Intra-Logistics with Integrated Automatic Deployment:
Safe and Scalable Fleets in Shared Spaces

DELIVERABLE 4.1

Report on typical risks for human injury in the envisaged use cases

Dissemination Level: PUBLIC

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Executive Summary

In order for the technologies developed in ILIAD to become practically useful and exploitable, it is imperative that the system can run both safely and efficiently.

This deliverable details the results of a Preliminary Hazard Analysis (PHA) of the adopted use case for ILIAD demo scenario, and provides general discussion regarding how the associated risks can be mitigated or at least reduced adequately using the developed safe motion units of autonomous vehicles, facilitating the transition to safe automation. A systematic study of human safety in shared environments is being carried out in parallel with the goal of building an extensive injury safety database. Such a database contains the basic human injury biomechanics information during collisions, and connect it to safe motion planning and control for preventing human injury.

This report presents the PHA, which was carried out after several iterations internally at LUH and externally with ILIAD partners involved in this task (ORU, PISA and ACT-OR). For each use case we found many hazards, which can be classified in workspace sharing hazards, task–specific manipulated object hazards, software or system failure hazards and secondary hazards.

1   Introduction

This report summarises the risks for human injury encountered in intra-logistics applications, associated with the identified use cases and the operation scenarios where multiple autonomous mobile systems are moving in a dynamic environment that is shared with humans. It also forms the base for a complete analysis of the human injury/safety within the context of ILIAD.

Most of these intra-logistics applications are comprised of an array of operations that deal with transport, loading, unloading, storing and moving pallets in a warehouse. More specifically, existing intra-logistics centers managed by ILIAD partner Orkla Foods Sverige AB (OF) and advisory board member Asda Stores Ltd. lend themselves to a selection of meaningful tasks. In Section 2, we outline those typical tasks and the envisaged use cases that are relevant for a range of ILIAD end users with their operation cycles. In the following section (Section 3) the overall approach of hazard analysis on each ILIAD envisaged use case will be described, listing the detailed Unified Modeling Language (UML) sequence diagrams for each of the use cases and the actual risks associated with the hazards discussed. Section 4 is drawing conclusions on the carried-out risk analysis and summing-up this report.

2   Typical tasks and envisaged use cases considered for ILIAD

The following tasks can be gleaned from existing intra-logistics centres that are to be automated, and further extended to include deployment specific tasks, within ILIAD.

- **Storing pallets on high shelves.** Typically picking is done by a mobile transporter (e .g. forklift, operator) from pallets on the floor at one of the stations (a station is a place at which mobile transporters can stop and perform a specific task; drop and/or pick operations of production units, pallets, etc.) in the workspace area. When the picking station for a particular type of goods is occupied, the pallets are stored on high shelves until the picking station needs to be replenished. The task of the fleet (a group of mobile transporters) here is to transport pallets from the warehouse-to-production entry racks to the high shelves.

- **Moving pallets from rack to staging posts.** Upon receiving an order for a whole pallet, it has to be taken directly from the rack to one of the staging posts for "exit" delivery (outside the warehouse). A similar task is when the storage shelves are fully occupied and hence that pallets need to be stored efficiently in a buffering zone on the floor in the workspace area, i.e. without interfering the common paths of the vehicles.

- **Replenishment of empty picking locations.** Whenever a picking station is empty, its empty pallet has to be removed, and a new pallet has to be fetched from the high shelf and placed at the picking station. This task may also include cutting of the plastic wrapping around the boxes on the new pallet.

- **Picking operations.** Individual boxes are picked from pallets at the picking stations and loaded onto a pallet for delivery. When either the order is complete or a pallet is full, the pallet has to be taken to a staging post.

It is worth mentioning here that various use cases that include a combination of these tasks can be created to reflect, e .g. the daily operation cycle at one of Asda or OF stores. It is theoretically nearly impossible to cover all the possible use cases and assess their risks while considering normal operations in a real store and treating its concrete daily routine without forgetting something, therefore one usually comes up with some representative usage scenarios that adequately includes/captures most of the usual activities. For this reason, the following ILIAD demo use case is considered as the standard use case for this hazard and risk analysis:

ILIAD Use Case: A potential demo scenario which shows the relevant capabilities of the ILIAD system and is reported in [1]. It is described from an end-user perspective, and has been planned together with Logistic Engineering Services Ltd. (LES) and OF, as well as the ILIAD Advisory Board, in order to distill a scenario that is relevant for a range of end users.

3   Hazard analysis and risk evaluation

3.1   The overall approach of the hazard analysis

In order to cover the wide range of hazards associated with the motion of fleets of advanced AGVs with manipulation capabilities in mixed environments, a thorough hazard analysis obtained using a similar method as described in [2] is needed. The approach to analyse the hazards associated with each use case is comprised of the following steps:

1. **Thorough understanding of the usage scenarios of the system followed by a time-sequence representation**

   The usage scenario of the system is first modelled with an appropriate object-oriented modelling language that adequately describes the system architecture, its processes and interactions between the different actors at a high-level. The *UML Use Case and Sequence Diagrams* provide a graphical representation fulfilling these requirements. Hence it can be used to visually depicts the objects and classes involved in the usage scenarios together with the sequence of messages that is exchanged between them. Each use case is broken down further into sequences of sub-tasks/activities whose possible hazards are to be identified in the subsequent step.

2. **Preliminary Hazard Analysis**

A PHA is carried out through brainstorming sessions about relevant possible hazardous situations, and described using UML diagrams, technical specifications concerning injuries involved in such situations and their standard risk assessment procedures [3]. In particular, we extended the hazard checklist from the European standards EN ISO 10218–1 and EN ISO 10218–2 in order to identify a comprehensive list of hazards for each subtask of a use case [4, 5]. The demo scenario for the potential ILIAD use case integrates forklifts, robotic manipulators, grippers, etc. In this risk study, we consider that most of the classical risks related to those machinery objects are already covered by their respective manufacturers (e .g. booms or mechanical appendages/arms, rollers, belts, sharp edges, electrocution,etc.), therefore we focus only on the risks that are directly associated with the different subtasks of the usage scenario.

3.2   Hazard and risk analysis results

Use case I: A potential demo scenario

The potential demo scenario for the first milestone of ILIAD which shows the relevant capabilities of the ILIAD system is used as a standard use case for identifying typical hazards and their associated risks for human injury. As pointed out in ILIAD deliverable D7.1 [1], the scenario is described from an end-user perspective, and has been planned together with LES and OF, as well as the ILIAD Advisory Board, in order to distill a scenario that is relevant for a range of end users. In this section, the use case is translated into functional specifications that can be broken down further into sequences of sub-tasks/activities.

In the ILIAD use case for the demo scenario mobile forklifts (with or without manipulator arms) operate autonomously in large areas of a food store accessible to and shared with human workers. The main scenario defined in D7.1 has been refined and interacting modules (i .e. actors in UML terms) of each task are identified. The mobile vehicles (equipped with manipulator arms or not) may encounter humans while moving between different workstations because most of the workspace area is shared and freely accessible to human workers. Furthermore, vehicles can navigate autonomously in the allowed workspace area and directly exchange status, (sensory) information, task assignments, planned paths or control commands from the respective modules that are off-the-vehicle. Pallets can be picked up by the forklifts, transported on the mobile platform to some dedicated station/location and dropped there. On the other hand, manipulator arms can interact with the pallets and product boxes to carry out different missions (e .g., grasping, dropping, unwrapping). Figure 1 shows the rough outline of the interaction between the actors involved in the operations of the ILIAD use case.
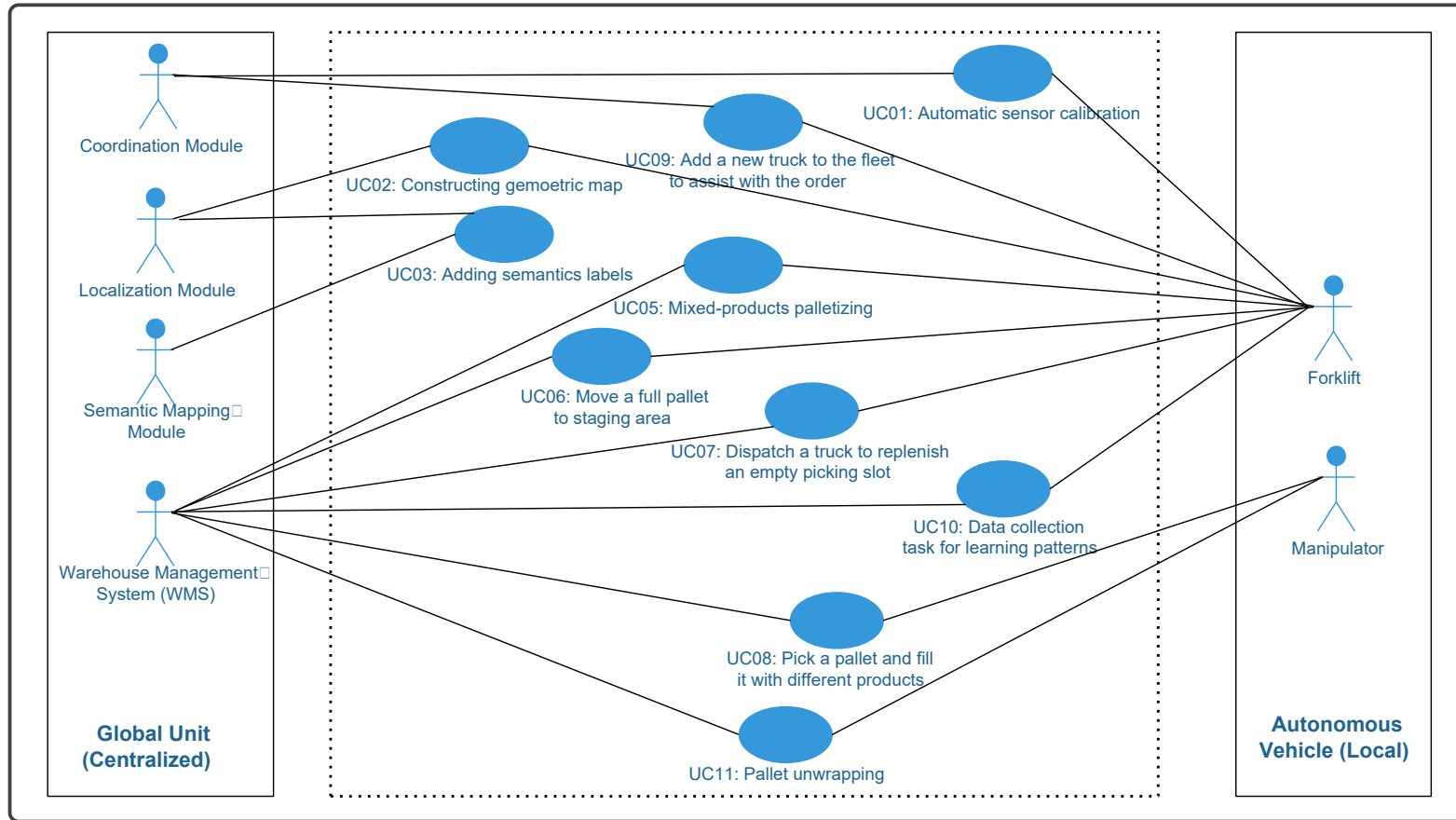
Figure 1: The demo scenario UML use case diagram.

Description of tasks in the ILIAD demo scenario

1. A fleet of at least two vehicles is deployed in a new warehouse, performs (online) sensor calibration via some manoeuvres in sufficient open floor space (given only bounds on where the robots are allowed to go).
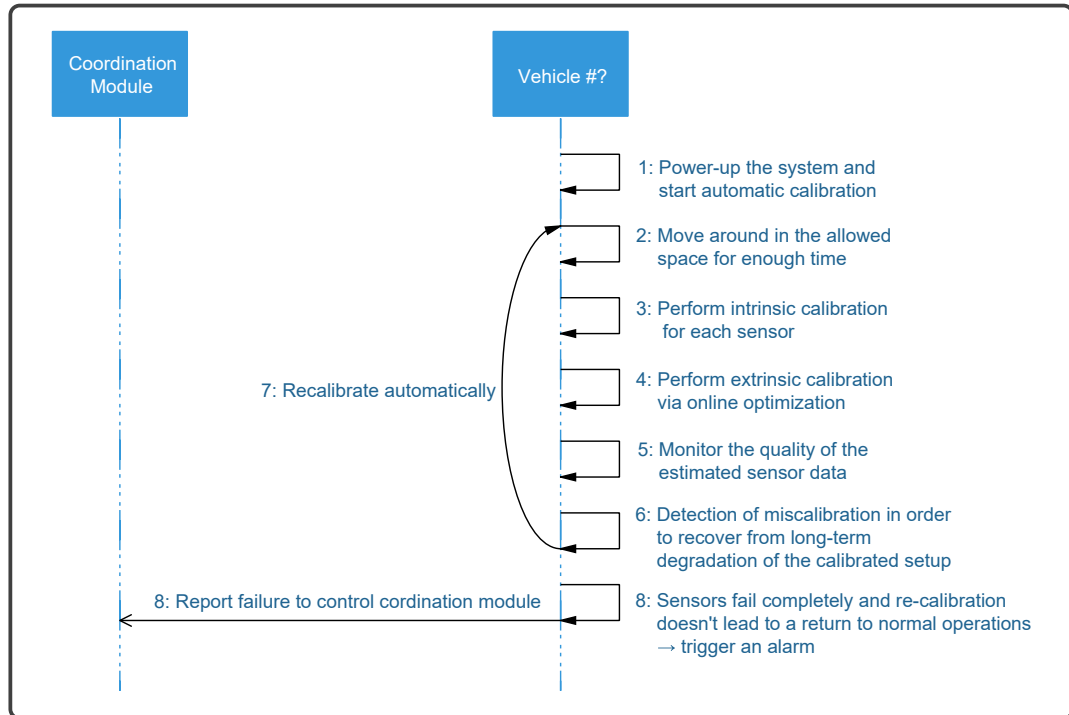
Figure 2: UML sequence diagram for UC01: Automatic sensor calibration.

2. The fleet of vehicles, whose sensors are calibrated, starts moving around the warehouse and constructing (using heterogeneous sensor information from sensors distributed over the fleet) a globally-consistent geometric map (T1.2, T1.3).

Figure 3: UML Sequence Diagram for UC02: Constructing a global geometric map.

3. After completing the geometric mapping by covering the whole warehouse (except the no-go areas), the image and range data collected are analysed in order to add semantic labels annotating the geometric map (T1.4).
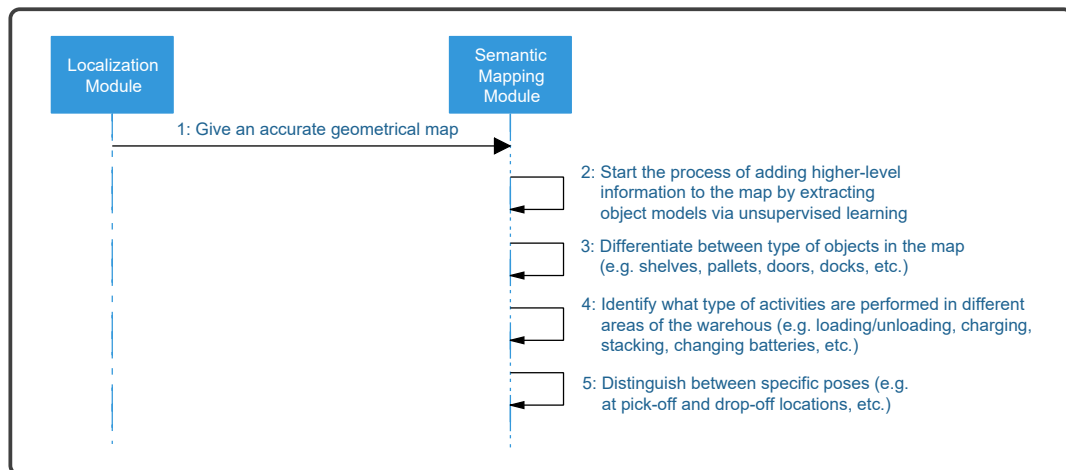
Figure 4: UML sequence diagram for UC03: Adding semantics labels to the geometric map.

4. Staff, or researchers acting as staff, are walking, picking and operating/driving material handling equipment (MHE) (i .e. manually) through the warehouse.[1]
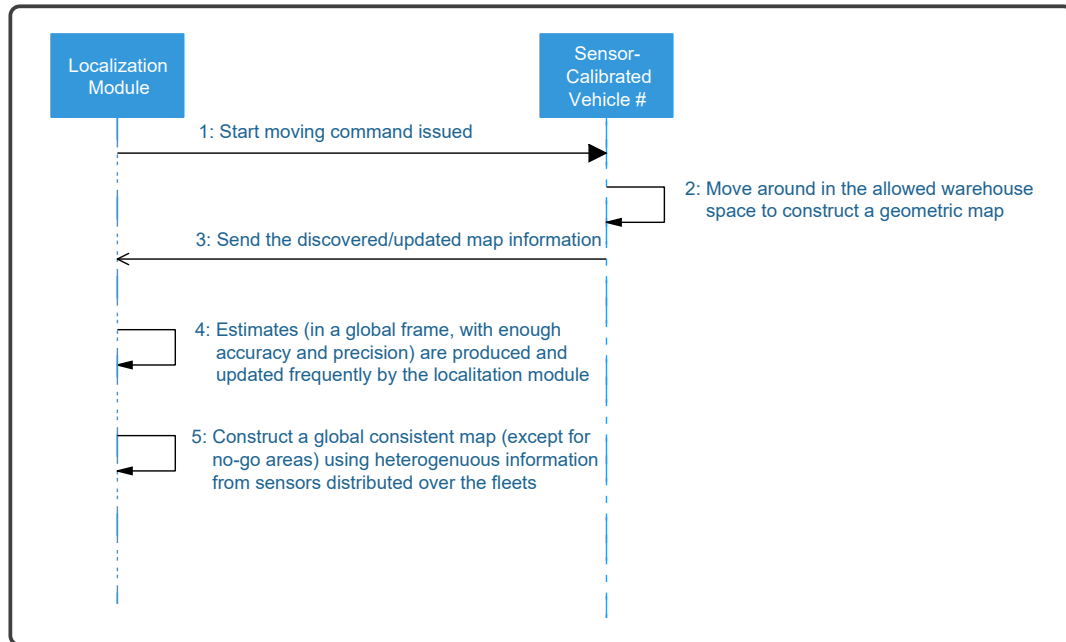
5. A mission order is given to some vehicle (manually, or from the WMS) to put x units of product i and y units of product k on a pallet, and place the mixed pallet at position u (for shipping).
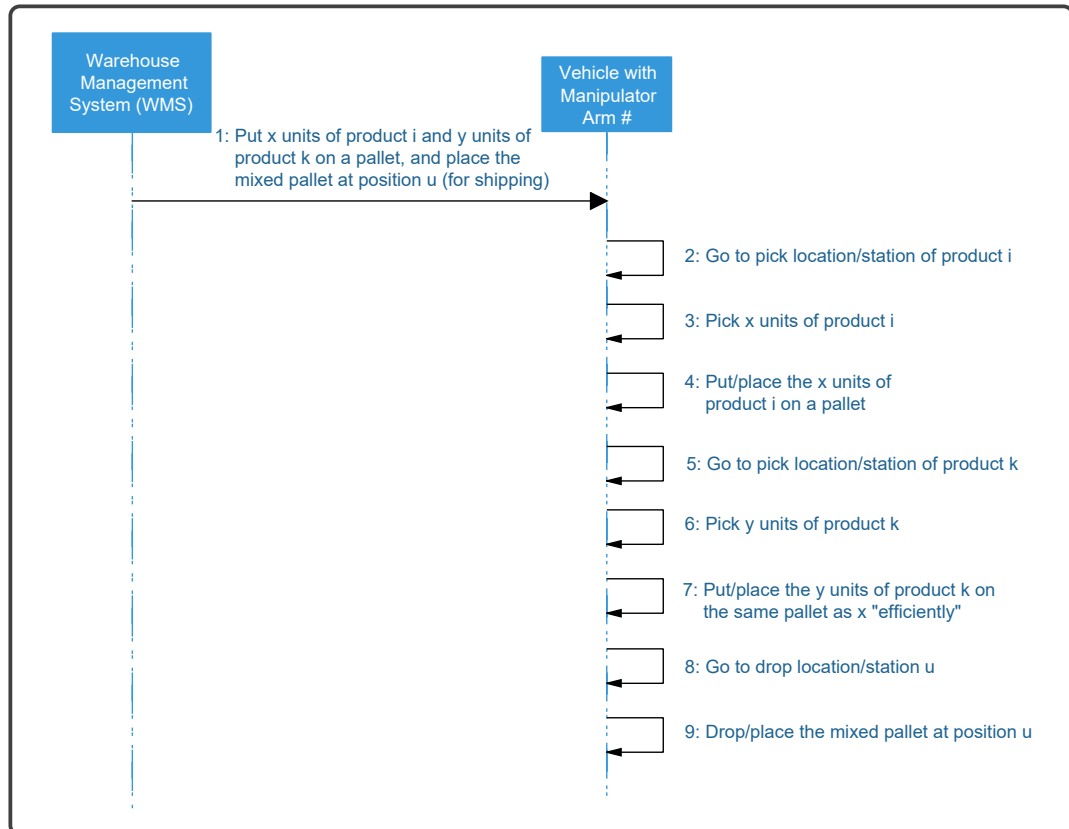
Figure 5: UML sequence diagram for UC05: Palletizing of mixed-products.

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[1]This is a general condition which is implicitly taken care of in the hazard analysis by assuming a shared workspace for each relevant task of the use case scenario.

6. Some vehicle is ordered to move a full pallet of product l to the staging area.
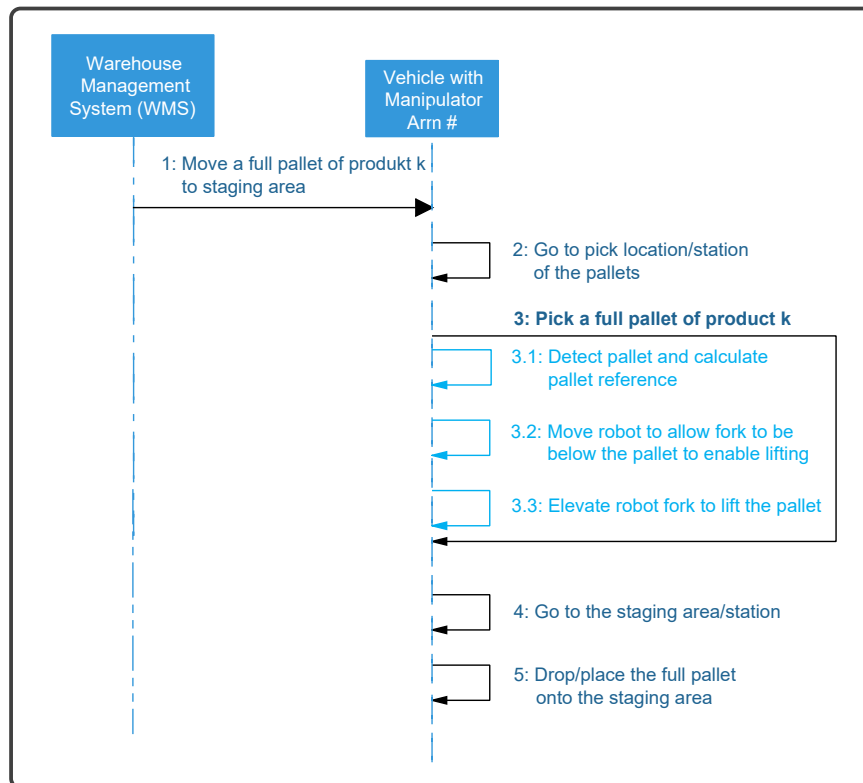
Figure 6: UML sequence diagram for UC06: Moving a full pallet to the staging area.

7. A vehicle is dispatched to replenish the empty picking slot k from a shelf (T5.1, T5.2).
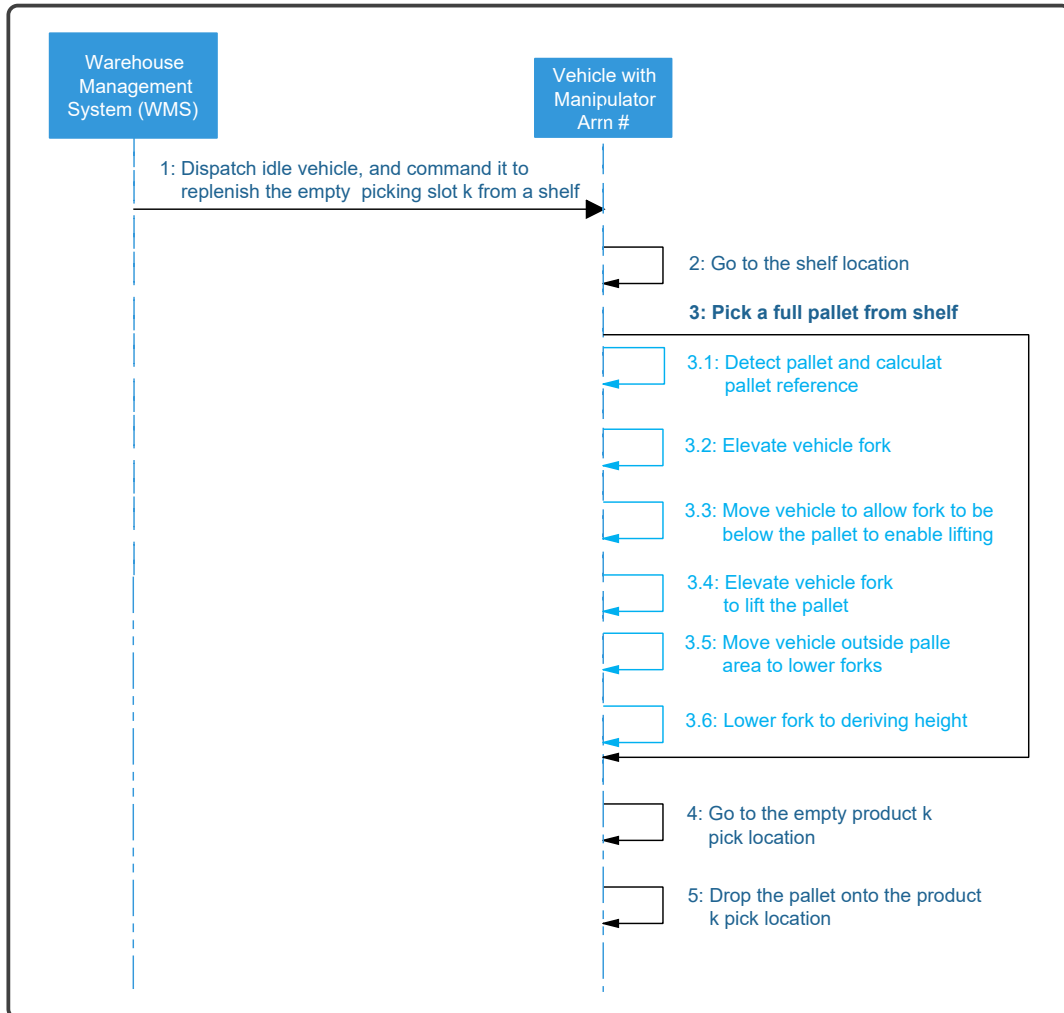
Figure 7: UML sequence diagram for UC07: Dispatch of an idle vehicle to replenish an empty product picking slot.

8. The vehicle with the manipulator is sent to pick up an empty pallet (T5.3, T5.4, T5.6) and then go to i in order to start picking (assuming that boxes of i can be placed below boxes of k on the pallet). Objects are placed in a smart and stackable way (T6.4, T6.5).
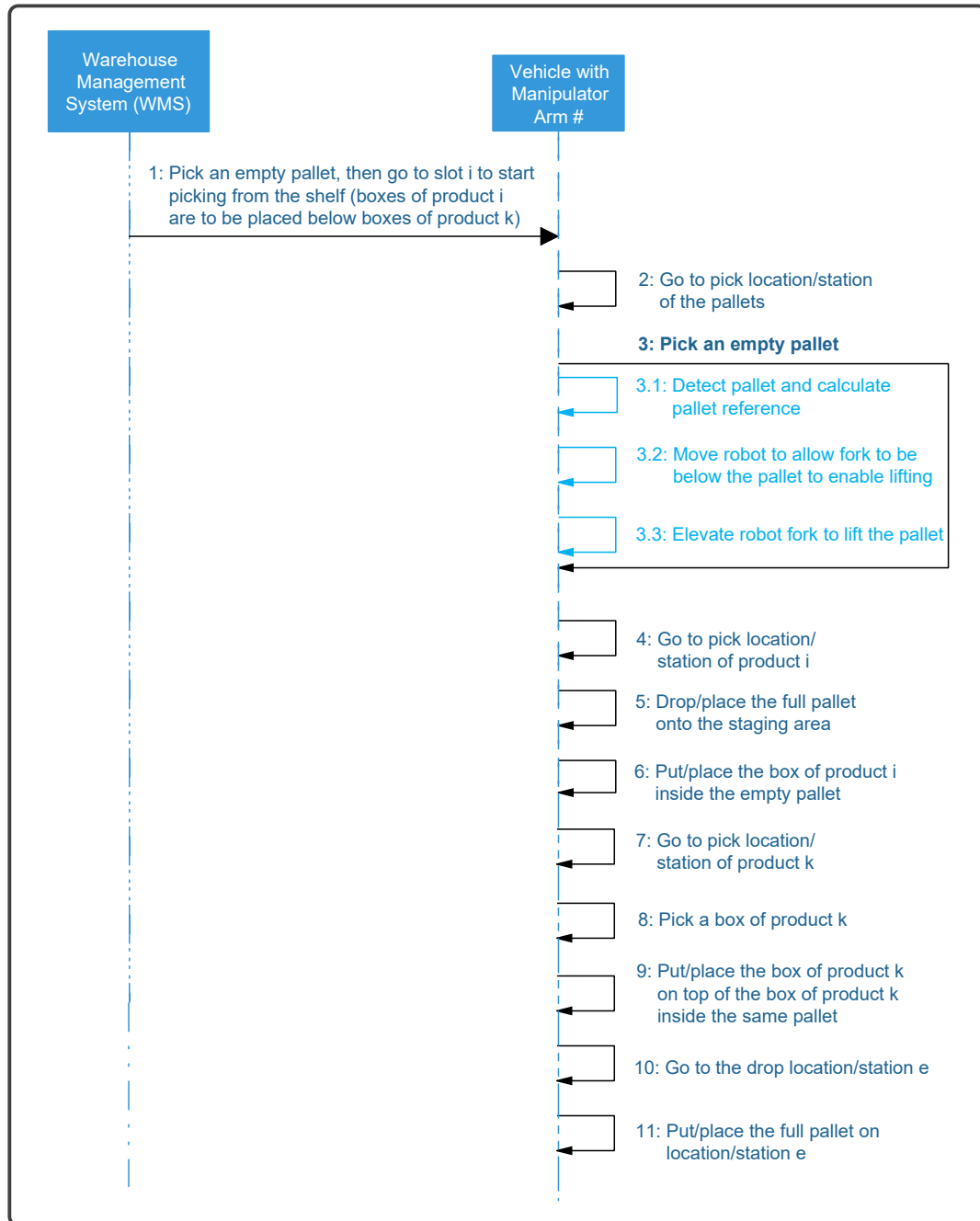
Figure 8: UML sequence diagram for UC08: Picking a pallet and filling it with different products.

9. A new vehicle is added to the fleet while the others are performing their tasks. It calibrates itself, reports its presence and availability to the coordinator, and is automatically tasked to assist with completing the order (T5.5, T5.6).
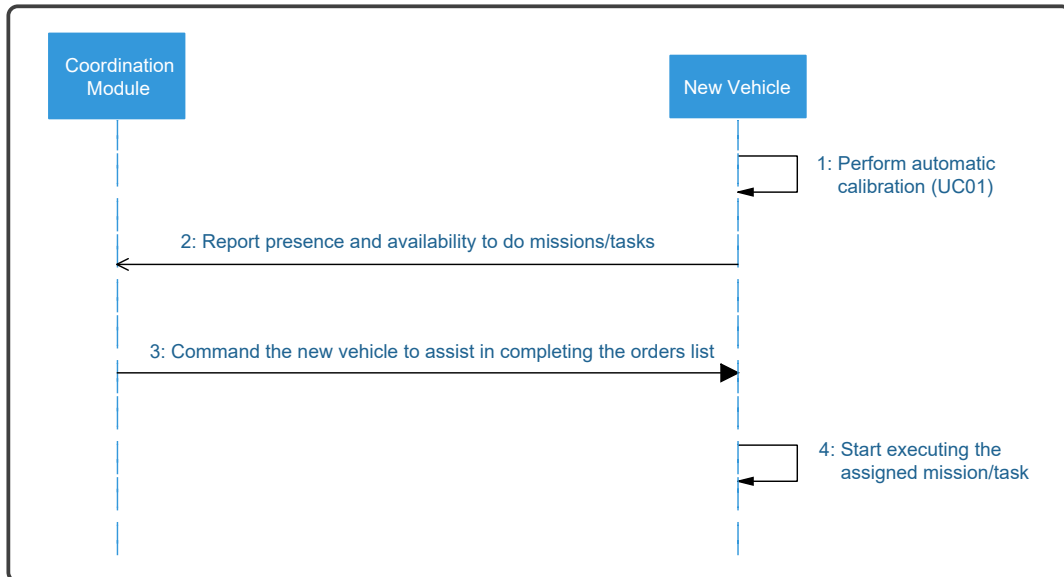
Figure 9: UML sequence diagram for UC09: Adding a new vehicle to the working fleet.

10. When k has been replenished, the non-picking vehicle that is now idle is assigned with a data collection task to gather data for learning patterns.
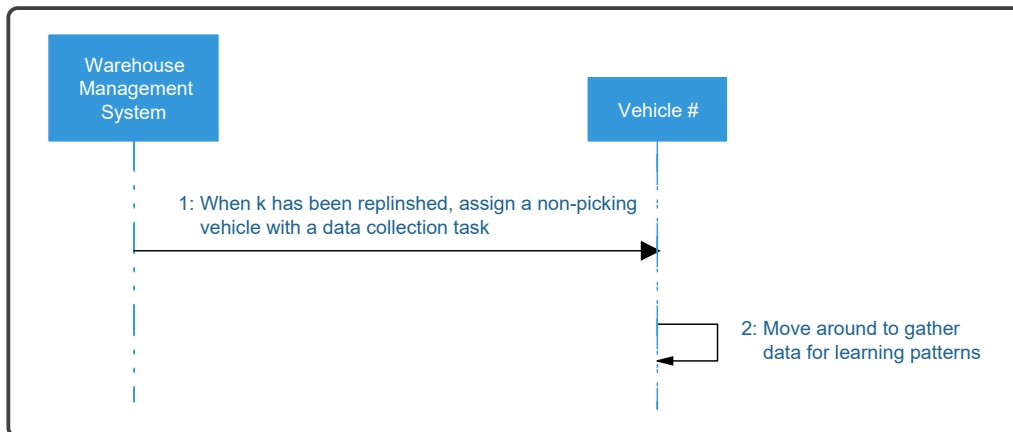
Figure 10: UML sequence diagram for UC10: Data collection task (for learning patterns).

11. A picking vehicle needs to unwrap the new pallet k before picking, since it is wrapped in plastic stretch wrap (T6.3, T6.4).
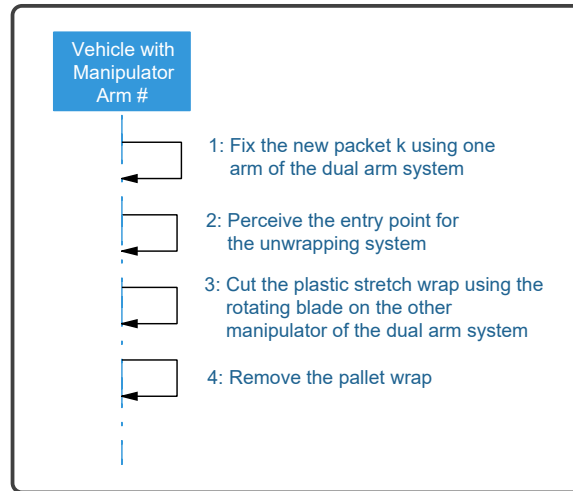
Figure 11: UML sequence diagram for UC11: Unwrapping the plastic stretch wrap of pallet.

12. When the order is fulfilled, it is put on a marshalling lane.

Description of basic missions/subtasks

In order to avoid describing the same information everywhere, we defined primitive missions/subtasks for repeating patterns in the envisioned use cases. This representation yields a clearer, more compact presentation of the hazard analysis while making the sequence diagrams and the single steps of a use case more traceable and easier to grasp. The most relevant ones to the ILIAD use case are described and presented by the according sequence diagrams in the following.

1. Going from one location in the geometric map to another (navigating through the vehicles' workspace).
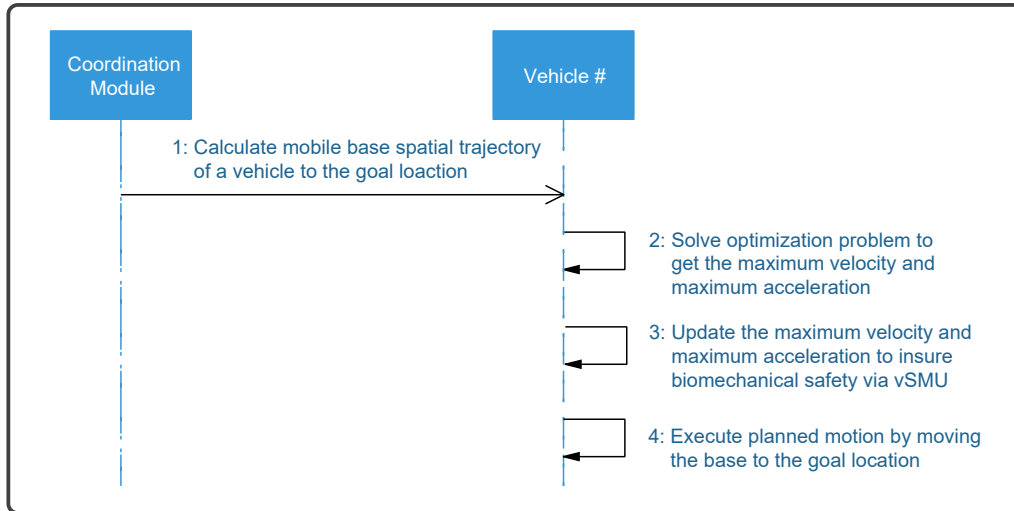
Figure 12: UML sequence diagram for ST0.1: Going to a location.

2. Placing a product box on a pallet.
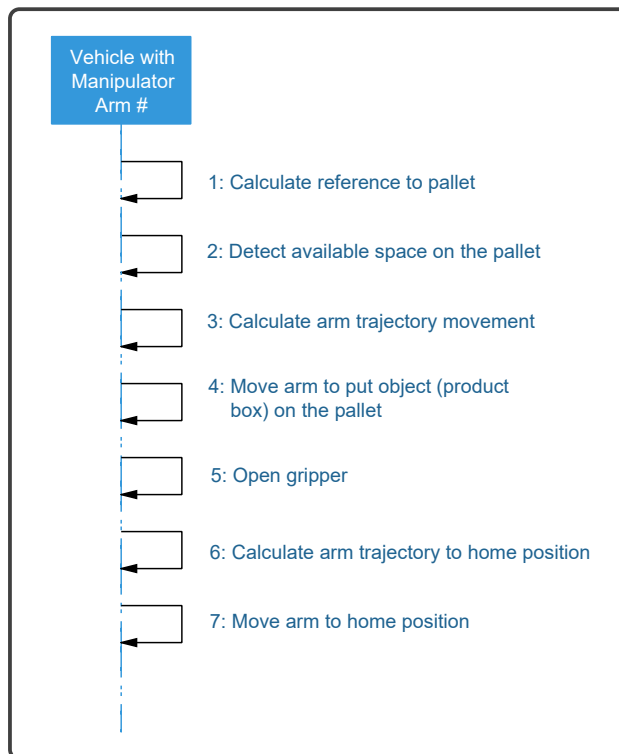
Figure 13: UML sequence diagram for ST0.2: Placing a product box on a pallet.

3. Picking a product box from a temporary storage location.
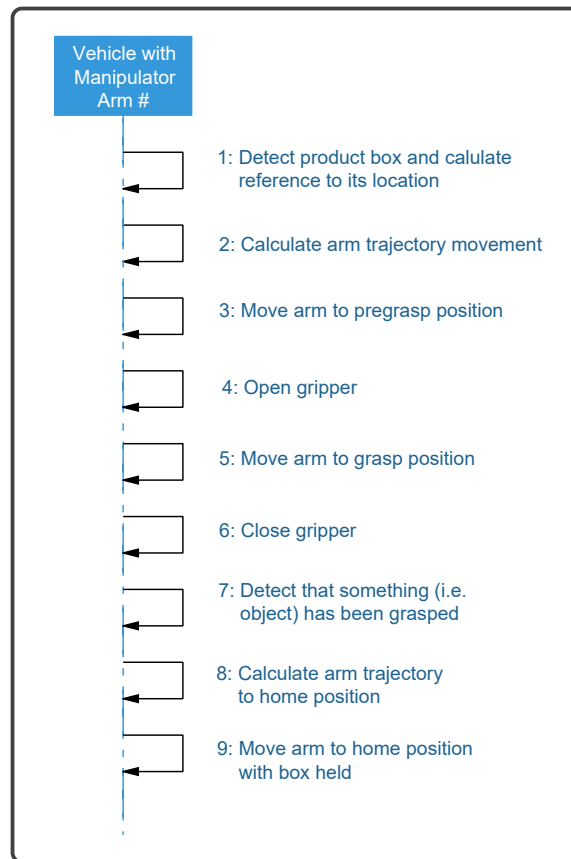
Figure 14: UML sequence diagram for ST0.3: Picking a product box.

List of hazards and associated risks for the ILIAD use case

A hazard analysis which was carried out on the presented scenario revealed in total 596 relevant hazards. The result of the analysis is presented in Table 1, where the hazards are associated with the identified sets of use cases/primitive subtasks and categorized according to their type and origin. A detailed description of each column of Table 1 is given in the following:

- **Use case description** A short description and an identifier for each step of the identified use cases or subtasks.

- **Origin related to** The type of source that leads to the hazardous situation (e.g. mechanical, control system, ...)

- **Origin of hazard** Situation or defect that leads to a specific hazards.

- **Hazard/Hazardous situation** Description of the actual hazard that leads to harm or damage.

- **Potential harm or other consequences** Ultimate consequences to humans, machinery or the workspace.

Most of the classical human–vehicle collision, vehicle–vehicle collision and vehicle–environment collisions hazards have been identified. More specific hazards are linked to the picking (grasping), dropping and unwrapping tasks that could suffer from some failures and lead to unintended behaviour and/or accidents, with the possibility of presence of humans in close vicinity of the vehicles (i.e., workspace sharing). This leads to the following categories of hazards:

- Hazards originating from failures in a shared workspace while performing movement tasks, especially when there are humans in the vicinity of the manipulator arm: e.g. vehicle/fork/manipulator arm traps human or grasps some human body parts.

- Task-specific manipulated object (pallet or product box) hazards: e.g. Vehicle/fork/manipulator arm drops/throws object directly on/at human or the ground, some pallet drop/fall off the during vehicle/fork movement, manipulator arm carries object not intended to be manipulated by it, product box is not on pallet properly.

- Hazards resulting from software bugs, lost communication or system (hardware & software) failures: e.g. unintended movement of the vehicle/fork/manipulator arm or end-effector, obsolete map information that doesn't adequately reflect the current dynamics of the warehouse.

- Secondary hazards that might occur as a consequence of one of the previous hazards: e.g. unsuitable floor due to some spilled product on the floors or scattered objects that are mistakenly dropped or fell off.

4   Conclusions

We performed the complete hazard analysis of the use case for ILIAD demo scenario. This task also helps our partners to model their scenarios, and in turn, the consortium can jointly improve and refine them. Flexible safety measures are used in the robotic domain in [6], where the safety context is simply the distance from the robot to a human,

because only the robot–to–human collision hazard is taken into account. A richer context is needed in order to address a wider range of hazards as expected for the ILIAD use case. We are currently working on adapting our safe motion unit (SMU) and extending it into a vehicle safety unit (vSMU) that can guarantee both human and vehicle safety for all types of autonomous vehicles/robots by tackling the safety concerns from injury biomechanics and specification perspectives, respectively [7, 8]. Completing the development of the vSMU will help in mitigating almost all risks that originate from motions of the vehicles or the manipulator arms in the vicinity of human workers. This report will also be used at a later stage of the project in order to decide, with our partners (UNIPI, ORU and ACT), which use case to be further elaborated and the associated risks to be quantitatively assessed so that they can be completely mitigated or at least reduced adequately. It might be subject to additional analysis in order to validate the safety monitoring and enhancement strategies. Of course other specific use cases that are more relevant to some of ILIAD's typical tasks (e .g. deployment-specific tasks) may also be added in later stages of ILIAD and their risks can be analysed following the same methodology (i .e. extending this report).

References

[1] ILIAD consortium (2017). Report on hardware/software and functional requirements, evaluation metrics. Deliverable 7.1, ILIAD project.

[2] R. Woodman, A. F. Winfield, C. Harper, and M. Fraser (2012), "Building safer robots: Safety driven control," The International Journal of Robotics Research, vol. 31, no. 13, pp. 1603–1626.

[3] Rausand, Marvin (2005), "Preliminary hazard analysis," Norwegian University of Science and Technology.

[4] DIN EN ISO 10218–1 Robots and robotic devices - Safety requirements for industrial robots - Part1: Robots (2012–01), Beurth Verlag, Berlin.

[5] DIN EN ISO 10218–2 Robots and robotic devices - Safety requirements for industrial robots - Part1: Robot systems and Integration (2012–03), Beurth Verlag, Berlin.

[6] S. Haddadin, M. Suppa, S. Fuchs, T. Bodenmüller, A. Albu–Schäffer, and G. Hirzinger (2011), "Towards the robotic co–worker," in Robotics Research. Springer, pp. 261–282.

[7] Haddadin, S., Haddadin, S., Khoury, A., Rokahr, T., Parusel, S., Burgkart, R., Bicchi, A. and Albu-Schäffer, A. (2012), "On making robots understand safety: Embedding injury knowledge into control," The International Journal of Robotics Research, 31(13), 1578-1602.

[8] N. Mansfeld, B. Djellab, J. R. Veuthey, F. Beck, C. Ott and S. Haddadin (2017), "Improving the performance of biomechanically safe velocity control for redundant robots through reflected mass minimization," 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS).

Appendix A   List of preliminary hazards and associated risks

The result of the PHA together with the associated risks are listed in Table 1.

Table 1: List of preliminary hazards and associated risks

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
ST0.1: Go From A to B				
ST0.11: Calculate spatial vehicle trajectory to goal (global: coordinator)	Control System AND Environment	Map information (static + dynamic) is not up to date, not covering all working area, or erroneous due to, e .g. hardware failure (sensors), synchronization problems, occlusions etc.	Human-vehicle collision	stabbing or puncture, friction, abrasion, impact
			Vehicle-vehicle collision	damage to vehicle, crushing, impact, leads to other hazards (e .g. hardware failure)
			Vehicle-environment collision	damage to vehicle, damage to workspace, crushing, impact, leads to other hazards (e .g. unsuitable floor due to scattered objects)
			Unintended movement of vehicle	leads to other hazards (e .g. human-vehicle collision)
ST0.12: Calculate velocity and acceleration (local: on vehicle)	Control System	No solution is found	Vehicle does not move (potentially blocking shared paths)	leads to other hazards (e .g. vehicle-vehicle collision)
	Control System	Sensor information is erroneous due to e .g. hardware failure, synchronization problems, pertubation (light) disturbs vehicle sensors, occlusions etc.	Human-vehicle collision	stabbing or puncture, friction, abrasion, impact
			Vehicle-vehicle collision	damage to vehicle, crushing, impact

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
			Vehicle-environment collision	damage to vehicle, damage to workspace, crushing, impact
ST0.13: vSMU decides safe maximums	Control System	Biomechanical injury data is corrupted or not conservative	Human safety is not guaranteed in collisions	leads to more severe hazards
			Unintended movement of vehicle	leads to other hazards (e.g. human-vehicle collision)
ST0.14: Execute planned motion	Environment	Vehicle surrounded by large crowd of people	Human-vehicle collision	stabbing or puncture, friction, abrasion, impact
			Vehicle has to slow down/stop	leads to other hazards (e.g. human-vehicle collision)
			Malicious behavior of people	leads to other hazards (e.g. human-vehicle collision)
	Noise	Vehicle movement	Noise	human discomfort, stress, effect on the hearing and balance, reduced/loss of awareness, effect on speech communication and perception of acoustic signals, loss of hearing, consequence of human error
	Vibration	Vehicle movement	Vibration: losening of connections, fasteners, components, unexpected failure (e.g. vehicle stop)	fatique, damage to vehicle, human discomfort

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
			Vibration: expulsion of parts	leads to other hazards (e.g. unsuitable floor due to scattered objects)
	Environment	Unsuitable floor (slippery, spillage, has some holes)	Unintended movement of vehicles	leads to other hazards (e.g. human-vehicle collision)
			Vehicle fall	crushing, trapping, impact
			Vehicle stuck	leads to other hazards (e.g. vehicle-vehicle collision)
	Mechanical	Hardware failure (e.g. gears)	Unintended movement of vehicles	leads to other hazards (e.g. human-vehicle collision)
	Mechanical OR Control System	Unintended movement of vehicle	Human-vehicle collision	stabbing or puncture, friction, abrasion, impact
			Vehicle-vehicle collision	damage to vehicle, crushing, impact, leads to other hazards (e.g. hardware failure)
			Vehicle-environment collision	damage to vehicle, damage to workspace, crushing, impact, leads to other hazards (e.g. unsuitable floor due to scattered objects)
			Vehicle is stuck in part of the environment	damage to vehicle, leads to other hazards (e.g. vehicle-vehicle collision)

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
	Mechanical OR Control System	Unintended movement of manipulator arm	Manipulator arm hits human during vehicle motion	abrasion, impact
			Manipulator arm clamps human or human parts	crushing, shearing, trapping
			Manipulator arm hits other vehicle	damage to manipulator, damage to vehicle
			Manipulator arm hits walls, shelves, etc.	damage to manipulator, damage to vehicle, damage to workspace, leads to other hazards
			Manipulator is stuck in part of the environment	damage to manipulator, leads to other hazards (e .g. vehicle-vehicle collision)
	Mechanical OR Control System	Unintended movement of forks	Fork hits human	stabbing or puncture, abrasion, impact
			Fork clamps human or human parts	crushing, shearing, trapping
			Fork hits other vehicle	damage to vehicle
			Fork hits walls, shelves, etc.	damage to vehicle, damage to workspace, leads to other hazards (e .g. unsuitable floor due to scattered objects)

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
			Fork is stuck in part of the environment	damage to vehicle, leads to other hazards (e.g. vehicle-vehicle collision)
ST0.2: Place Product Box On Pallet				
ST0.21: Calculate pallet reference	Control System AND Environment	Sensor information is erroneous due to e.g. hardware failure, synchronization problems, pertubation (e.g. light) disturbs vehicle sensors, occlusions etc.	Manipulator arm hits other reachable objects	damage to manipulator, damage to object/workspace, leads to other hazards (e.g. unsuitable floor due to scattered objects)
			Product box placed loosely on pallet (might fall, damage)	product damage, abrasion, falling: impact
ST0.22: Detect available pallet space	Control System	Sensor information is erroneous due to e.g. hardware failure, synchronization problems, pertubation (light) disturbs vehicle sensors, occlusions etc.	Loading already full pallet, putting box on unstable place	product damage, abrasion, falling: impact
ST0.23 & ST0.26: Calculate arm trajectory	Control System	Software bug or software failure	Unintended movement of manipulator arm	leads to other hazards (e.g. human-vehicle collision)
			Manipulator arm hits other reachable objects	damage to manipulator, damage to object/workspace, leads to other hazards (e.g. unsuitable floor due to scattered objects)
ST0.24: Move arm to put product box on pallet	Mechanical OR Control System	Unintended movement of manipulator arm	Manipulator arm (with product box) hits human	abrasion, impact

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
			Manipulator arm (with product box) clamps human or human parts	crushing, shearing, trapping
			Manipulator arm (with product box) hits other vehicle	damage to manipulator, damage to vehicle
			Manipulator arm (with product box) hits walls, shelves, etc.	damage to manipulator, damage to vehicle, damage to workspace, leads to other hazards (e.g. unsuitable floor due to scattered objects)
			Manipulator arm (with product box) pushes movable object(s)	product damage, abrasion, falling: impact, leads to other hazards (e.g. unsuitable floor due to scattered objects)
			Objects being dropped on/thrown at human	impact, abrasion, damage to object, leads to other hazards (e.g. unsuitable floor due to scattered objects)
	Mechanical AND Interaction	Manipulator arm drops product box on the ground	Shared path is locked, unsuitable driving floor	leads to other hazards (e.g. vehicle-vehicle collision)
			Damage to product box	leads to other hazards (e.g. product spill on the floor)

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
			Sharp edges of broken box	cutting or severing, stabbing or puncture
			Human-vehicle collision while human retrives box from the ground	stabbing or puncture, friction, abrasion, impact
			Product spill on the floor	product damage, falling: impact, leads to other hazards (e .g. unsuitable floor)
	Mechanical	Open/broken product box manipulated by vehicle	Product spill on the floor	product damage, falling: impact, leads to other hazards (e .g. unsuitable floor)
			Part of product fall/spill on human	product damage, hygiene problems, leads to other hazards (e .g. unsuitable floor)
	Noise	Manipulator arm movement	Noise	human discomfort, stress, consequence of human error
ST0.25: Open gripper	Mechanical OR Control System	Unintended movement of jigs or gripper	Gripper grasps human or human parts	crushing, shearing, trapping
	Mechanical AND Interaction	Manipulator arm drops product box on the ground	Shared path is locked, unsuitable driving floor	leads to other hazards (e .g. vehicle-vehicle collision)
			Damage to product box	leads to other hazards (e .g. product spill on the floor)

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
			Sharp edges of broken box	cutting or severing, stabbing or puncture
			Human-vehicle collision while human retrives box from the ground	stabbing or puncture, friction, abrasion, impact
			Product spill on the floor	product damage, falling: impact, leads to other hazards (e .g. unsuitable floor)
	Noise	Dropping box on pallet	Noise	human discomfort, stress, effect on the hearing and balance, reduced/loss of awareness, effect on speech communication and perception of acoustic signals, loss of hearing, consequence of human error
	Mechanical	Hardware failure (e .g. motor, end-effector mechatronics, etc.)	Fails to release box	leads to other hazards
			Separated part of gripper hits/falls on human	stabbing or puncture, abrasion, impact
ST0.27: Move arm to home position	Mechanical OR Control System	Unintended movement of manipulator arm	Manipulator arm hits human	abrasion, impact
			Manipulator arm hits other vehicle	damage to manipulator, damage to vehicle

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
			Manipulator arm hits walls, shelves, etc.	damage to manipulator, damage to vehicle, damage to workspace, leads to other hazards (e .g. unsuitable floor due to scattered objects)
			Manipulator arm clamps human or human parts	crushing, shearing, trapping
			Manipulator arm pushes movable object(s)	product damage, abrasion, falling: impact, leads to other hazards (e .g. unsuitable floor due to scattered objects)
ST0.3: Pick Product				
ST0.31: Detect product and calculate product box reference	Control System AND Environment	Sensor information is erroneous due to e .g. hardware failure, synchronization problems, occlusions, pertubation (light) etc.	Manipulator arm hits other reachable objects	damage to manipulator, damage to object/workspace, leads to other hazards (e .g. unsuitable floor due to scattered objects)
			Manipulator arm mistakes a hazardous object for the product	burns, leads to other hazards (e .g. manipulator cuts human or human parts)
			Manipulator arm picks several objects, some fall during vehicle motion	stabbing or puncture, abrasion, impact
			Product not grasped properly later	leads to other hazards (e .g. unsuitable floor due to scattered objects)

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
			Product box placed loosely on pallet (might fall, damage)	product damage, abrasion, falling: impact
ST0.32: Calculate arm trajectory	Control System	Software bug or software failure	Unintended movement of manipulator arm	leads to other hazards (e.g. manipulator hits human)
			Manipulator arm hits other reachable objects	damage to manipulator, damage to object/workspace, leads to other hazards (e.g. unsuitable floor due to scattered objects)
ST0.33: Move arm to "pregrasp" position	Mechanical OR Control System	Unintended movement of manipulator arm	Manipulator arm clamps human or human parts	crushing, shearing, trapping
			Manipulator arm hits human	abrasion, impact
			Manipulator arm pushes movable object(s)	product damage, abrasion, falling: impact, leads to other hazards (e.g. unsuitable floor due to scattered objects)
			Manipulator arm hits other vehicle	damage to manipulator, damage to vehicle

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
			Manipulator arm hits walls, shelves, etc.	damage to manipulator, damage to vehicle, damage to workspace, leads to other hazards (e .g. unsuitable floor due to scattered objects)
	Mechanical AND Interaction	Manipulator arm hits product to be grasped and pushes it on the ground	Shared path is locked	leads to other hazards (e .g. vehicle-vehicle collision)
			Damage to product box	leads to other hazards (e .g. product spill on the floor)
			Sharp edges of broken product box	cutting or severing, stabbing or puncture
			Product spill on the floor	product damage, falling: impact, leads to other hazards (e .g. unsuitable floor)
			Human-vehicle collision while human retrives box from the ground	stabbing or puncture, friction, abrasion, impact
ST0.34: Open gripper	Mechanical OR Control System	Unintended movement of jigs or gripper	Gripper grasps human or human parts	crushing, shearing, trapping
	Control System	Hardware failure (e .g. end-effector)	Fails to open gripper	leads to other hazards
			Separated part of gripper hits/falls on human	stabbing or puncture, abrasion, impact

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
ST0.35: Move arm to "grasp" position	Mechanical OR Control System	Unintended movement of manipulator arm	Manipulator arm clamps human or human parts	crushing, shearing, trapping
			Manipulator arm hits human	abrasion, impact
			Manipulator arm hits other vehicle	damage to manipulator, damage to vehicle
			Manipulator arm hits walls, shelves, etc.	damage to manipulator, damage to vehicle, damage to workspace, leads to other hazards
			Manipulator arm pushes movable object(s)	product damage, abrasion, falling: impact, leads to other hazards (e .g. unsuitable floor due to scattered objects)
	Mechanical AND Interaction	Manipulator arm hits product to be grasped and pushes it on the ground	Shared path is locked, unsuitable driving floor	leads to other hazards (e .g. vehicle-vehicle collision)
			Damage to product box	leads to other hazards (e .g. product spill on the floor)
			Sharp edges of broken product box	cutting or severing, stabbing or puncture
			Product spill on the floor	product damage, falling: impact, leads to other hazards (e .g. unsuitable floor)

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
			Human-vehicle collision while human retrives box from the ground	stabbing or puncture, friction, abrasion, impact
ST0.36: Close gripper	Mechanical OR Control System	Unintended movement of jigs or gripper	Gripper grasps human or human parts	crushing, shearing, trapping
	Mechanical AND Interaction	Gripper pushes product box to the ground	Shared path is locked, unsuitable driving floor	leads to other hazards (e .g. vehicle-vehicle collision)
			Damage to product box	leads to other hazards (e .g. product spill on the floor)
			Sharp edges of broken product box	cutting or severing, stabbing or puncture
			Product spill on the floor	product damage, falling: impact, leads to other hazards (e .g. unsuitable floor)
			Human-vehicle collision while human retrives box from the ground	stabbing or puncture, friction, abrasion, impact
	Control System	Vehicle grasps with too much force	Damage to product box	leads to other hazards (e .g. product spill on the floor)
	Mechanical	Hardware failure (e .g. end-effector)	Grasp failure	leads to other hazards (e .g. objects being dropped on/thrown at human)

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
			Separated part of gripper hits/falls on human	stabbing or puncture, abrasion, impact
ST0.37: Detect if product box is successfully grasped	Mechanical	Hardware failure (e.g. sensors)	Grasp failure	leads to other hazards (e.g. objects being dropped on/thrown at human)
	Control System	False detection	Grasp another object with similar shape	leads to other hazards (e.g. manipulator arm (with product box) hits human)
ST0.38: Calculate arm trajectory to home	Control System	Software bug or software failure	Unintended movement of manipulator arm	leads to other hazards (e.g. human-vehicle collision)
			Manipulator arm hits other reachable objects	damage to manipulator, damage to object/workspace, leads to other hazards (e.g. unsuitable floor due to scattered objects)
ST0.39: Move arm to home position	Mechanical OR Control System	Unintended movement of manipulator arm	Manipulator arm (with product box) hits human	abrasion, impact
			Manipulator arm (with product box) clamps human or human parts	crushing, shearing, trapping
			Manipulator arm (with product box) hits other vehicle	damage to manipulator, damage to vehicle

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
			Manipulator arm (with product box) hits walls, shelves, etc.	damage to manipulator, damage to vehicle, damage to workspace, leads to other hazards (e .g. unsuitable floor due to scattered objects)
			Manipulator arm (with product box) pushes movable object(s)	product damage, abrasion, falling: impact, leads to other hazards (e .g. unsuitable floor due to scattered objects)
			Objects being dropped on/thrown at human	impact, abrasion, damage to object, leads to other hazards (e .g. unsuitable floor due to scattered objects)
	Mechanical AND Interaction	Manipulator arm drops product box on the ground	Shared path is locked	leads to other hazards (e .g. vehicle-vehicle collision)
			Damage to product box	leads to other hazards (e .g. product spill on the floor)
			Sharp edges of broken box	cutting or severing, stabbing or puncture
			Product spill on the floor	product damage, falling: impact, leads to other hazards (e .g. unsuitable floor)
			Human-vehicle collision while human retrives box from the ground	stabbing or puncture, friction, abrasion, impact

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
	Mechanical	Open/broken product box manipulated by manipulator arm	Part of product fall/spill on human	product damage, hygiene problems, leads to other hazards (e .g. unsuitable floor)
			Product spill on the floor	product damage, falling: impact, leads to other hazards (e .g. unsuitable floor)

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
ST0.4: Manipulator Arm Motion				
	Mechanical OR Control System	Unintended movement of manipulator arm	Manipulator arm hits human	abrasion, impact
			Manipulator arm clamps human or human parts	crushing, shearing, trapping
			Manipulator arm hits other vehicle	damage to manipulator, damage to vehicle
			Manipulator arm hits walls, shelves, etc.	damage to manipulator, damage to vehicle, damage to workspace, leads to other hazards (e .g. unsuitable floor due to scattered objects)
			Manipulator arm is stuck in part of the environment	damage to manipulator, leads to other hazards (e .g. vehicle-vehicle collision)
ST0.5: Gripper Motion				
	Mechanical	Hardware failure (e .g. end-effector)	Separated part hits/falls on human	stabbing or puncture, abrasion, impact
	Mechanical OR Control System	Unintended movement of jigs or gripper	Gripper grasps human or human parts	crushing, shearing, trapping

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
ST0.6: Fork Motion				
	Mechanical OR Control System	Unintended movement of forks	Fork hits human	stabbing or puncture, abrasion, impact
			Fork clamps human or human parts	crushing, shearing, trapping
			Fork hits other vehicle	damage to vehicle
			Fork hits walls, shelves, etc.	damage to vehicle, damage to workspace, leads to other hazards (e .g. unsuitable floor due to scattered objects)
			Fork is stuck in part of the environment	leads to other hazards
	Mechanical	Geometry of forks	Far reaching sharp edges of fork	stabbing or puncture
	Noise	Forks move with too high speed	Noise	human discomfort, stress, effect on the hearing and balance, reduced/loss of awareness, effect on speech communication and perception of acoustic signals, loss of hearing, consequence of human error

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
	Mechanical	Hardware failure (e .g. fork failure, sensor, separation)	Separated part hits/falls out on human	stabbing or puncture, abrasion, impact, leads to other hazards (e .g. unsuitable floor due to scattered objects)
			Vehicle fork clamps human or human parts	crushing, shearing, trapping
ST0.7: Motion with/close to full pallet				
	Mechanical OR Control System	Unintended movement of vehicle/manipulator arm/forks	Pallet being dropped on/thrown at human	impact, abrasion, damage to product, damage to pallet, leads to other hazards (e .g. unsuitable floor due to scattered objects)
			Products being dropped on/thrown at human	impact, abrasion, damage to product, leads to other hazards (e .g. unsuitable floor due to scattered objects)
			Pallet being dropped on/thrown at other vehicle/environment	damage to product, damage to pallet, damage to vehicle, damage to workspace, leads to other hazards (e .g. unsuitable floor due to scattered objects)

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
			Products being dropped on/thrown at vehicle/environment	impact, abrasion, damage to product, damage to vehicle, damage to workspace, leads to other hazards (e.g. unsuitable floor due to scattered objects)
	Mechanical	Pallet/Products fell on the floor	Shared path is locked	leads to other hazards (e.g. vehicle-vehicle collision)
			Human-vehicle collision while human retrives pallet parts/products from the ground	stabbing or puncture, friction, abrasion, impact
			Damage to pallet	leads to other hazards (e.g. products being dropped on/thrown at humans)
			Sharp edges of broken pallet	cutting or severing, stabbing or puncture
			Damage to product box	leads to other hazards (e.g. product spill on the floor)
			Sharp edges of broken product box	cutting or severing, stabbing or puncture
			Product spill on the floor	product damage, falling: impact, leads to other hazards (e.g. unsuitable floor)

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
ST0.8: Motion with/close to empty pallet				
	Mechanical OR Control System	Unintended movement of vehicle/manipulator arm/forks	Pallet being dropped on/thrown at human	impact, abrasion, damage to product, damage to pallet, leads to other hazards (e.g. unsuitable floor due to scattered objects)
			Pallet being dropped on/thrown at other vehicle/environment	damage to product, damage to pallet, damage to vehicle, damage to workspace, leads to other hazards (e.g. unsuitable floor due to scattered objects)
	Mechanical	Pallet fell on the floor	Shared path is locked	leads to other hazards (e.g. vehicle-vehicle collision)
			Human-vehicle collision while human retrives pallet parts from the ground	stabbing or puncture, friction, abrasion, impact
			Damage to pallet	leads to other hazards (e.g. products being dropped on/thrown at humans)
			Sharp edges of broken pallet	cutting or severing, stabbing or puncture

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
UC01: Automatic Sensor Calibration				
UC01.1: System power-up and calibration start	Electrical	Unintended movement of vehicle, manipulator, end-effector and/or forks due to electromagnetic interference or surges in the energy source	All hazards that originate from unintended movement of the vehicle, manipulator arm, end-effector and forks, see: ST0.14: Execute planned motion, ST0.4: Manipulator Arm Motion, ST0.5: Gripper Motion, ST0.6: Fork Motion	
			Contact with live parts or connections, Confusion of various voltages within a system, Contact with discrete components in the electrical (electronic) circuitry, i.e. capacitors	electric shock, burn or scald
	Control System	Software bug or software failure	Vehicle will not start as no command is issued	no consequences as vehicle start-up is not done in daily workspace
UC01.2: Wander around in the allowed space		All hazards associated with ST0.1: Go From A to B		
UC01.3 & 1.4: Calibration		All hazards that originate from erroneous sensor information, see: ST0.11: Calculate spatial robot trajectory to goal (coordinator), ST0.21: Calculate pallet reference, ST0.31: Detect product and calculate product reference, UC06.3.1 & UC07.3.1 & UC08.2.1: Detect pallet and calculate pallet reference, UC11.2: Perceive unwrapping entry point		
UC01.7: Recalibration		All hazards associated with UC01.2, UC01.3 and UC01.4		

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
UC01.8: Sensor failure and failure reporting		All hazards associated with UC01.2, UC01.3 and UC01.4		
UC02: Geometric Mapping				
UC02.1: Motion start command	Control System	Software bug or software failure	Human-vehicle collision	stabbing or puncture, friction, abrasion, impact
			Vehicle-vehicle collision	damage to vehicle, crushing, impact
			Vehicle-environment collision	damage to vehicle, damage to workspace, crushing, impact
			Unintended movement of vehicles	leads to other hazards (e.g. human-vehicle collision)
UC02.2: Move around to build a map		All hazards associated with ST0.1: Go From A to B		
UC02.3: Send information to localization module	Control system	Software bug or software failure or lost communication	Collected map information can't reach the localization module	leads to other hazards (e.g. vehicle-environment collision)
UC02.5: Construct geometric map	Control system	Software bug or software failure	Map erroneous	leads to other hazards (e.g. vehicle-environment collision)

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
UC03: Semantic Mapping				
UC03.2 - UC03.4: Differentiate between various map objects	Control System	Failure of automatic semantic mapping	Different map objects can't be identified from each other	leads to other hazards (e.g. manipulator arm mistakes a hazardous object for the product)
UC03.5: Manual check and input	Human Error	Human does not notice error in automatic labelling	Erroneous picking, placing and unwrapping tasks, confused activities (e.g. loading to unloading or vice versa)	leads to other hazards (e.g. manipulator arm mistakes a hazardous object for the product)
	Human Error	Human allocates wrong label (either wrong product or completely wrong type e.g. shelf instead of picking location)	Erroneous picking, placing and unwrapping tasks, confused activities (e.g. loading to unloading or vice versa)	leads to other hazards (e.g. manipulator arm mistakes a hazardous object for the product)
UC05: Mixed Palletizing				
UC05.2 & UC05.5: Go to product pick location		All hazards associated with ST0.1: Go From A to B		
UC05.3 & UC05.6: Pick some units of some product		All hazards associated with ST0.3: Pick Product		
UC05.4 & UC05.7: Put some product units on a pallet		All hazards associated with ST0.2: Place Product Box On Pallet		
UC05.8: Go to pallet drop location		All hazards associated with ST0.1: Go From A to B		

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
UC05.9: Drop the "mixed" pallet (lower the fork)		All hazards associated with ST0.6: Fork Motion		
		All hazards associated with ST0.7: Motion with/close to full pallet		
	Control System AND Environment	Sensor information is erroneous due to e .g. hardware failure, synchronization problems, occlusions, pertubation (light) etc.	Vehicle lowers the pallet on human/human part (e .g. foot)	impact, abrasion, damage to product, damage to pallet, leads to other hazards (e .g. pallet not placed properly)
	Mechanical OR Control System	Vehicle forks/pallet make contact with other object while lowering forks	Object is pushed over on human	impact, abrasion, damage to product,leads to other hazards (e .g. unsuitable floor due to scattered objects)
			Object is pushed over on the ground	leads to other hazards (e .g. unsuitable floor due to scattered objects)
			Pallet not placed properly (unstable, might fall)	leads to other hazards (e .g. products being dropped on/thrown at human)
	Control System	Software bug or software failure	Vehicle fork (with pallet) hits other reachable objects	leads to other hazards (e .g. products being dropped on/thrown at human)
	Mechanical OR Control System	Fork speed to high	Pallet being dropped on/thrown at human	impact, abrasion, damage to product, damage to pallet, leads to other hazards (e .g. unsuitable floor due to scattered objects)

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
			Products being dropped on/thrown at human	impact, abrasion, damage to product, leads to other hazards (e .g. unsuitable floor due to scattered objects)
			Pallet being dropped on/thrown at other vehicle/environment	damage to product, damage to pallet, damage to vehicle, damage to workspace, leads to other hazards (e .g. unsuitable floor due to scattered objects)
			Products being dropped on/thrown at vehicle/environment	impact, abrasion, damage to product, damage to vehicle, damage to workspace, leads to other hazards (e .g. unsuitable floor due to scattered objects)
UC06: Move Full Pallet To Staging Area				
UC06.2: Go to pallet pick location		All hazards associated with ST0.1: Go From A to B		
UC06.3: Pick a full pallet				
UC06.3.1: Detect pallet and calculate pallet reference	Control System AND Environment	Sensor information is erroneous due to e .g. hardware failure, synchronization problems, occlusions, pertubation (light) etc.	Vehicle hits other reachable objects	damage to object/workspace, leads to other hazards (e .g. unsuitable floor due to scattered objects)

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
			Vehicle gets stuck by trying to lift heavy structure/object instead of pallet	damage to vehicle, damage to object/workspace, leads to other hazards (e .g. unsuitable floor due to scattered objects)
			Pallet not picked properly, placed loosely on fork (might fall, overlap)	pallet damage, product damage, abrasion, impact, leads to other hazards (e .g. pallet drop on/thrown at human)
	Control System	False detection (software)	Vehicle mistakes other object for pallet	leads to other hazards (e .g. vehicle hits human with object)
			Vehicle mistakes a hazardous object for the pallet	burns, leads to other hazards (e .g. vehicle cuts human or human parts with hazardous object)
	Control System	Software bug or software failure	Vehicle hits other reachable objects	damage to object/workspace, leads to other hazards (e .g. unsuitable floor due to scattered objects)
UC06.3.2: Move vehicle to allow fork to be below the pallet to enable lifting		All hazards associated with ST0.1: Go From A to B		
		All hazards associated with ST0.7: Motion with/close to full pallet		
UC06.3.3: Elevate vehicle fork to lift the pallet		All hazards associated with ST0.6: Fork Motion		

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
		All hazards associated with ST0.7: Motion with/close to full pallet		
	Mechanical OR Control System	Fork speed to high	Pallet being dropped on/thrown at human	impact, abrasion, damage to product, damage to pallet, leads to other hazards (e .g. unsuitable floor due to scattered objects)
			Products being dropped on/thrown at human	impact, abrasion, damage to product, leads to other hazards (e .g. unsuitable floor due to scattered objects)
			Pallet being dropped on/thrown at other vehicle/environment	damage to product, damage to pallet, damage to vehicle, damage to workspace, leads to other hazards (e .g. unsuitable floor due to scattered objects)
			Products being dropped on/thrown at vehicle/environment	impact, abrasion, damage to product, damage to vehicle, damage to workspace, leads to other hazards (e .g. unsuitable floor due to scattered objects)
	Mechanical	Broken pallet manipulated by vehicle	Sharp edges of broken pallet	cutting or severing, stabbing or puncture, leads to other hazards(e .g. products being thrown at/dropped on human)

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
UC06.4: Go to staging area		All hazards associated with ST0.1: Go From A to B		
UC06.5 Drop the full pallet (lower the vehicle fork)		All hazards associated with ST0.6: Fork Motion		
		All hazards associated with ST0.7: Motion with/close to full pallet		
	Control System AND Environment	Sensor information is erroneous due to e.g. hardware failure, synchronization problems, occlusions, pertubation (light) etc.	Vehicle lowers the pallet on human/human part (e.g. foot)	impact, abrasion, damage to product, damage to pallet, leads to other hazards (e.g. pallet not placed properly)
	Mechanical OR Control System	Vehicle forks/pallet make contact with other object while lowering forks	Object is pushed over on human	impact, abrasion, damage to product,leads to other hazards (e.g. unsuitable floor due to scattered objects)
			Object is pushed over on the ground	leads to other hazards (e.g. unsuitable floor due to scattered objects)
			Pallet not placed properly (unstable, might fall)	leads to other hazards (e.g. products being dropped on/thrown at human)
	Control System	Software bug or software failure	Vehicle fork (with pallet) hits other reachable objects	leads to other hazards (e.g. products being dropped on/thrown at human)

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
	Mechanical OR Control System	Fork speed to high	Pallet being dropped on/thrown at human	impact, abrasion, damage to product, damage to pallet, leads to other hazards (e.g. unsuitable floor due to scattered objects)
			Products being dropped on/thrown at human	impact, abrasion, damage to product, leads to other hazards (e.g. unsuitable floor due to scattered objects)
			Pallet being dropped on/thrown at other vehicle/environment	damage to product, damage to pallet, damage to vehicle, damage to workspace, leads to other hazards (e.g. unsuitable floor due to scattered objects)
			Products being dropped on/thrown at vehicle/environment	impact, abrasion, damage to product, damage to vehicle, damage to workspace, leads to other hazards (e.g. unsuitable floor due to scattered objects)
UC07: Replenish Empty Slot				
UC07.2: Go to shelf location		All hazards associated with ST0.1: Go From A to B		
UC07.3: Pick a full pallet from shelf				

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
UC07.3.1: Detect pallet and calculate pallet reference	Control System AND Environment	Sensor information is erroneous due to e .g. hardware failure, synchronization problems, occlusions, pertubation (light) etc.	Vehicle hits other reachable objects	damage to vehicle, damage to workspace, leads to other hazards (e.g. objects being dropped on/thrown at human)
			Vehicle gets stuck by trying to lift heavy structure/object instead of pallet	damage to vehicle, damage to workspace, leads to other hazards (e.g. objects being dropped on/thrown at human)
			Pallet not picked properly, placed loosely on fork (might fall, overlap)	pallet damage, product damage, abrasion, impact, leads to other hazards (e.g. pallet drop on/thrown at human)
	Control System	False detection (software)	Vehicle mistakes a hazardous object for the pallet	burns, leads to other hazards (e .g. vehicle cuts human or human parts with hazardous object)
			Vehicle mistakes other object for pallet	leads to other hazards (e .g. vehicle hits human with object)
	Control System	Software bug or software failure	Vehicle hits other reachable objects	damage to object/workspace, leads to other hazards (e .g. unsuitable floor due to scattered objects)
UC07.3.2: Elevate vehicle fork		All hazards associated with ST0.6: Fork Motion		

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
	Mechanical OR Control System	Unintended movement of fork	Fork hits object stored on a high level	leads to other hazards with higher severity (e .g. pallet being dropped on human)
UC07.3.3: Move vehicle to allow fork to be below the pallet to enable lifting		All hazards associated with ST0.1: Go From A to B		
		All hazards associated with ST0.7: Motion with/close to full pallet, but with higher severity as the products are potentially stored on a high shelf		
UC07.3.4: Elevate vehicle fork to lift the pallet		All hazards associated with ST0.6: Fork Motion		
		All hazards associated with ST0.7: Motion with/close to full pallet, but with higher severity as the products are potentially stored on a high shelf		
	Mechanical OR Control System	Fork speed to high	Pallet being dropped on/thrown at human	impact, abrasion, damage to product, damage to pallet, leads to other hazards (e .g. unsuitable floor due to scattered objects)
			Products being dropped on/thrown at human	impact, abrasion, damage to product, leads to other hazards (e .g. unsuitable floor due to scattered objects)

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
			Pallet being dropped on/thrown at other vehicle/environment	damage to product, damage to pallet, damage to vehicle, damage to workspace, leads to other hazards (e.g. unsuitable floor due to scattered objects)
			Products being dropped on/thrown at vehicle/environment	impact, abrasion, damage to product, damage to vehicle, damage to workspace, leads to other hazards (e.g. unsuitable floor due to scattered objects)
	Mechanical AND Interaction	Broken pallet manipulated by vehicle	Sharp edges of broken pallet	cutting or severing, stabbing or puncture
UC07.3.5: Move vehicle outside pallet area to lower forks		All hazards associated with ST0.1: Go From A to B		
		All hazards associated with ST0.7: Motion with/close to full pallet, but with higher severity as the products are potentially stored on a high shelf		
UC07.3.6: Lower fork to driving height		All hazards associated with ST0.6: Fork Motion		
		All hazards associated with ST0.7: Motion with/close to full pallet, but with higher severity as the products are potentially stored on a high shelf		

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
	Mechanical OR Control System	Fork speed to high	Pallet being dropped on/thrown at human	impact, abrasion, damage to product, damage to pallet, leads to other hazards (e.g. unsuitable floor due to scattered objects)
			Products being dropped on/thrown at human	impact, abrasion, damage to product, leads to other hazards (e.g. unsuitable floor due to scattered objects)
			Pallet being dropped on/thrown at other vehicle/environment	damage to product, damage to pallet, damage to vehicle, damage to workspace, leads to other hazards (e.g. unsuitable floor due to scattered objects)
			Products being dropped on/thrown at vehicle/environment	impact, abrasion, damage to product, damage to vehicle, damage to workspace, leads to other hazards (e.g. unsuitable floor due to scattered objects)
UC07.4: Go to empty product pick location		All hazards associated with ST0.1: Go From A to B		
UC07.5: Drop the full pallet (lower the fork)		All hazards associated with ST0.6: Fork Motion		
		All hazards associated with ST0.7: Motion with/close to full pallet		

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
	Control System AND Environment	Sensor information is erroneous due to e .g. hardware failure, synchronization problems, occlusions, pertubation (light) etc.	Vehicle lowers the pallet on human/human part (e .g. foot)	impact, abrasion, damage to product, damage to pallet, leads to other hazards (e .g. pallet not placed properly)
	Mechanical OR Control System	Vehicle forks/pallet make contact with other object while lowering forks	Object is pushed over on human	impact, abrasion, damage to product,leads to other hazards (e .g. unsuitable floor due to scattered objects)
			Object is pushed over on the ground	leads to other hazards (e .g. unsuitable floor due to scattered objects)
			Pallet not placed properly (unstable, might fall)	leads to other hazards (e .g. products being dropped on/thrown at human)
	Control System	Software bug or software failure	Vehicle fork (with pallet) hits other reachable objects	leads to other hazards (e .g. products being dropped on/thrown at human)
	Mechanical OR Control System	Fork speed to high	Pallet being dropped on/thrown at human	impact, abrasion, damage to product, damage to pallet, leads to other hazards (e .g. unsuitable floor due to scattered objects)
			Products being dropped on/thrown at human	impact, abrasion, damage to product, leads to other hazards (e .g. unsuitable floor due to scattered objects)

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
			Pallet being dropped on/thrown at other vehicle/environment	damage to product, damage to pallet, damage to vehicle, damage to workspace, leads to other hazards (e .g. unsuitable floor due to scattered objects)
			Products being dropped on/thrown at vehicle/environment	impact, abrasion, damage to product, damage to vehicle, damage to workspace, leads to other hazards (e .g. unsuitable floor due to scattered objects)

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
UC08: Pallet Picking & Palletizing				
UC08.2: Go to pallet pick location		All hazards associated with ST0.1: Go From A to B		
UC08.3: Pick an empty pallet				
UC08.3.1: Detect pallet and calculate pallet reference	Control System AND Environment	Sensor information is erroneous due to e .g. hardware failure, synchronization problems, occlusions, pertubation (light) etc.	Vehicle hits other reachable objects	damage to vehicle, damage to workspace, leads to other hazards (e .g. objects being dropped on/thrown at human)
			Vehicle gets stuck by trying to lift heavy structure/object instead of pallet	damage to vehicle, damage to workspace, leads to other hazards (e .g. objects being dropped on/thrown at human)
			Pallet not picked properly, placed loosely on fork (might fall, overlap)	pallet damage, product damage, abrasion, impact, leads to other hazards (e .g. pallet drop on/thrown at human)
	Control System	False detection (software)	Vehicle mistakes a hazardous object for the pallet	burns, leads to other hazards (e .g. vehicle cuts human or human parts with hazardous object)
			Vehicle mistakes other object for pallet	leads to other hazards (e .g. vehicle hits human with object)

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
	Control System	Software bug or software failure	Vehicle hits other reachable objects	damage to object/workspace, leads to other hazards (e.g. unsuitable floor due to scattered objects)
UC08.3.2: Move vehicle to allow fork to be below the pallet to enable lifting		All hazards associated with ST0.1: Go From A to B		
		All hazards associated with ST0.8: Motion with/close to empty pallet		
UC08.3.3: Elevate vehicle fork to lift the pallet		All hazards associated with ST0.6: Fork Motion		
		All hazards associated with ST0.8: Motion with/close to empty pallet		
	Mechanical OR Control System	Fork speed to high	Pallet being dropped on/thrown at human	impact, abrasion, damage to product, damage to pallet, leads to other hazards (e.g. unsuitable floor due to scattered objects)
			Pallet being dropped on/thrown at other vehicle/environment	damage to product, damage to pallet, damage to vehicle, damage to workspace, leads to other hazards (e.g. unsuitable floor due to scattered objects)
	Mechanical AND Interaction	Broken pallet manipulated by vehicle	Sharp edges of broken pallet	cutting or severing, stabbing or puncture

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
UC08.4 & UC08.7: Go to product pick location		All hazards associated with ST0.1: Go From A to B		
UC08.5 & UC08.8: Pick some units of some product		All hazards associated with ST0.3: Pick A Product		
UC08.6 & UC08.9: Put some product units on a pallet		All hazards associated with ST0.2: Place Product Box On Pallet		
UC08.10: Go to pallet drop location		All hazards associated with ST0.1: Go From A to B		
UC08.11: Drop the "mixed" pallet (lower the fork)		All hazards associated with ST0.6: Fork Motion		
		All hazards associated with ST0.7: Motion with/close to full pallet		
	Control System AND Environment	Sensor information is erroneous due to e .g. hardware failure, synchronization problems, occlusions, pertubation (light) etc.	Vehicle lowers the pallet on human/human part (e .g. foot)	impact, abrasion, damage to product, damage to pallet, leads to other hazards (e .g. pallet not placed properly)
	Mechanical OR Control System	Vehicle forks/pallet make contact with other object while lowering forks	Object is pushed over on human	impact, abrasion, damage to product, leads to other hazards (e .g. unsuitable floor due to scattered objects)
			Object is pushed over on the ground	leads to other hazards (e .g. unsuitable floor due to scattered objects)

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
			Pallet not placed properly (unstable, might fall)	leads to other hazards (e.g. products being dropped on/thrown at human)
	Control System	Software bug or software failure	Vehicle fork (with pallet) hits other reachable objects	leads to other hazards (e.g. products being dropped on/thrown at human)
	Mechanical OR Control System	Fork speed to high	Pallet being dropped on/thrown at human	impact, abrasion, damage to product, damage to pallet, leads to other hazards (e.g. unsuitable floor due to scattered objects)
			Products being dropped on/thrown at human	impact, abrasion, damage to product, leads to other hazards (e.g. unsuitable floor due to scattered objects)
			Pallet being dropped on/thrown at other vehicle/environment	damage to product, damage to pallet, damage to vehicle, damage to workspace, leads to other hazards (e.g. unsuitable floor due to scattered objects)

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
			Products being dropped on/thrown at vehicle/environment	impact, abrasion, damage to product, damage to vehicle, damage to workspace, leads to other hazards (e.g. unsuitable floor due to scattered objects)
UC09: Add New Truck				
UC09.1: Automatic calibration		All hazards associated with UC01: Automatic Sensor Calibration		
UC09.2: Report presence	Control System	Software bug or software failure	Vehicle will not start as no command is issued	no consequences as vehicle start-up is not done in daily workspace
UC10: Data Collection For Learning				
UC10.1: Move around to gather learning data for learning patterns		All hazards associated with ST0.1: Go From A to B		
UC11: Packet Unwrapping				
UC11.2: Perceive unwrapping entry point	Control System AND Environment	Sensor information is erroneous due to e.g. hardware failure, synchronization problems, occlusions, pertubation (light) etc.	Manipulator arm cuts human body part	stabbing or puncture, cutting or severing
			Pallet not unwrapped (properly)	leads to other hazards (e.g. human slips on wrapping)
			Mistakes other object for pallet/entry point: cuts mistaken object	damage to product, damage to end-effector, damage to workspace

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
	Control System	False detection (software)	Mistakes other object for pallet/entry point: cuts mistaken object	damage to product, damage to end-effector, damage to workspace
			Pallet not unwrapped (properly)	leads to other hazards (e.g. human slips on wrapping)
	Control System	Software bug or software failure	Manipulator cuts other reachable objects	damage to product, damage to end-effector, damage to workspace
UC11.3: Cut the plastic stretch wrap using the rotating blade		All hazards associated with ST0.4: Manipulator Arm Motion		
	Mechanical	Hardware failure (e.g. blade motor)	Wrapping cannot be removed	leads to other hazards (e.g. human slips on wrapping)
	Mechanical	Movement or rotation of sharp tool on end-effector	Manipulator arm cuts human body part	stabbing or puncture, cutting or severing
			Manipulator arm cuts part of some vehicle	damage to vehicle/manipulator arm, damage to end-effector
			Manipulator arm cuts product	damage to product, damage to end-effector
			Manipulator arm cuts walls, shelves, etc.	damage to workspace, damage to end-effector

Table 1: Continued list of preliminary hazards

Use case description	Origin related to	Origin of hazard	Hazard/ Hazardous situation	Potential harm or other consequences
	Control System	Pallet not unwrapped (properly)	Product not picked properly later	leads to other hazards (e.g. product being dropped on human)
			Wrapping cannot be removed	leads to other hazards (e.g. human slips on wrapping)
UC11.4: Remove the pallet wrap		All hazards associated with ST0.3: Pick Product		
	Mechanical	Manipulator arm unable to grasp wrapping (properly)	Human slips on wrapping	falling: impact
			Vehicle slips on wrapping	leads to other hazards (e.g. human-vehicle collision, vehicle-vehicle collision, vehicle-environment collsion)
			Human picks wrapping from the ground	leads to other hazards (e.g. human-vehicle collision)
		Sensor information is erroneous/insufficient due to e.g. hardware failure, occlusions, pertubation (light) etc.	Manipulator arm unable to grasp wrapping (properly): wrapping cannot be removed	leads to other hazards (e.g. human slips on wrapping)