone.
	3. The operator hits the person
	1. The operator checks the rear and side of the machine before slewing via CMS.
	2. The person standing in the slewing radius perceives the intent to move the excavator
	3. The person standing in the slewing radius leaves the danger zone
	1. The ODS detects the obstacle and warns the operator.
	2. The operator stops the movement and informs the person.
	1. The operator is annoyed by the ODS and disables the warnings.
	2. The operator hits the person.
Exceptions	No obstacle detected or object falsely detected
Success Criteria	1. No damage, no harm, no casualties
	2. Time lost in machine blockage
	3. No abrupt stops
	4. Persons in the area increase awareness of vehicles movements
Challenges and Problems	1. Reliable detection of (fast) objects and persons in proximity
	2. Detection of type of obstacle
	3. Detection of severity of object approach (in detection range but in safe distance - too close)
	4. Do not annoy the operator by any active obstacle warnings.

Table 25: Use Case 3.2: Collision Avoidance (with persons or objects)

XR Flow - How situation unfolds with XR interaction

Advanced flow	1. The operator starts the machine and checks that it is ready for use.
	2. The operator drives to the working position.
	3. The operator starts the working procedure (e.g., trenching)
	4. The operator digs in the centre line and swings 45° to the left for unloading. This procedure is continued.
	5. The operator wants to swing to the right (e.g., to change the attachment)
	6. The CWS detects a person in the slewing area.
	7. The slewing process will be slowed down when slewing in the danger zone.
	8. XR technology helps to perceive the obstacle when the operator moves into this direction (vibratory feedback, ambient light, buzzing, AR-visualization, etc.).
	9. The operator detects the person within the danger area.
	10.Theioperator does not initiate the slewing movement.
	11. XR-technology helps to inform the person in the danger area (light, sound, projection in the danger zone)

Table 26: XR Flow for Construction Use case 3.2

5.3.3 Use Case 3.3

The use case “Infield Design” describes the task of designing a digital terrain model during operation with the on-board machine control system and without usage of predefined digital models. After checking the operability of the system, the operator has to drive to the working position and use the UI to start the infield design process. The operator has to set the outline of the pit by moving the bucket to the desired position. Then, the operator sets the profile of the pit with the help of the UI. The referenced outline points are usually setup by a survey assistant e.g. by setting surveyor’s stakes in the soil. Afterwards, the operator has to verify the created model with respect to the real environment and start the digging. The use case is depicted in the use-case diagram in Figure 29 and is described in the following table.

Use case name	Infield Design
Use case number	3.3
Summary description	Create a pit design model on site
Status	Medium level of detail
Stakeholders/actors (primary actor bolded)	**1. operator**
	2. surveyor assistant
Relevant characteristics (of primary actor)	1. Basic knowledge on geometry
	2. Basic knowledge on civil works and soil behaviour
	3. spatial imagination skills
Use case goal	Create a DTM (digital terrain model) for pit excavation on site.
Frequency of occurrence	Occasionally
Preconditions/Requirements	1. excavator with bucket and 3D-machine control system
	2. reference points set up by surveyor assistant
	3. area is free of obstacles
Post-Condition(s)	A correctly referenced DTM
Basic flow	1. The operator starts the machine and checks that it is ready for use.
	2. The operator drives to the working position.
	3. The operator checks if the 3D-system is operational and with high precision.
	4. The operator navigates the GUI to set up an infield design by outline and profile.
	5. The operator sets the outline of the pit by inserting the reference points manually.
	6. The operator sets profile (slope angle, base area) of the pit
	7. The operator checks the resulting model
	8. The operator moves the excavator in the 3D-model visualization to check if model and environment are aligned as expected.
Alternative flow(s)	1. The operator sets the outline by referencing the marker posts.
	2. The operator sets the outline by reference to a virtual 3D model.
Exceptions	-
Success Criteria	1. Correctness of DTM
	2. Time on task
Challenges and Problems	1. complex operations and information required for 3D model manipulations
	2. mapping of virtual model to real environment

Table 27: Use Case 3.3: Infield Design

XR Flow - How situation unfolds with XR interaction

Advanced flow	1. The operator starts the machine and checks that it is ready for use.
	2. The operator drives to the working position.
	3. The operator checks if the 3D-system is operational and with high precision.
	4. The operator navigates the GUI to set up an infield design by outline and profile.
	5. The operator sets the outline of the pit by inserting the reference points manually.
	6. XR-support: The reference points are visualized with alignment to the real environment
	7. The operator sets profile (slope angle, base area) of the pit
	8. XR-support: The outline is visualized with alignment to the real environment
	9. XR: The operator checks the resulting model with alignment to the real environment
Alternative flow(s)	1. The operator sets the outline by referencing the marker posts.
	2. The operator sets the outline by reference to a virtual 3D model.

Table 28: XR Flow for Construction Use case 3.3

5.4 Use case diagrams

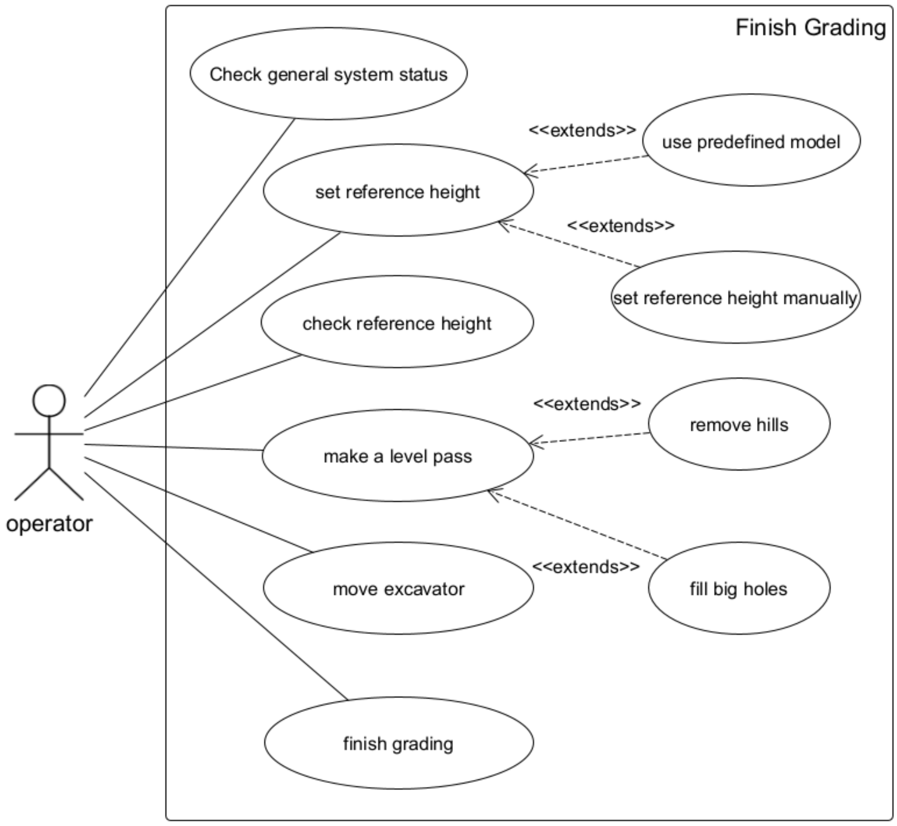

Figure 27 Use-Case Diagram for “Construction Use Case 3.1. - Finish Grading”

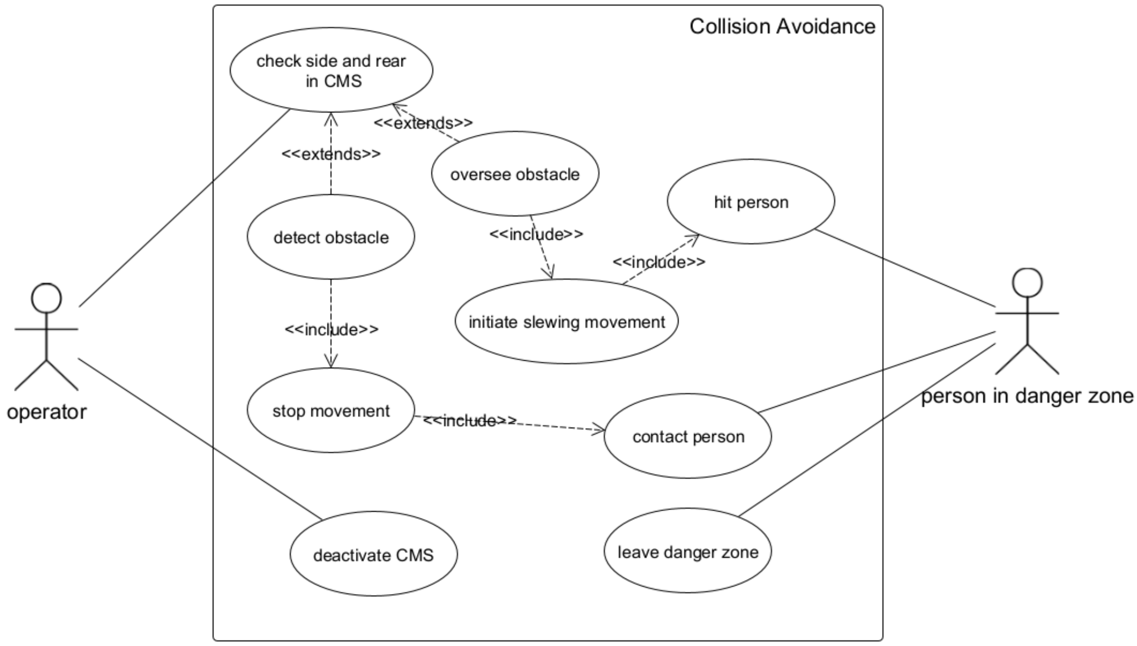

Figure 28 Use-Case Diagram for “Construction Use Case 3.2. - Collision Avoidance”

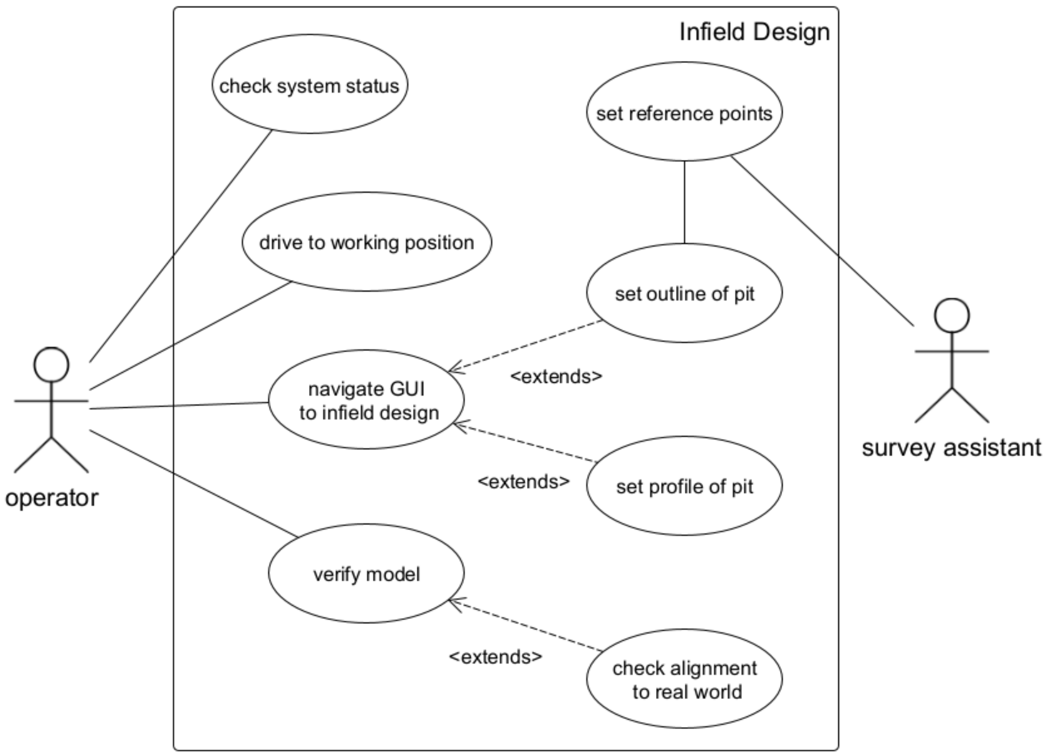

Figure 29 Use-Case Diagram for “Construction Use Case 3.3. - Infield Design” User stories

5.5 User Stories

The user stories describe tasks of different priorities which must be handled by relevant users. For the construction use cases, the user stories are presented in Table 29.

ID	PRIORITY	AS A [type of user]	I NEED TO [do some task]	SO THAT I CAN [get some result]	STATUS	UC 3.1	UC 3.2	UC 3.3
3.1	Must have	Operator	get a clear indication of the system status	rely on the functionality or understand malfunction	Open	x	x	x
3.2	Must have	Operator	get a clear indication of the reference between virtual model and reality	work in the proper area	Open	x		x
3.3	Must have	Operator	Move the bucket according to target design	Make the finish grade efficiently and fast	Open	x		
3.4	Must have	Operator	Overview the whole working area and the height difference between target design and real surface	Plan the soil distribution	Open	x		x
3.5	Must have	Operator	Model a digital terrain model in field	Work with a 3D-control system	Open	x		x
3.6	Must have	Operator	Observe the blind spots on the right and rear	Detect potential collisions and stop dangerous manoeuvres	Open	x	x	
3.7	Must have	Operator	Recognize obstacles and persons in blind spots	Avoid collisions	Open	x	x	

Table 29: User Stories for construction Use Cases

5.6 Issues

The following issues have been depicted:

- The operator's view on the attachment and the graphical user interface are not in one visual axis.
- Current 3D-machine control interfaces offer a visual display of target and actual bucket height. It hardly allows a comprehensive view of the entire work area to plan e.g., backfilling.
- Current operation requires confident usage and understanding of 3D-machine control systems and confidence in proper alignment of 3D-model to real world.
- Spatial imagination to align the abstract, virtual reference model with real references.
- Infield design requires a spatial imagination to design profile and outline with reference to the real environment.
- Collision Warning Systems often annoy the operator due to the high frequency of warnings. This leads to deactivation of CWS.

6 Conclusions

Use Cases are firstly described as they are in the production models of the selected work machines (snowgroomer, reachstacker and excavator). In the second phase, we also added an XR extension paragraph. It describes how the situation unfolds with help of XR interaction.

We decided also to utilize user stories to describe especially the operator's role in the process. User Stories are centred on the result and the benefit of the thing you're describing, whereas Use Cases can be more granular, and describe how your system will act. We also listed potential issues which we found during this phase.

We also utilized use-case diagrams, which model the behaviour of a system and help to capture the requirements of the system. Use-case diagrams describe the high-level functions and scope of a system. These diagrams also identify the interactions between the system and its actors.

This document gives good basis to make requirement specification and technical analysis. This document will be updated in later phases when design work is progressing.

This documents essential part for designing and implementing XR systems to all use cases as document gives better understanding to non-domain expert of actual tasks and its issues. This information will be used to focusing development to most critical and / or most productive tasks.

In the snow grooming use case, the most important aspect is to support the human operator when there is limited visibility, so that there is knowledge about the environment that is not visible.

In logistics use cases it is important to assist the remote controller to avoid material damages like pushing dents or even holes to adjacent containers with handled container. Also, twistlocks of the trailer can be stuck if the road truck driver is not careful enough when opening locks.

Finally, within the construction use case it is important that the information is provided in the view of the operator while working at a task. Additionally, obstacle avoidance is, as in all the use case, one of the main important aspects.

7 Abbreviations / Acronyms

[BIM]	Building Information Modelling
[CWS]	Collision Warning System
[CMS]	Camera-Monitor-System
[DTM]	Digital Terrain Model
[GNSS]	Global Navigation Satellite System
[RC]	Remote Control
[RS]	Reach Stacker
[RTK]	Real Time Kinematic
[XR]	Extended Reality
[WP]	Work Package
[UML]	Unified Modelling Language
[HMI]	Human-Machine-Interfaces
[OEM]	Original Equipment Manufacturer
[UC]	Use Case
[TOS]	Terminal operating system
[CPI]	Container position indicator

References

THERE ARE NO REFERENCES IN THIS DOCUMENT.