D6.3: PRELIMINARY EVALUATION AND ASSESSMENT OF CPSOSAWARE PLATFORM

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Work Package	WP6 Industry Driven Trial and Evaluation

Abstract

This report constitutes the output of tasks T6.3 “Connected l3-l4 autonomous Cars: CPSoS trials Evaluation and analysis infrastructure” and T6.4 “Human-Robot Collaboration in Manufacturing: CPSoS trials Evaluation and analysis infrastructure”, this document describes the testing scenarios, identifies the expected behaviour of the system in the two use-cases and plans the approach that will be taken during the evaluation phases of the system. As such, for each scenario, evaluation criteria will be listed with the description of the evaluation procedure. Eventually equipment that is necessary for the evaluation in the use-cases are identified and listed here.

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Executive summary

This report constitutes the output of tasks T6.3 “Connected l3-l4 autonomous Cars: CPSoS trials Evaluation and analysis infrastructure” and T6.4 “Human-Robot Collaboration in Manufacturing: CPSoS trials Evaluation and analysis infrastructure” and as such it describes the testing scenarios, identifies the expected behaviour of the system in the two use-cases and plans the approach that will be taken during the evaluation phases of the system. As such, for each scenario, evaluation criteria will be listed with the description of the evaluation procedure.

Going into the detail of the document, the two pilots have been divided and each one described the Use Case, the standard scenario and the additional scenarios that will be tested.

As for the Automotive Case, we have 6 scenarios:

- **Scenario 1:** Co-operative Situational Awareness
- **Scenario 2:** Rear-end collision Co-operative Awareness
- **Scenario 3:** Rear-end collision Co-operative Awareness at traffic lights
- **Scenario 4:** Co-operative Situational Awareness in high speed driving 1
- **Scenario 5:** Co-operative Situational Awareness in high speed driving 2
- **Scenario 6:** Co-operative Situational Awareness in traffic jam

Due to the highly complex and dynamic test scenarios to validate these scenarios, public datasets will be used which allow to have a huge amount of acquisitions of various sensors (Dataset: KITTI and KITTI-360, Lyft, Cityscapes)

Also for the Manufacturing Case Study, the pilot cell and the standard scenario are described first.

Subsequently, 6 other additional scenarios are identified:

- **Scenario 1:** Gravity Shelf Refill Scenario
- **Scenario 2:** Windshield Container Refill Scenario
- **Scenario 3:** Robot Singularity Scenario
- **Scenario 4:** Slow down zone entrance - SSM
- **Scenario 5:** Safety Zone Violation Scenario 1 – SMS
- **Scenario 6:** Safety Zone Violation Scenario 2 – SMS

To validate these scenarios, various tools and equipment will be required, for example:

- Questionnaire
- Smart watch acquisition
- Vision system
- 3 axial Accelerometer acquired by a LabVIEW system
- Tracking of robot inverse kinematic
- Use of the various sensors of the cell (camera, etc.)

Due to the variety of scenarios specific equipment and tools will be used for each situation and the steps for validation are further described.

1 Introduction

1.1 Document introduction

Deliverable D6.3 is intended to contain the output of the quantification phase of Task 6.3 and Task 6.4.

During the initial phases of the CPSOSAWARE project the two use-cases (Automotive Driving and Collaborative Manufacturing) are defined and described in detail. In this definition phase, the use-cases are outlined, main interesting components are identified and requirements are extracted and described. The main part of the description of the use-cases is reported in "D1.2 Requirements and Use Cases" with the aim to extract the functional and non-Functional requirements for the CPSOSAWARE developments. After the initial definition phase and the following development phase, the CPSoSaware developments will be integrated on the two pilot demonstrators and tested/validated in specific testing scenarios.

This document describes the testing scenarios, identifies the expected behaviour of the system in the two use-cases and plans the approach that will be taken during the evaluation phases of the system. As such, for each scenario, evaluation criteria will be listed with the description of the evaluation procedure. Eventually, equipment that are necessary for the evaluation in the use-cases are identified and listed here.

In the definition of the evaluation phases the description of the "testers" population in terms of number and type (e.g. desired percentage of assembly operators with height below 25 percentile; operators with height between 25 and 75 percentile and so on), will be made.

The aim is the identification and full definition of the evaluation experiments that are desired for the proper evaluation of the system.

Part of the testing with drivers and assembly operators should have took place during this first period of the project; unfortunately the COVID-19 pandemic emergency hindered the possibility to perform the physical tests in both use-cases; for this reason this deliverable will be focused on the planning and definition of the evaluation phases.

In this document, after a generic introduction describing the functionalities of the system and application in the use-case, the scenarios will be analysed and described in a standard table form.

1.2 Relation to other deliverables

D6.3 is intended to deliver the results of the preliminary quantification phase of the Use Cases in CPSoSaware. The deliverable is connected to "D6.5: Final Evaluation and assessment of CPSoSaware Platform [36]" that will report the whole testing and evaluation phases on the existing scenarios in the two use-cases.

There is also a strong connection with "D1.2 Requirements and Use Cases [M12]" that introduces the Use Case and extracts the requirements.

2 Autonomous driving

2.1 Use Case and Pilot description

2.1.1 Co-Operative Awareness

Road safety is one of the main concerns of the automotive industry which can be largely affected by the number of moving vehicles on roads. By increasing the number of vehicles and their interactions with each other and establishing a way of communication between them, the road safety can be improved [12][13][14]. Connected vehicles will improve safety and enable new services not just to autonomous vehicle even to drivers and passengers as well.

Co-operative awareness is one of the key road safety services provided which improves safety of road vehicles, pedestrian and passengers by broadcasting messages to other vehicles. This way of communication can involve all types of connections to other traffic agents as summarized below:

- V2I (Vehicle to Infrastructure): Provides the information regarding traffic lights, traffic congestions, road conditions, road networks, etc to vehicle (or driver).
- V2D (Vehicle to Device): communication between vehicles and surrounding cyclists or other type of moving devices.
- V2H (Vehicle to Home): The way of communication between vehicles and homes which can be sued to giving back power to home in the case of emergencies or updating vehicle status to home bases.
- V2G (Vehicle to Grid): Electric cars can connect to grid and return electricity to grid whenever is required.
- V2V (Vehicle to Vehicle): the most practical way of car communication is connecting a vehicle to another vehicle. In this way, vehicles can establish a ''talk'' and exchange messages.
- V2P (Vehicle to Pedestrian): vehicle communicate with surrounding pedestrian and get their status.

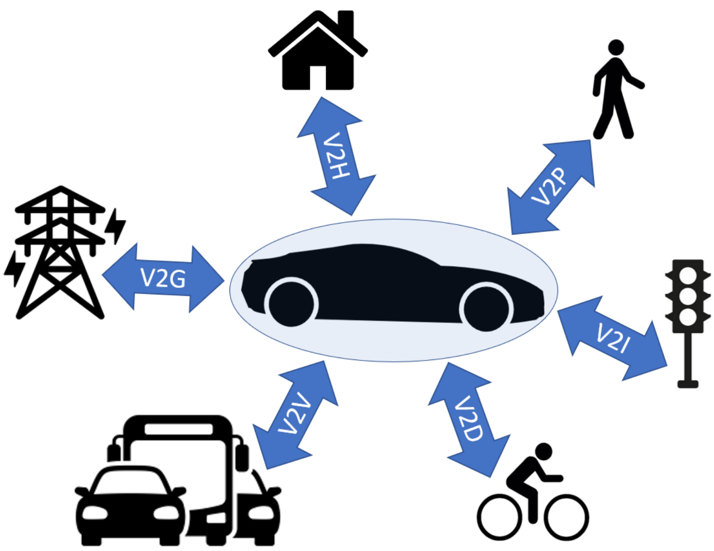


Figure 1: Common vehicular communication with other stationary and moving objects

Cooperative awareness is one of the components of V2V communication and reflects the ability to provide and broadcast information regarding the status of the ego vehicle such as position, speed, acceleration, direction of moving trajectory. etc and its detected surrounding objects such as moving pedestrians and their estimated motions, traffic situations, traffic events, etc. the provided information can be distributed to neighbouring vehicles as basic status of communication using cooperative awareness Messages [15][16].

Exchanging messages between moving vehicles as well as between vehicles and road infrastructure helps each vehicle to understand its surrounding in a better way. Either the vehicle is controlled by a human or being driven autonomously, the provided information from the cooperative Awareness infrastructure let them to perceive their surrounding in an advanced way. In this case the vehicle receives information even when the local and boarded sensors of the vehicle (e.g. camera, ultrasonic, LIDAR, etc) could not observe them. In this case, the environmental map of the ego vehicle surroundings can be provided with more elaborate information which help the ego vehicle to act more precisely in dynamic environments with potentially hazardous situations. Thus, the road safety can be enhanced.

To achieve this level of communications, standardization organisations such as Intelligent Transportation Systems (ITS) define the basis of the specific periodic message exchange as cooperative awareness [17][18][20]. This standard specifies Cooperative Awareness Messages (CAMs) as part of the standard In the European Union (EU) [10][12], whereas in the U.S., the same functionality is enabled by the Basic Safety Message (BSM) [20][21].

In EU the ITS-G5 standard defines the Vehicle to Vehicle and Vehicle to Infrastructure (see [10]) networking protocol. This standard has its basis from IEEE 802.11p standard, which was already established in the U.S. IEEE 802.11p [10][11][12] standard to define the wireless access in vehicular environment (WAVE) as the physical and MAC layer and is the basis for dedicated short-range communications (DSRC) vehicle-based communication networks, particularly for applications such as vehicle safety services [17] The main target of standardizing the communication protocols is to provide an accurate and detailed framework for data sharing in order to robustify the mobility and sensing functions involved in autonomous driving.

Subsection 0 summarizes the use-cases and the requirements for testing scenario related to the co-operative awareness pillar of autonomous driving. Each distinct use case is briefly described and illustrated graphically, if necessary, while the functional and non-functional requirements are also discussed.

2.2 Use-Cases testing Scenarios

2.2.1 Testing of Safety Use-Cases

In this section we analyse the proposed test cases, which are required to be defined, tested, evaluated, and fulfilled based on the definition of Cooperative Awareness as it is derived by the standards [12][10].

First, the used terms in this section are explained as presented in Table 1:

Table 1: Test requirements of functional test of Cooperative Awareness Use Cases

	Term	Description
1	Ego Vehicle	The test vehicle which is considered at the main vehicle where all the required functions are running.
2	Neighbouring vehicle	The moving and stationary vehicles in certain distance to the ego vehicle
3	Moving object	Any moving pedestrian, vehicle, cyclist, etc
4	Driving tube	The moving trajectory of the vehicle
5	TTC	Time to Collision

First of all, the requirements of the test cases are defined as presented in Table 2-1:

Table 2: Test requirements of functional test of Cooperative Awareness use cases

	Requirement	Functional or Non-functional
1	If there is any moving object in the surrounding area of the vehicle which may cross the driving tube of the ego vehicle, it shall be detected by the ego vehicle.	Functional
2	If there is any moving object in the surrounding area of the vehicle which may cross driving road, it shall be detected by the ego vehicle.	Functional
3	The motion of the detected moving objects shall be estimated	Functional

4	The relative position of each moving object to the ego vehicle shall be calculated	Functional
5	A message including the position of the vehicle and the information in section 1 to 4 shall be broadcasted to the neighbouring vehicle.	Functional

In addition to the functional and the non-functional requirements, D6.3 also analyses the scenarios which will be tested to track the progress in terms of the satisfaction of the afore-mentioned requirements, while also assessing how the contributions, made in CPSoSAware, will produce impact on safety and society indexes.

Test scenarios

Here we present the proposed test cases, in which the performance of the Cooperative awareness functions are evaluated. As it is explained in Table 2, the main characteristic of the functions which need to be tested in this section, assess the ability of the system to detect hazardous situations around the ego vehicle. This can be achieved when the surrounding map of the vehicle is built precisely and the motion of each moving object around the ego vehicle is estimated correctly. Without having a clear understanding of the surrounding scene of the vehicle the collected information from the surrounding environment of the vehicle, are not enough trustworthy to be broadcasted to other road vehicles. Therefore, the first stage of evaluating the Co-operative awareness functions involves assessing the accuracy of the perception engine installed in the vehicle. The collected information are broadcasted and transmitted to other road agents as the next challenge.

Based on the above two main criteria the following test cases are presented:

- Scenario 1: Co-operative Situational Awareness

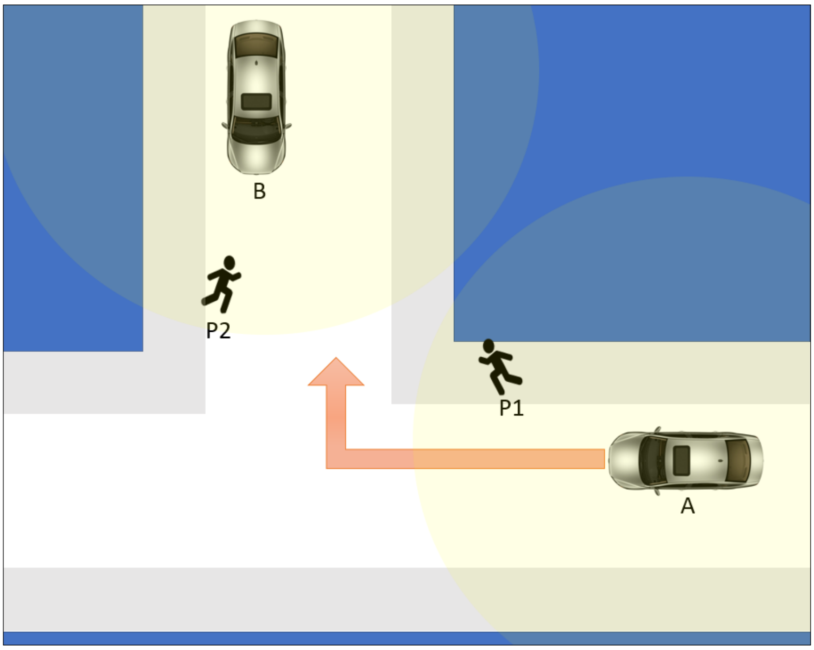


Figure 2: Scenario one: Co-operative Situational Awareness

Description:
Vehicle A wants to change its driving direction by turning right. At this time, Pedestrian P2 is crossing the road where Vehicle A is moving in. P2 can just be detected by Vehicle B and P1 is only seen by Vehicle A. Vehicle A and B should first estimate the motion of P1 and P2 and then inform each other by broadcasting the required information.

Conditions:
The test conditions are as follow:

Agent	Condition	Expected behaviour
Vehicle A	Driving straight with speed less than 30 kph	- Detects the moving Pedestrian P2. - Estimates the motion of pedestrian P2. - Inform neighbouring vehicle regarding the driving event including its ego position and motion of detected pedestrian P1. - Initialize the connection to able to receive the transmitted message of surrounding vehicles
Vehicle B	Driving straight with speed of less than 30 kph, reducing speed to turn right	- Detects the moving Pedestrian P1. - Estimate the motion of pedestrian P1. Inform neighbouring vehicle regarding the driving event including the its ego

		position and motion of detected pedestrian P1. - Initialize the connection to able to receive the transmitted message of surrounding vehicles

- **Scenario 2**: Rear-end collision Co-operative Awareness

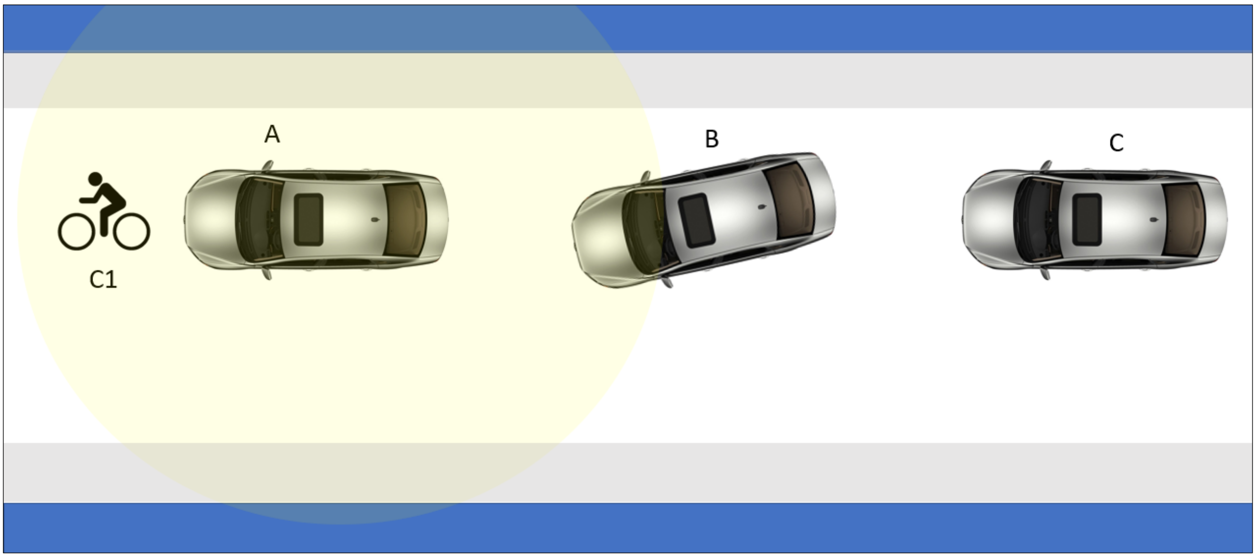


Figure 3: Scenario two: Rear-end collision Co-operative Awareness

Description:
Vehicle A is being driven at high speed (>30kph) and detects a low speed moving cyclist in front. Vehicle A stops by an emergency brake to avoid the collision. Vehicle B immediately gets immediately notified of the collision probability and change its driving lane to avoid the rear-end collision with Vehicle A. But Vehicle C has a poor visibility to see Vehicle A. In this case the Vehicle A shall broadcast the useful information regarding the traffic event to inform Vehicle C.

Conditions:
The test conditions are as follow:

Agent	Condition	Expected behaviour
Vehicle A	Driving straight with speed higher than 30 kph and suddenly stops.	- Detects the moving Pedestrian cyclist C1. - Estimate the motion of pedestrian cyclist C1. - Inform neighbouring vehicle regarding the driving event including the its ego

		position and motion of detected cyclist C1.
Vehicle B	Driving straight with speed of more than 30 kph, and overtaking Vehicle A.	
Vehicle C	Driving straight with speed of more than 30 kph.	- Initialize the connection to able to receive the transmitted message od surrounding vehicles

- **Scenario 3**: Rear-end collision Co-operative Awareness at traffic lights

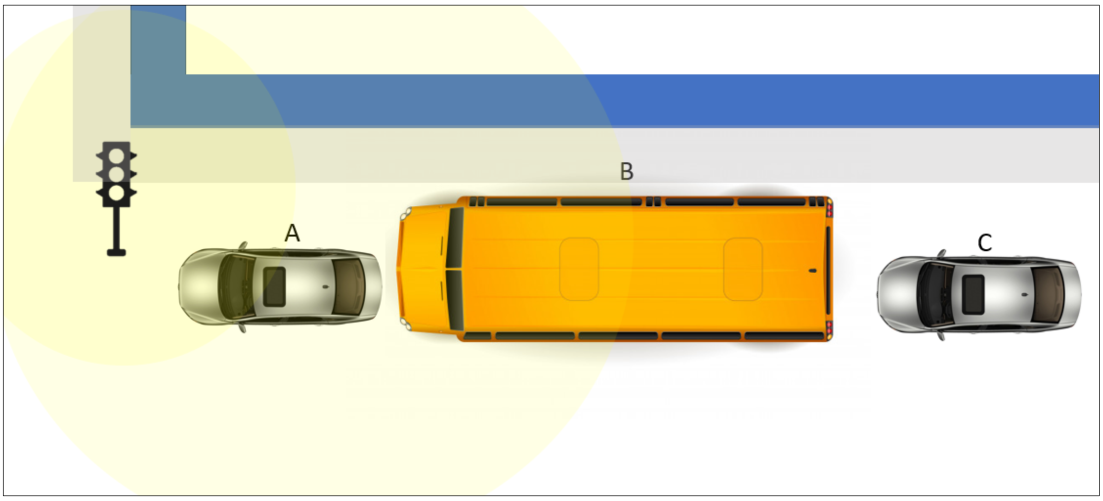


Figure 4: Scenario three: Rear-end collision Co-operative Awareness at traffic lights

Description:
Vehicle A drives in high speed (>30kph) and stops immediately at a traffic light which just switched to red. Bus B can act quickly and stops before colliding to Vehicle A but the visibility of vehicle C is interrupted by the size of Bus B. in this case Vehicle C will receive the information not just from V2I regarding the traffic light even but from broadcasted information.

Conditions:
The test conditions are as follow:

Agent	Condition	Expected behaviour
Vehicle A	Driving straight with speed of more than 30 kph and suddenly stops at the traffic light.	- Detects the traffic light and its conditions. - Inform neighbouring vehicle regarding the traffic event.
Vehicle B	Driving straight with speed of more than 30 kph, suddenly brake to avoid collision to Vehicle A.	
Vehicle C	Driving straight with speed of more than 30 kph.	- Initialize the connection to able to receive the transmitted message od surrounding vehicles.

- **Scenario 4**: Co-operative Situational Awareness in high speed driving

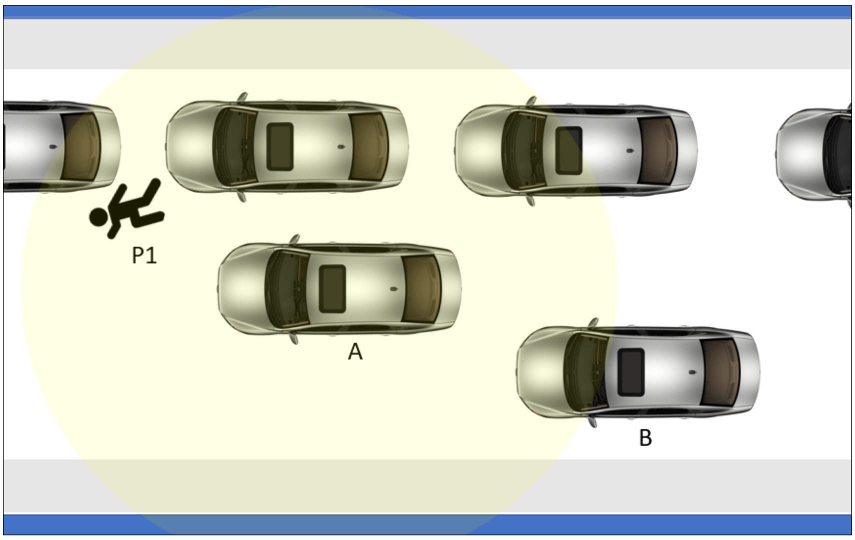


Figure 5: Scenario four: Co-operative Situational Awareness in high speed driving

Description:
Vehicle A drives in high speed (>30kph) and detects a kid running into road. Vehicle B is over taking Vehicle A and cannot observe the running kid. In this case Vehicle A shall detect the motion of the running kid P1 and inform Vehicle B about the potential collision.

Conditions:
The test conditions are as follow:

Agent	Condition	Expected behaviour
Vehicle A	Driving straight with speed of more than 30 kph.	- Detects the moving Pedestrian P1. - Estimate the motion of Pedestrian P1. - Inform neighbouring vehicle regarding the driving event including its ego position and motion of detected Pedestrian P1.
Vehicle B	Driving straight with speed of more than 30 kph, and overtaking Vehicle A.	- Initialize the connection to able to receive the transmitted message of surrounding vehicles.

- **Scenario 5**: Co-operative Situational Awareness in high speed driving

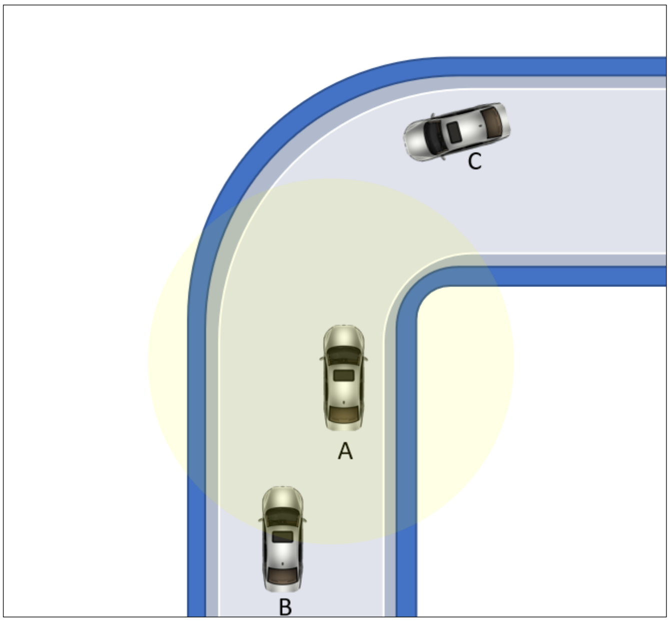


Figure 6: Scenario five: Co-operative Situational Awareness in high speed driving

Description:
Vehicle B is being driven at high speed (>50kph) and started to overtake Vehicle A, which is moving in front of that. The visibility of Vehicle B is limited to occurrence of Vehicle A and it cannot detect Vehicle C, which is approaching them. To avoid the hazardous collision in this scenario, Vehicle A shall detect vehicle C and its motion and inform Vehicle B.

Conditions:
The test conditions are as follow:

Agent	Condition	Expected behaviour
Vehicle A	Following the road with speed of more than 50 kph.	- Detects the approaching vehicle C. - Estimates the motion of vehicle C. - Informs neighbouring vehicle regarding the driving event including the its ego position and motion of detected vehicle C.
Vehicle B	Following the road with speed of more than 50 kph, and overtaking Vehicle A while turning.	- Initialize the connection to able to receive the transmitted message of surrounding vehicles.

- **Scenario 6**: Co-operative Situational Awareness in traffic jam.

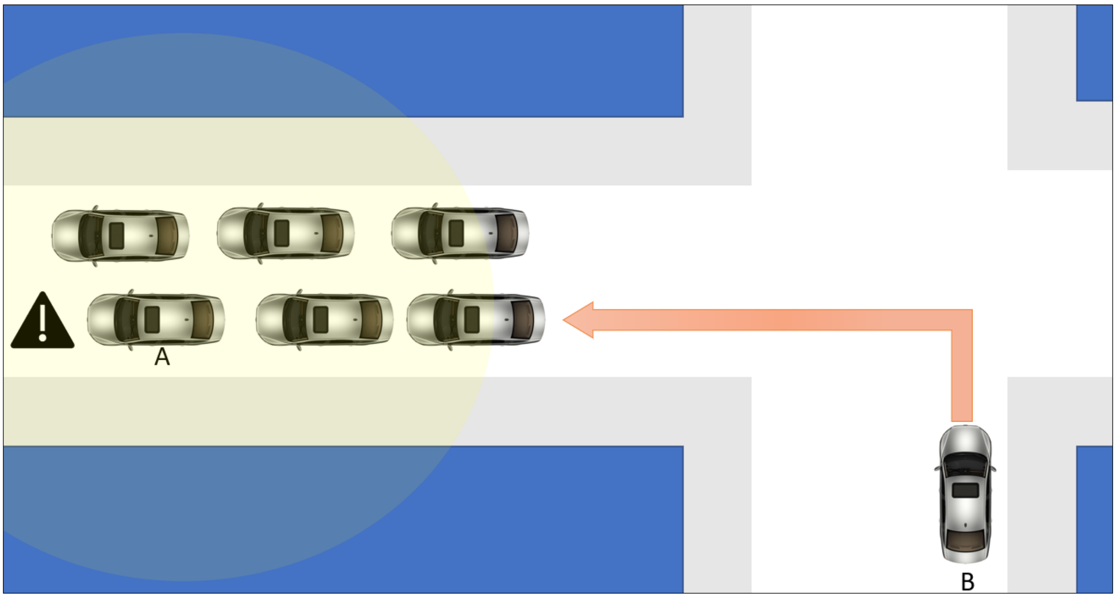


Figure 7: Scenario six: Co-operative Situational Awareness in traffic events

Description:
Due to traffic (e.g. an accident, etc) a queue of vehicles has been formed in a one-way street. New vehicles such as Vehicle B does not have enough visibility to detect the event and avoid entering the street. In this case Vehicle A shall detect the event and broadcast the useful information to inform other agents (e.g. Vehicle B) about the event.

Conditions:
The test conditions are as follow:

Agent	Condition	Expected behaviour
Vehicle A	Stopping in a traffic jam.	- Detects the traffic jam. - Informs neighbouring vehicle regarding the traffic event including the its ego.
Vehicle B	Following the road with speed of less than 50 kph, and entering the one way street.	- Initialize the connection to able to receive the transmitted message od surrounding vehicles.

2.2.2 Validation parameters

As we discussed in section above, [11], [12], exchanging of traffic information between road vehicles improved traffic safety under the paradigm of cooperative intelligent transportation systems. Recently, several researches have tried to investigate and define the standards for the best way of wireless charging in the automotive industry. Moreover, many projects have investigated efficient working of various applications, KPIs, and proposed solutions to the technical challenges in its implementation.

Apart from the useful information which are broadcasted in a cooperative wireless communication, the surrounding information of the vehicle including ego position, heading, surrounding traffic map, etc called Local Dynamic Map is the most vital information which is obtained through cooperative awareness messages (CAMs).

Since CAMs include critical data, that are used by several intelligent Transportation System Applications, (ITS) and can affect vehicle safety. Therefore, it is an essential step to verify the quality of the provided information of the perception section of the ego vehicle. Evaluating the level of situational awareness and its accompanied perception engine is a crucial step for assessing the reliability of safety functions in ITS applications. Accurate performance indexes for vehicle safety awareness should assess the precision of received information in CAMs.

Recently, several studies defined the evaluation parameters for the provided information of CAMs. These parameters can be fully defined from the quality of the perception part of the ego vehicle to the status of the sent and received CAMs [17]. Some works defined this parameter as the number of vehicles that receive a CAM to the vehicles that are expected to receive a CAM within a certain distance [18], [19]. Other works define an Awareness Quality Level (AQL) as the number of actual surrounding vehicles and those which received the corresponding CAMs [20]. The present delay between two broadcasted sequences can be defined as another evaluation parameter for a particular ego vehicle.

The above methods check whether the CAMs are transmitted correctly or not. But one of the key parameters to evaluate the performance of a Cooperative Awareness application is to know if the provided information, included in CAMs, is accurate enough. Any detected error during proving CAMs can lead the ITS applications to a hazardous state. In this case, objects which are closer to the vehicle can be detected in longer distances. This mal-function of cooperative communication may lead the ITS application to underestimate the risk of collision which effect the safety.

Some recent works have proposed accurate indicators for the performance evaluation of C-ITS safety applications by introducing two safety awareness metrics (SAM) that examine the precision of information in the Local Dynamic Map (LDM). The first metric uses normalized error in CAM that gets corrupted due to GPS error or age of the last received information. The second metric uses a weight function to prioritize the error at lower distances that cause a higher safety concern [17], [21].

As it is illustrated in [17], [18], any position error in CAMs could impact the vehicle safety awareness. In this scenario where vehicles are moving in the direction as shown by the arrows. Vehicle A receives periodic CAMs from other vehicles B, C and D and updates its Local Dynamic Map (LDM) accordingly. $\acute{B}$, $\acute{C}$, and $\acute{D}$ show the position of vehicles B, C, and D as advertised in their last CAM received at vehicle A.

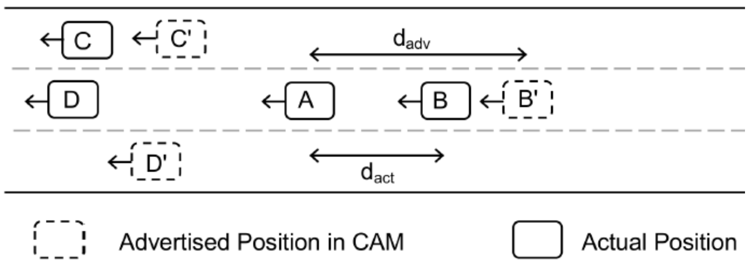


Figure 8: Situational awareness KPIs

The advertised neighbour positions are different than the actual either due to GPS error or because neighbouring vehicles have moved since the CAM was last received.

The existing awareness quality level (AQL) presented in [17], [21] uses the intersection of actual number of neighbours and the number of neighbours discovered using CAM as a measure of awareness as follow:

$$Awarness_k^T(i) = \frac{|N_k^T(i) \cap V_k^T(i)|}{V_k^T(i)}, \quad (2\text{-}1)$$

Where $V_k^T(i)$ represents actual number of neighbors of vehicle i and $N_k^T(i)$ represents advertised number of neighbors received by vehicle i in CAM within an area k at a certain time$T$.

AQL is calculated by averaging the $Awarness$ over all the vehicles M and time instants$T$.

$$AQL(i) = \frac{\sum_{j=1}^{T} \sum_{i \epsilon M} Awarness_k^T(i)}{T \times M}, \qquad (2\text{-}2)$$

This metric shows exactly how many of the surrounding vehicles are known to the ego vehicle. Clearly a higher value for AQL mean a higher and more reliable cooperative awareness.

The above metric can provide a good estimation of the awareness quality level if all the positions are provided accurately. In the case that there is an error in positioning of the vehicles the awareness quality level will be affected. In some recent works, this drawback is solved by introducing new metrics that consider the accuracy of safety information received in CAM i.e., Normalized Error based Safety Awareness Level ($S\hat{A}L$) and Weighted Normalized Error based Safety Awareness Level ($\mu S\hat{A}L$). It proposed a normalized error-based safety awareness level metric that also takes into account the position error in the received CAM. To evaluate $S\hat{A}L$, every vehicle i first calculates position error $V\epsilon_k^T(i,n)$ of a single neighbor n within an area k and at time T i.e., absolute difference of the distance between actual and advertised neighbour positions.

$$\epsilon_k^T(i,n) = \left| \sqrt{(x_{act}^T(n) - x_{adv}^T(i,n))^2} + \sqrt{(y_{act}^T(n) - y_{adv}^T(i,n))^2} \right|, \quad \text{(2-3)}$$

Where $x_{act}^T(n)$ and $y_{act}^T(n)$ are the actual GPS latitude and longitude of neighbour vehicle n, and $x_{adv}^T(i,n)$ and $y_{adv}^T(i,n)$ are the GPS latitude and longitude of the neighbor vehicle n as advertised in its last CAM received by the vehicle i at a given time instant T. Position Error $\epsilon_k^T(i,n)$ provides the absolute value of dissimilarity between the actual and received position information of the neighbour in meters.

The normalized error $\hat{\epsilon}_k^T(i,n)$ between vehicle i and its neighbor n within an area k at a time instant T can be defined as:

$$\hat{\epsilon}_k^T(i,n) = \begin{cases} 0 & \epsilon_k^T(i,n) \leq \epsilon_{tol} \\ \frac{\epsilon_k^T(i,n)}{\epsilon_{max}} & \epsilon_k^T(i,n) \in \left] \epsilon_{tol}, \epsilon_{max} \right] \\ 1 & \epsilon_k^T(i,n) > \epsilon_{tol} \end{cases}, \quad \text{(2-4)}$$

Where ϵ_{max}, the maximum error, is position and ϵ_{tol} is the tolerable position error. In this case, the mean normalized error$\bar{\epsilon}_k^T(i)$ of vehicle i within an area k at a time instant T can be given as:

$$\bar{\epsilon}_k^T(i) = \frac{1}{V_k^T(i)} \sum_{j=1}^{V_k^T(i)} \hat{\epsilon}_k^T(i,n), \quad \text{(2-5)}$$

Where $V_k^T(i)$ represent the neighbors of the ego vehicle. Based on the above parameters, the following parameters can be derived. Firstly, the mean normalized weighted error $\overline{\mu\epsilon}_k^T(i)$ by defining $w(a,c,d)$ as a sigmoid function:

$$\overline{\mu\epsilon}_k^T(i) = \frac{1}{V_k^T(i)} \sum_{j=1}^{V_k^T(i)} \hat{\epsilon}_k^T(i,n) \times w(a,c,d_{act}). \quad \text{(2-6)}$$

$$w(a,c,d) = \frac{1}{1+e^{-a(d-c)}}. \quad \text{(2-7)}$$

Depending on a and c, the sigmoid function returns a distinct weight value at different distances d. If d_{act} is the actual distance between a vehicle i and its neighbour n, sigmoid function assigns a higher weight to the position error of neighbors that are nearby and vice versa. The mean normalized safety awareness $\mu S\hat{A}L_k^T(i)$ can be defined as:

$$\mu S\hat{A}L_k^T(i) = \frac{|N_k^T(i) \cap V_k^T(i)|}{V_k^T(i)} \times (1 - \overline{\mu\epsilon}_k^T(i)) \;. \qquad (2\text{-}8)$$

Finally, we can compute the normalized error-based safety awareness level $S\hat{A}L_k^T(i)$ metric within an area k by averaging the $S\hat{A}L_k^T(i)$ over all M vehicles and time instants M.

$$\mu S\hat{A}L_k^T(i) = \frac{|N_k^T(i) \cap V_k^T(i)|}{T \times M}. \qquad (2\text{-}8)$$

The above-mentioned parameters can be evaluated for any scenarios which includes the application of Cooperative awareness.

2.2.3 Validation Data Set

To ensure the functionality of any cooperative awareness function it is tested under specific conditions. In each situation intelligent vehicles have to perceive the environment, understand the current situation and plan and execute an appropriate behavior accordingly. The reliable results of the test and validation process of these functionalities prove the usability of the functions in safety applications.

Due to the highly complex and dynamic test scenarios, testing an actual vehicle in real world scenarios is problematic. Therefore, virtual environments and recorded use cases with logged data are widely used in the automotive industry to test and validate the ADAS functions. In this case having access to the sufficient data set is an essential requirement to ensure the quality of the test and validation of the ADAS functions.

In this work we rely on two main data resources to ensure that all the required use case will be covered properly. The first benefit from the already existing opensource data bases which are widely used in ADAS test and verification. A short list of the most common data sets are presented as follow:

A) KITTI and KITTI-360

KITTI data set presents a large-scale dataset that contains rich sensory information and full annotations. It recorded several suburbs of Karlsruhe, Germany, corresponding to over 320k images and 100k laser scans in a driving distance of 73.7km. The logged data have been annotated both for static and dynamic 3D scene elements with rough bounding primitives and transferred this information into the image domain, resulting in dense semantic and instance annotations for both 3D point clouds and 2D images.

For our data collection KITTI equipped a station wagon with one 180° fisheye camera to each side and a 90° perspective stereo camera (baseline 60 cm) to the front. Furthermore, they mounted a Velodyne HDL-64E and a SICK LMS 200 laser scanning unit on top of the roof. Additionally in the KITTI-360 a full 360° field of view due to the additional fisheye cameras and the pushbroom laser scanner is gained. In addition, KITTI system is equipped with an IMU/GPS localization system.

B) Lyft

Lyft has recently offered to the public a set of autonomous driving data set that it calls the “largest public data set of its kind,” containing over 55k 3D frames of captured footage. All the recorded scenarios have been annotated human reviewers. Lyft data have been collected by seven cameras and as many as three lidars depending on the car used, plus a drivable surface map and HD spatial semantic data that corresponds to the captured info to provide context to researchers.

The data set is the work of Lyft Level 5 autonomy, the division of the ride-hailing company that is responsible for its research and development of self-driving vehicle technology. In a blog post detailing the move, Lyft notes that this part of the company has been working on its hardware and self-driving software for two years and wanted to make public some of the data it has collected in that time in order to “help level the playing field for all researchers interested in autonomous technology.”

C) Cityscapes

The Cityscapes Dataset is an opensource database which mainly focuses on semantic understanding of urban street scenes. In the following, an overview on the design choices and features that were made to target the dataset’s focus have been described:

Polygonal annotations:

- Dense semantic segmentation
- Instance segmentation for vehicle and people

Diversity:

- 50 cities
- Several months (spring, summer, fall)
- Daytime
- Good/medium weather conditions
- Manually selected frames
- Large number of dynamic objects
- Varying scene layout
- Varying background

Volume

- 5 000 annotated images with fine annotations (examples)
- 20 000 annotated images with coarse annotations (examples)

Metadata

- Preceding and trailing video frames. Each annotated image is the 20th image from a 30 frame video snippets (1.8s)
- Corresponding right stereo views
- GPS coordinates
- Ego-motion data from vehicle odometry

- Outside temperature from vehicle sensor

Extensions by other researchers

- Bounding box annotations of people
- Images augmented with fog and rain

Benchmark suite and evaluation server

- Pixel-level semantic labeling
- Instance-level semantic labeling
- Panoptic semantic labeling

Apart from the above mentioned data set, other datasets such as: Waymo Open Dataset, Oxford Radar RobotCar Dataset, Berkeley DeepDrive, and Astyx Dataset HiRes2019 can be used for data logging as well.

As it was mentioned before due to the complexity of the test cases and the recorded environments, it may be possible that a required scenario which is required to be tested is available at the provided datasets. In such a case, it is needed that the required test case is arranged to be recorded using the test vehicle at Panasonic Automotive Systems Europe GmbH.

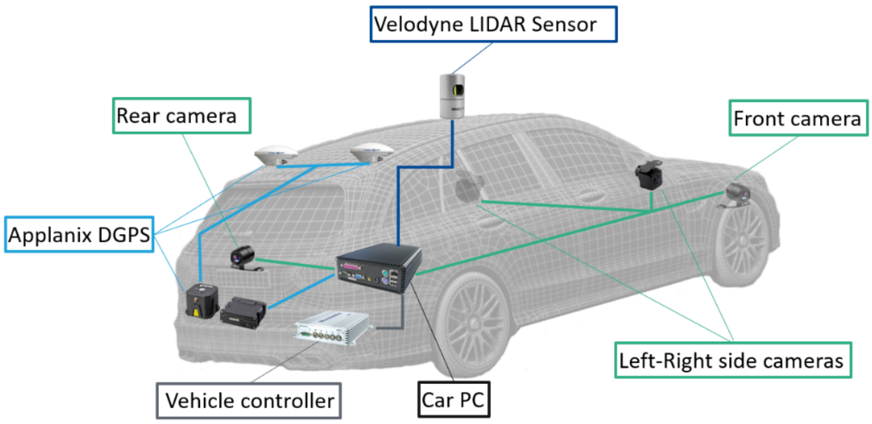


Figure 9: Panasonic test vehicles (Mercedes Benz C-Class)

The required scenarios are recorded using the following procedure:

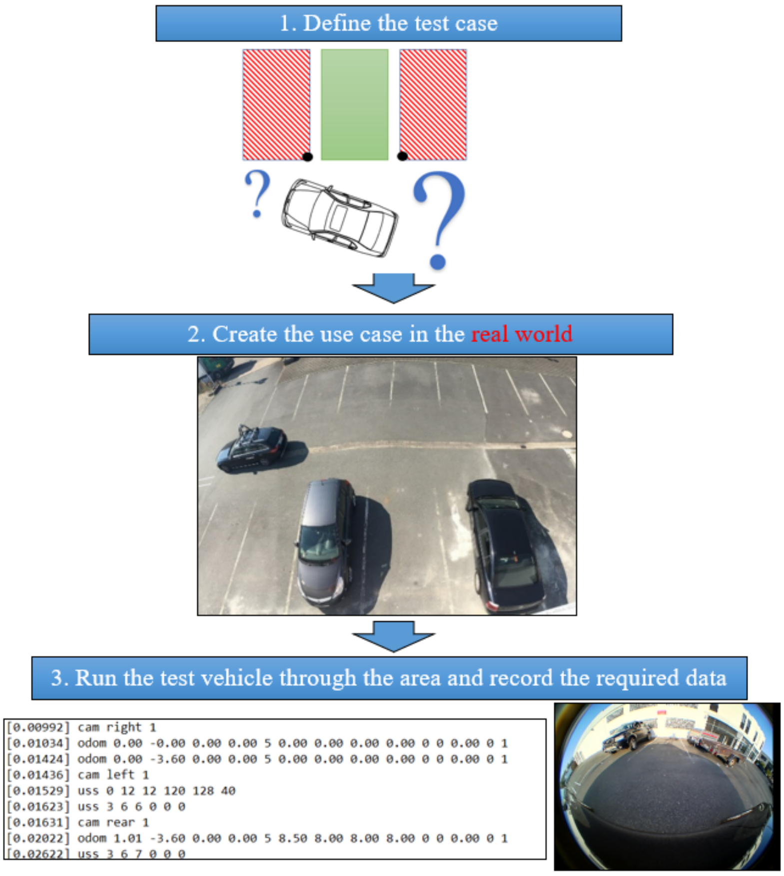


Figure 10: Data logging procedure at Panasonic Automotive Systems Europe GmbH

3 Manufacturing

3.1 Use Case and Pilot description

As described in D1.2, the reference CRF Use-Case in the CPSoSaware project is based on a Human-Robot Collaboration (HRC) use case in the final assembly shop floor.

More specifically, the reference case is based on a new concept of assembly of sensors on a windshield with the direct interaction and collaboration between the operator and the robot according to Human Robot Collaboration approaches and rules.

The use-case is inspired from a line workstation, but CRF is implementing the Use-Case in a laboratory Pilot in which the main aspects of the application can be reproduced.

The following description is referred to the Pilot implementation in CRF premises; it will implement new functions and technologies in an innovative way with reference to the standard work approach in plant.

In the project, multiple scenarios have been defined and will be described hereby. It is important to note that the scenarios are mainly intended to be a base for the development of the main innovative concept into the use-case. According to future specific development in the project, some of this scenarios may be only considered at a design phase and for the completeness of the software development, but not directly and experimentally tested.

In the following section a description of the functionalities in the standard scenario is made in general terms; afterwards the more detailed description for each scenario is made in terms of tables highlighting the specific functionalities, describing the events in the scenario and making a preliminary hypothesis of the procedures that could be implemented for the full analysis of the scenario itself.

3.1.1 Standard Desired functionality and scenario

The reference Use-Case is based on a mixed workstation for the assembly of windshield and rear mirrors on the chassis of a vehicle in a low JPH line (12 JPH – Job Per Hour). CRF use case is based only on the windshield assembly phases, which are those that could take major advances from the application of Human Robot Collaboration.

The application in the Project will be based on the potential in-plant use case, but will be realized in a laboratory environment in order to show all the relevant outcomes of the HRC application. In the plant workcell, more operations are performed, but they are not on interest for the collaborative part of the application. The only operations, that are reproducible on the CRF pilot, are those were the use of the collaborative robot modifies the sequence as follow:

Table 3: Collaborative windshield assembly main expected phases

	ROBOT	OPERATOR
1	Picks up one windshield and goes to an interactive position for the visual check	Other operations on the workcell
2	Small movements, driven by the operator in HG mode	Performs the visual check
3	Goes to the assembly position (defined by anthropometric adaptation)	Goes to logistics containers
4	Stationary position or minimal adjustments offering counterforce to assembly operations in golden zone	Picks up the first towel and sensor
5		Performs the assembly
		Goes to logistics containers
6	Cyclic repetition (to completed assembly number 4 to 6)	
7	Stationary position or minimal adjustments offering counterforce to assembly operations in golden zone	Releases the robot and exits the interactive zone
8	Assembles the windshield to the chassis	Performs other operations on the workcell

During all above operations the operator is capable to interact with the robot only from the front part of the windshield or from the gripper itself.

3.1.2 Collaborative Workspace (Layout considerations and constraints)

The final setup will be made in CRF premises, adapting an existing robotic cell laboratory. The current robot cell is equipped with two robot (COMAU NJ130 and COMAU SM40 controlled by a single C4G controller in cooperative configuration). In the new workcell the two existing robots will be put aside, and the additional Safe Robot[1] will be inserted for the collaborative operations.

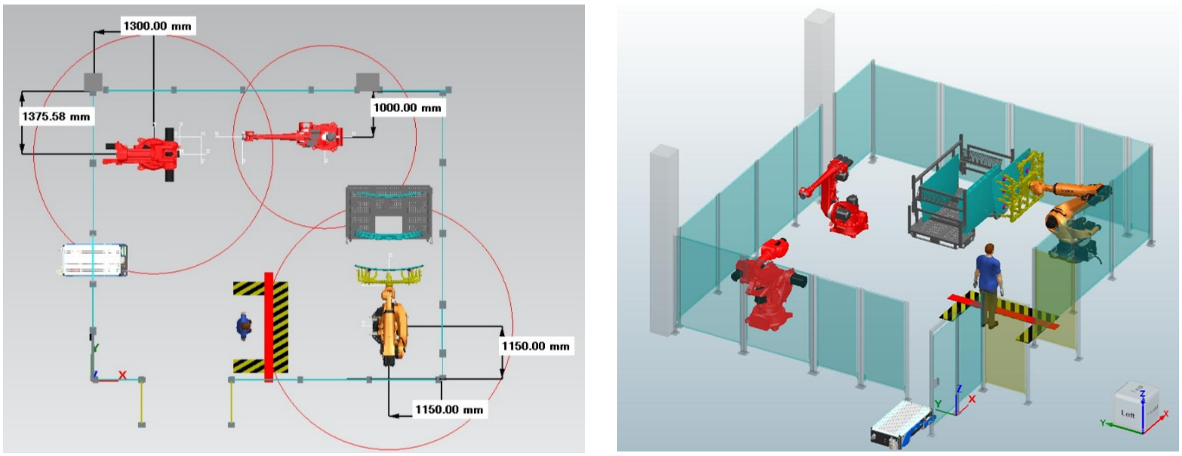
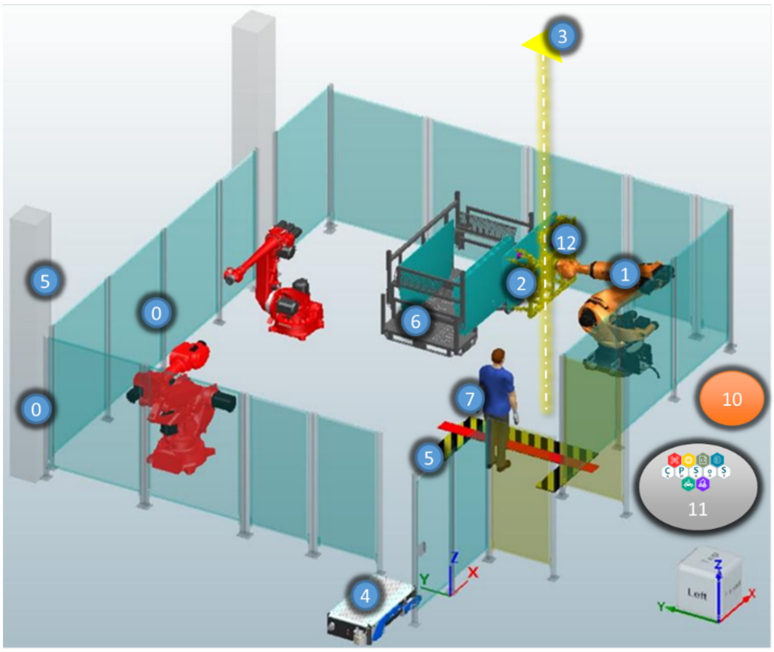


Figure 11: Final Layout in laboratory demonstrator

[1] Are robots intended for direct human robot interaction within a shared space, or where humans and robots are in close proximity

During testing, the old Robots won't be used. The above figure represents the expected final layout of the workcell. The adopted safe robot is the KUKA KR 150 R2700-2. In the following description, the two old Robot won't be considered anymore.

In the workcell, a backbone of a standard Safety system, running at high priority, will be installed independently from the higher control levels developed in the CPSOSAWARE project. This system bases its safety considerations mainly on the access management given by the supervision of the Safety Eye System. Some of the scenarios that will be described are related to the behaviour of this Safety system. Since his Safety layer is fixed, any further development could only run in parallel or be simulated at a System of System level. Signals could be duplicated safely in order to permit additional SW to verify the realistic behaviour without hindering the Safety backbone.



0: Old robots (Passive)
1: Safe Robot *KUKA KR 150 R2700-2*
2: Dedicated handling Gripper
3: *Safety Eye*
4: AGV
5: Cameras for posture recognition
Amount and location TBD
6: windshield rack carrier
Passive element
7: operator
8: Safe working area monitored by Safety Eye
9: Robot safety zones
Red: no access
Yellow: slow down
10: Robot Controller
11: Additional Project's controllers
12: Camera for operator's drowsiness detection

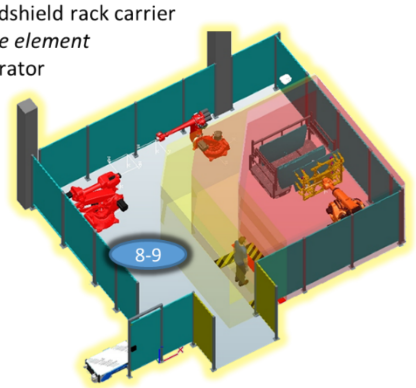


Figure 12: Main Actors in CRF's Pilot

The above figure gives a 3D simulation of the workcell with a representation of the main actors involved in the system. In the following representation the description of the scenarios will be based on different schematic representations of the workcell.

The following figure is the representation of the main simplified Layout of on-ground Passive elements that represent the base layout for the further descriptions:

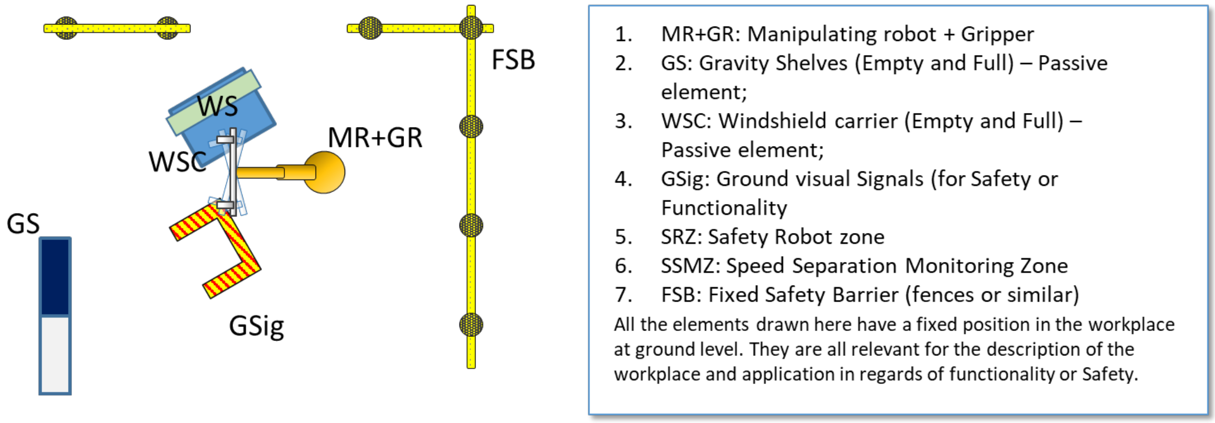


Figure 13: Simplified ground layout

Based on Figure 13 above, the full description of the main actors in the scene is given in the Figure 14.

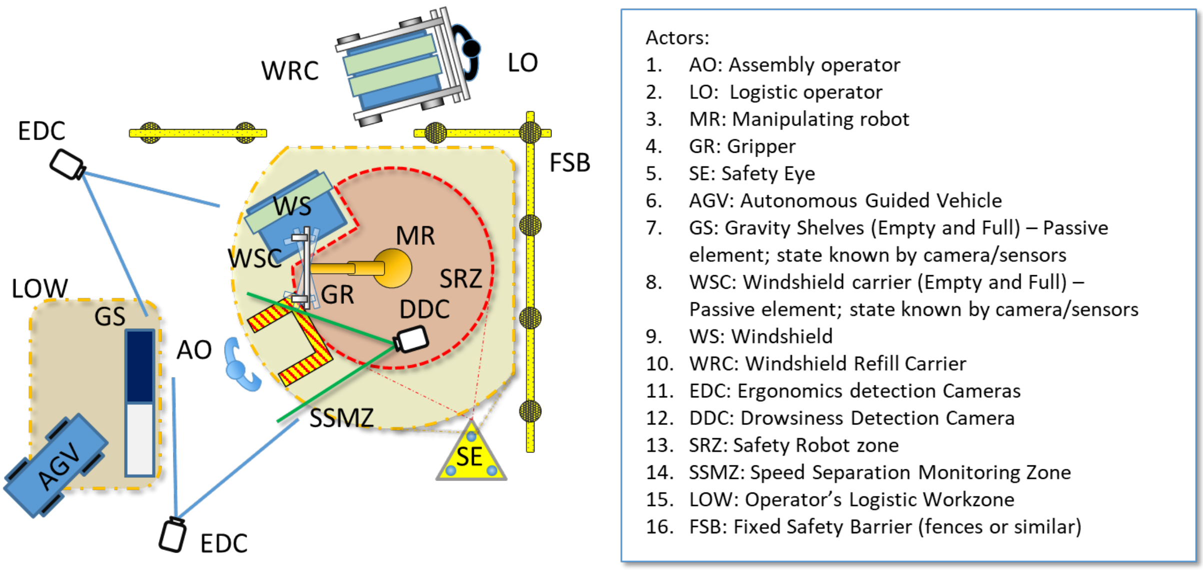


Figure 14: List on main actors in CRF pilot

From generic considerations on the share zones in the collaborative workplace in collaborative applications [9], four types of interest zones are defined:

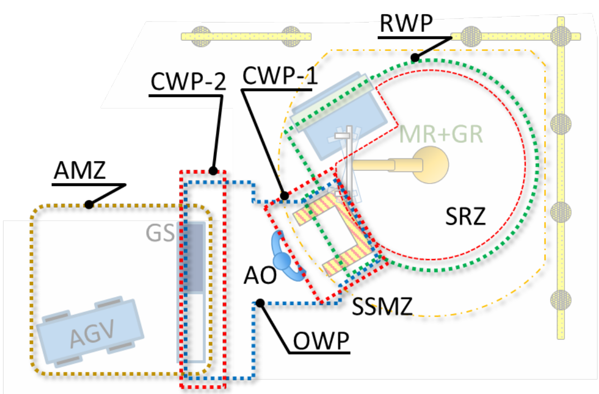
1. OWP: Operator's Work Place (zone of movement of the operator)
2. RWP: Robot Work Place (robot + gripper + component reachability zone)
3. CWP: Collaborative Work Place (according to ISO/TS 15066 [6])
4. SWP: Shared Work Place (zone where both robot and operator work)

In CRF Pilot the CWP corresponds to the SWP, since all operations in the same work area are always collaborative.

In the following Figure 15 a representation of the zones of interest drawn on the base layout is made. Besides of the four interest zones above, also the Safety zones defined by the Safety Eye (at ground level) are drawn.

As described later the logistic refurbishment of parts for the operator could be performed by the use of an AGV, or anyway simulated accordingly. Because of this assumption the figures represents two additional zones of interest: one AGV maneuvering zone and a collaborative Work Place (CWP-2) where the operator could interfere with the AGV performing the refill of the gravity shelves.

The definition of all the Collaborative zones is also fundamental to properly plan the task sequence of the operator and active devices. This is made after Safety considerations: indeed whenever the operator interacts nearly with an active device, the device needs to stop or slow down, and this can cause delays and micro-stops in the execution. During the initial planning these situations should be avoided unless strictly necessary, and in these cases a proper analysis and programming of the devices safety helps reducing the risk of micro-stops.



1. AO: Assembly operator
2. MR+GR: Manipulating robot + Gripper
3. AGV: Autonomous Guided Vehicle
4. GS: Gravity Shelves
5. SRZ: Safety Robot zone
6. SSMZ: Speed Separation Monitoring Zone
7. AMZ: AGV Manouvring zone
8. OWP: Operator's Work Place (zone of movement of the operator)
9. RWP: Robot Work Place (robot+gripper+component reachability zone)
10. CWP: Collaborative Work Place (according to ISO/TS 15066 [6])
    - CWP-1: zone of collaboration with the Robot
    - CWP-2: Zone of Collaboration with the AGV
11. SWP: Shared Work Place (zone where both robot and operator work)

NOTES:

- The limits of all active safety volumes (SRZ and SSMZ) are defined by the Safety Eye (SE)
- The layout with fixed components are represented in transparency
- For the specific application the *Collaborative Work Place* zones (CWP-1 and CWP-2) are coincident with the *Shared Work Place*

Figure 15: Collaborative Workplace description

3.1.3 Human operators planning – Task analysis

Previous Table 3 represents a more generic Task analysis of the interaction phases of the operator and the robot. A more detailed analysis of the operator's task is described in methodological terms in the contest of D1.2, the following tables apply the mixed MTM-task(Methods-Time Measurement) analysis to the specific standard scenario.

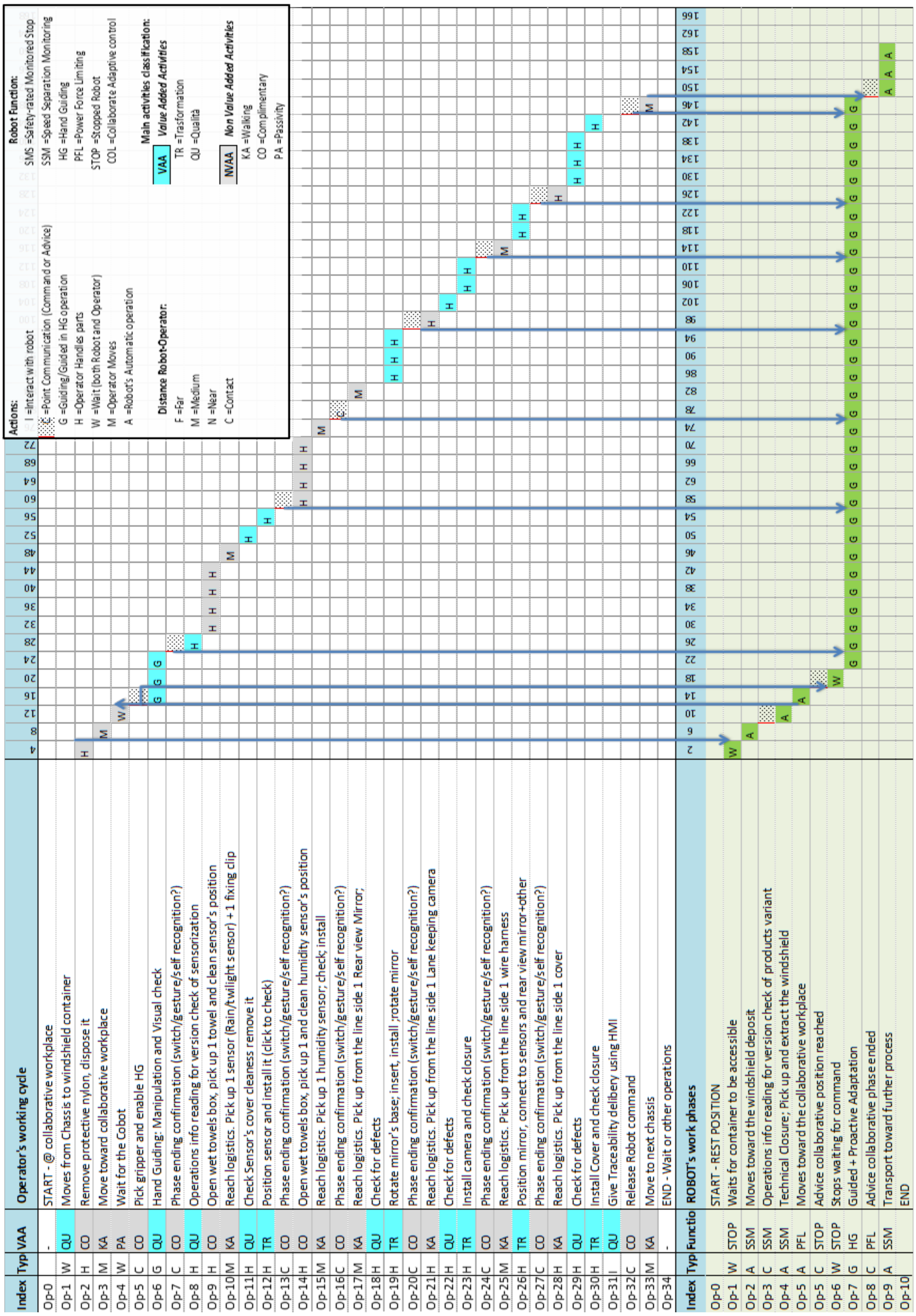


Figure 16: Task analysis of the CRF use case: Overview.

Index	Typ	VAA	Operator's working cycle		
Op-0		-	START - @ collaborative workplace		
Op-1	W	QU	Moves from Chassis to windshield container		
				Information Content	Container position. Known information
				Information exchange mode	Fixed marks.
Op-2	H	CO	Remove protective nylon, dispose it		
				Information Content	null
				Information exchange mode	null
Op-3	M	KA	Move toward collaborative workplace		
				Information Content	Destination position. Known information
				Information exchange mode	Fixed marks.
Op-4	W	PA	Wait for the Cobot		
				Information Content	null
				Information exchange mode	null
Op-5	C	CO	Pick gripper and enable HG		
				Information Content	HG enable
				Information exchange mode	Switch P0 / Self detection by handles on gripper / Self detection from ambient cameras with movements recognition
Op-6	G	QU	Hand Guiding: Manipulation and Visual check		
				Information Content	Trajectory / Position
				Information exchange mode	Physical contact-Interaction
Op-7	C	CO	Phase ending confirmation (switch/gesture/self recognition?)		
				Information Content	Phase Change
				Information exchange mode	OR: switch/gesture/self recognition/pattern on handles
Op-8	H	QU	Operations info reading for version check of sensorization		
				Information Content	Version and conformity of the product
				Information exchange mode	Visual HMI (not needed on Demo)
Op-9	H	CO	Open wet towels box, pick up 1 towel and clean sensor's position		
				Information Content	Destination position. Known information
				Information exchange mode	Fixed marks and Visual Information/SOP (Standard Operating Procedure).
Op-10	M	KA	Reach logistics. Pick up 1 sensor (Rain/twilight sensor) + 1 fixing clip		
				Information Content	Destination position. Known information
				Information exchange mode	Fixed marks and Visual Information/SOP (Standard Operating Procedure).
Op-11	H	QU	Check Sensor's cover cleaness remove it		
				Information Content	null
				Information exchange mode	null
Op-12	H	TR	Position sensor and install it (click to check)		
				Information Content	null
				Information exchange mode	null
Op-13	C	CO	Phase ending confirmation (switch/gesture/self recognition?)		
				Information Content	Phase Change
				Information exchange mode	OR: switch/gesture/self recognition/pattern on handles
Op-14	H	CO	Open wet towels box, pick up 1 and clean humidity sensor's position		
				Information Content	null
				Information exchange mode	null
Op-15	M	KA	Reach logistics. Pick up 1 humidity sensor; check; install		
				Information Content	Destination position. Known information
				Information exchange mode	Fixed marks and Visual Information/SOP (Standard Operating Procedure).
Op-16	C	CO	Phase ending confirmation (switch/gesture/self recognition?)		
				Information Content	Phase Change
				Information exchange mode	OR: switch/gesture/self recognition/pattern on handles
Op-17	M	KA	Reach logistics. Pick up from the line side 1 Rear view Mirror;		
				Information Content	Destination position. Known information
				Information exchange mode	Fixed marks and Visual Information/SOP (Standard Operating Procedure).
Op-18	H	QU	Check for defects		
				Information Content	null
				Information exchange mode	null
Op-19	H	TR	Rotate mirror's base; insert, install ;rotate mirror		
				Information Content	null
				Information exchange mode	null
Op-20	C	CO	Phase ending confirmation (switch/gesture/self recognition?)		
				Information Content	Phase Change
				Information exchange mode	OR: switch/gesture/self recognition/pattern on handles

Figure 17: Task analysis of CRF use case. Detail of tasks and interactions: operator 1/2

Index	Typ	VAA	Operator's working cycle		
Op-21	H	KA	Reach logistics. Pick up from the line side 1 Lane keeping camera		
				Information Content	Destination position. Known information
				Information exchange mode	Fixed marks and Visual Information/SOP (Standard Operating Procedure).
Op-22	H	QU	Check for defects		
				Information Content	null
				Information exchange mode	null
Op-23	H	TR	Install camera and check closure		
				Information Content	null
				Information exchange mode	null
Op-24	C	CO	Phase ending confirmation (switch/gesture/self recognition?)		
				Information Content	Phase Change
				Information exchange mode	OR: switch/gesture/self recognition/pattern on handles
Op-25	M	KA	Reach logistics. Pick up from the line side 1 wire harness		
				Information Content	Destination position. Known information
				Information exchange mode	Fixed marks and Visual Information/SOP (Standard Operating Procedure).
Op-26	H	TR	Position mirror, connect to sensors and rear view mirror+other		
				Information Content	null
				Information exchange mode	null
Op-27	C	CO	Phase ending confirmation (switch/gesture/self recognition?)		
				Information Content	Phase Change
				Information exchange mode	OR: switch/gesture/self recognition/pattern on handles
Op-28	H	KA	Reach logistics. Pick up from the line side 1 cover		
				Information Content	Destination position. Known information
				Information exchange mode	Fixed marks and Visual Information/SOP (Standard Operating Procedure).
Op-29	H	QU	Check for defects		
				Information Content	null
				Information exchange mode	null
Op-30	H	TR	Install Cover and check closure		
				Information Content	null
				Information exchange mode	null
Op-31	I	QU	Give Traceability delibery using HMI		
				Information Content	System Confirmation
				Information exchange mode	HMI
Op-32	C	CO	Release Robot command		
				Information Content	Disable HG
				Information exchange mode	OR: switch/gesture/self recognition/pattern on handles
Op-33	M	KA	Move to next chassis		
				Information Content	Movement
				Information exchange mode	Vision/wearable devices
Op-34		-	END - Wait or other operations		

Figure 18: Task analysis of CRF use case. Detail of tasks and interactions: operator 2/2

These figures provide the summarized task analysis for the use-case. The sequence of tasks is split into operator's tasks (white background cells) and robot's tasks (greenish background). Besides the title of the tasks (representing a short summary of sub-tasks) the graph represent:

- a generic classification of the type of action;
- a simplified classification of operations for an high level analysis of VAA and NVAA activities;
- the time graph of tasks (colors and letter on the graph reflect the previously listed information).

The arrows from the operator's graphs to robot's one and vice versa indicate moments in which the execution from one actor (target of the arrow) is constrained from the completion of the execution from the other actor (origin of the arrow). Arrows indicate the dependencies and interrelation of operator and robot. At these moments an interaction is due and, as a consequence, an HMI is requested. In the Robot's section, instead of the VAA/NVAA there is the classification of the interactive methods according to ISO 10218 part 2 and ISO/TS 15066. It is important to note that, for simplification's sake, the tasks are not here detailed to a low level MTM nomenclature. Because of this, the classification of the VAA/NVAA is not precise and in the same task there can be a mixture on the two distinct types. In these cases the most relevant type is shown, usually in coherence with the type of action.

In Figure 18 and Figure 17 there is a detail of the descriptions for the operator's actions with further information collected in reference to the need of information exchange, which is generating the moment of interaction and the need of HMIs (intended as any Human Robot Interaction) some HMIs are considered passive and do not require active HMIs to pass the information content (brow text). Figure 19 represent the description of the robot's phases. In the details there is a rough estimation of the Operator's-Robot distance and of the information content that the robot transmits to the operator.

Index	Typ	Functio	ROBOT's work phases		
Op-0			START - REST POSITION		
Op-1	W	STOP	Waits for container to be accessible		
				Distance robot-operator	M
				Information Content	null
				Information exchange mode	null
Op-2	A	SSM	Moves toward the windshield deposit		
				Distance robot-operator	M
				Information Content	Movement
				Information exchange mode	BLINKING LED + SOUND
Op-3	C	SSM	Operations info reading for version check of products variant		
				Distance robot-operator	M
				Information Content	Product conformity check
				Information exchange mode	Direct MES connection
Op-4	A	SSM	Technical Closure; Pick up and extract the windshield		
				Distance robot-operator	M
				Information Content	Movement
				Information exchange mode	BLINKING LED + SOUND
Op-5	A	PFL	Moves toward the collaborative workplace		
				Distance robot-operator	N
				Information Content	Movement
				Information exchange mode	BLINKING LED + SOUND
Op-5	C	STOP	Advice collaborative position reached		
				Distance robot-operator	N
				Information Content	Advice of collaborative phases Start
				Information exchange mode	Fixed LED + Advice Sound
Op-6	W	STOP	Stops waiting for command		
				Distance robot-operator	N
				Information Content	Wait State
				Information exchange mode	LED 2 slow blink
Op-7	G	HG	Guided + Proactive Adaptation		
				Distance robot-operator	C
				Information Content	Trajectory
				Information exchange mode	Physical contact-Interaction
Op-8	C	PFL	Advice collaborative phase ended		
				Distance robot-operator	C
				Information Content	Advice of collaborative phases Stop
				Information exchange mode	Fixed LED + Advice Sound
Op-9	A	SSM	Transport toward further process		
				Distance robot-operator	N
				Information Content	Movement
				Information exchange mode	BLINKING LED + SOUND
Op-10			END		

Figure 19: Task analysis of CRF use case. Detail of tasks and interactions: robot's phases

Based on the simplified representation previously defined the general and summarized storyboard for the standard scenario description is as follows:

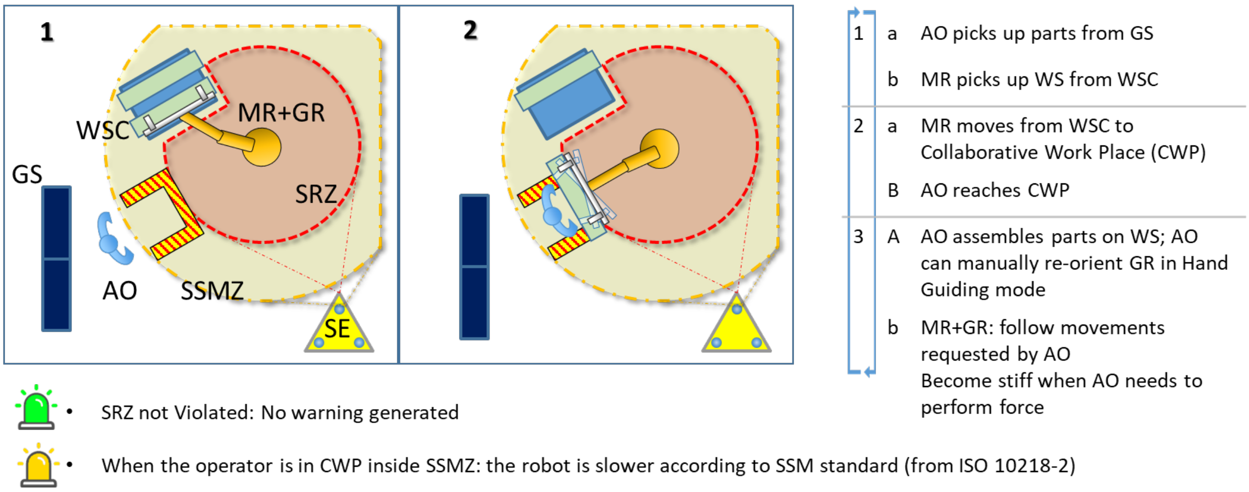
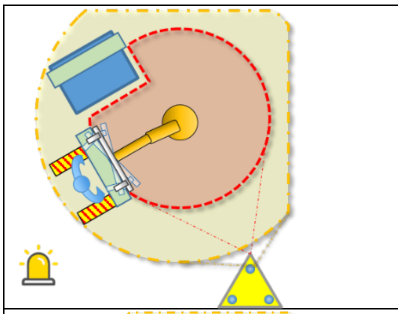
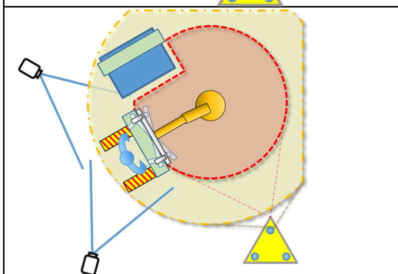
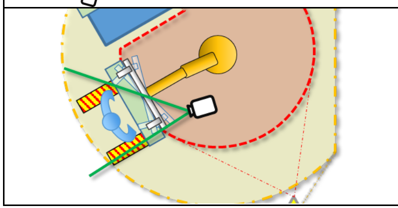


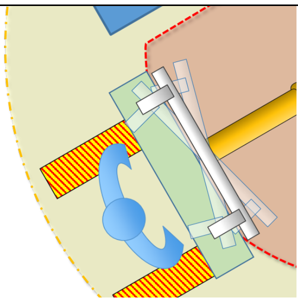
Figure 20: Simplified storyboard describing the standard scenario

The above standard scenario is cyclic and can be repeated indefinitely; the other scenarios that will be described represent unexpected events testing the concept resilience, as well as expected events that occur repeatedly during the execution of the standard scenario.

The events (later analysed at scenario level) in this second set of categories are summarized in the table below:

Table 4: Additional events managed during standard execution

	**Speed Separation Monitoring:** During all standard operations, the safety eye defines a zone (SSMZ-in yellow) that, when occupied by the operator, causes the robot to slow down to a safer speed level. The CWP-1 is inside the SSMZ, so, when the operator is in CWP-1, the robot gets slower according to SSM standard (from ISO 10218-2).
	**Ergonomics Real-Time analysis** An additional vision system detects the anthropometry of the operator and adjusts the gripper position to improve operator's ergonomics. The body detection allows also the generation of warnings in case of awkward positions, non-ergonomic actions and so on.
	**Operator's fatigue detection:** An additional vision system detects the drowsiness and fatigue of the operator. It can generate warnings and HMI signals toward the operator in order to reduce stress and fatigue.

	**Robot's stiffness control:** During HG manipulation the robot adjusts its position to allow the repositioning of the gripper. In case this adjustment risks to bring the robot's motion toward a singularity or a non-allowed configuration (for ergonomics constraints), the system reacts at three stages: 1. movement becomes stiffer in order to hinder manipulation over the forbidden zone 2. HMI warning are generated 3. Motion is blocked and resumes after direct operator's request

3.1.4 Robot and related hardware identification

The description of the workcell and its main elements is in D1.2.

In the next figure there is the simplified representation of the overall system architecture of the Pilot workcell.

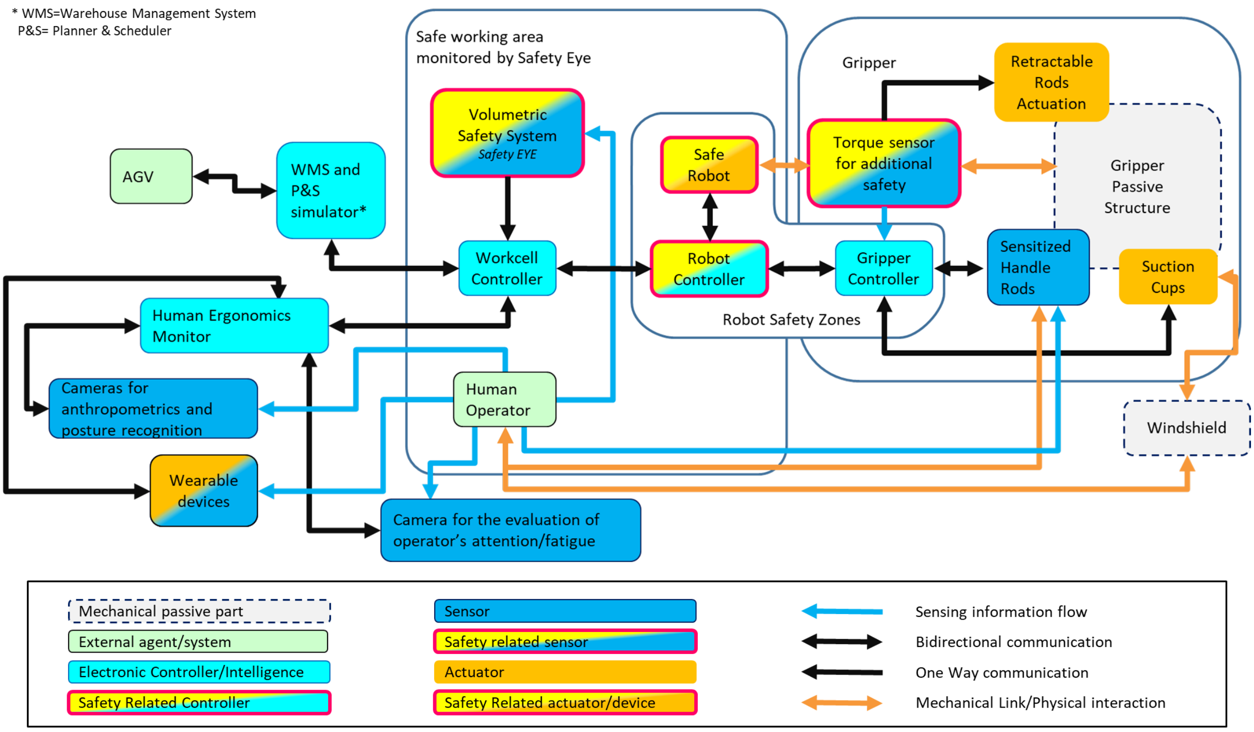


Figure 21: Overall system architecture representation

3.1.5 Example and content of the scenario descriptive table

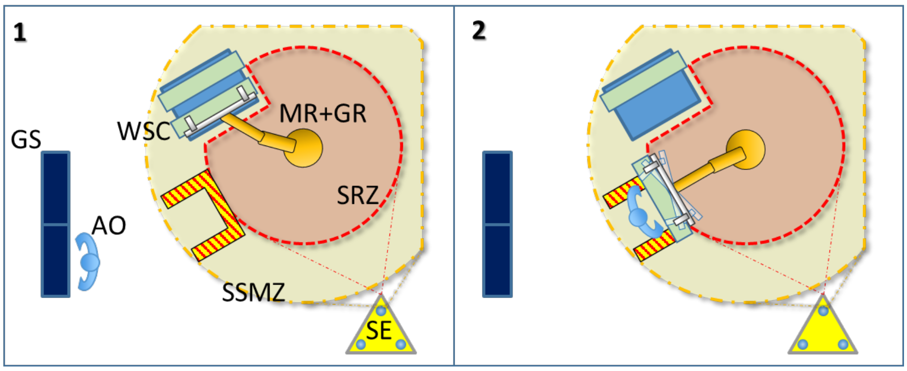
All the scenarios that will be described in the following are described according to the following schematic "table" representation. In the initial fields an introductory anagraphic is made with a generic description of the main phases and rationale. In the table there is also the description of the goal of the scenarios, intended as the description of what the scenarios wants to demonstrate. Finally, for each scenario there is a description of the tests planned to be executed on the scenario in order to validate the achievement of the goal. The following table is a Descriptive table with the general description of the content for each field.

Scenario Name	Simplified name of the scenario
Related Use Case	Manufacturing or Automotive
Scenario Description	
Brief Description	Brief functional description of the scenario
Challenges	Challenging objective of the scenario
Assumptions & Pre- Conditions	Conditions necessary for the realization of the scenario
Involved Actors	Actors and elements involved in the scenario
Scenario Initiation	Initial condition of the scenario, input necessary to make the scenario start
Novelty	Novelty compared to the current condition
Main Flow	Graphic and point description of how the various actors and elements involved interact and lead to the end of the scenario
Goal (Successful End Condition)	Goal or Goals that must be achieved to consider the scenario a success
Evaluation Criteria	Evaluation criteria for the scenario
Validation procedure (test methodology)	Description of methodologies to validate the scenario
Desired number of tests/testers	Description of how many and which tests will be needed depending on the evaluation criteria
Validation tools / equipment	Useful and necessary tools for the validation phase
Simplified planning	Simplified explanation of the steps that will be followed to validate the scenario

Table 5: Example table with fields exaplained

3.1.6 Schematic Standard scenario

The following schematic standard scenario describes, in tabular form, the normal operations expected during the use-case execution.

Scenario Name	**Standard Scenario**
Related Use Case	Manufacturing
Scenario Description	
Brief Description	The standard scenario represents the normal operating scenario of the cell. The operator, after having taken some components from the Gravity Shelf, proceeds with the assembly of the same on the windscreen. Meanwhile, the robot took the windshield from the container and pushed it towards the operator
Challenges	None
Assumptions & Pre- Conditions	1. There must be enough components on the gravity shelf and at least one windshield in the Windshields Container 2. The robotic cell is running and must be correctly powered
Involved Actors	• Assembly Operator • Cell components
Scenario Initiation	Normal start of production.
Novelty	Use of advanced sensors and new logics.
Main Flow	 *Figure 1-Standard Scenario*  • SRZ not Violated: No warning generated  • When the operator is in CWP inside SSMZ: the robot is slower according to SSM standard (from ISO 10218-2) 1) a. Assembly Operator picks up parts from Gravity Shelf b. Manipulating Robot+Gripper picks up Windshield from Windshields Container 2) a. Assembly Operator assembles parts on Windshield, eventually manipulation (orientation) gripper b. Manipulating Robot+Gripper: goes along with the Assembly Operator Become stiff when Assembly Operator needs to perform force

Goal (Successful End Condition)	Everything must work properly
Evaluation Criteria	The assembly operation is performed: 1. correctly 2. safely 3. on time
Validation procedure (test methodology)	Criteria 1: • Observation of the assembly phase • Time acquisition Criteria 2: • Respect to planned operations (no experimental validation in the scenario)
Desired number of tests/testers	Acquisition over 9-15 tests in various situations: • tests with various operators with different builds (from 3 to 5 operators) • possible authentication via different devices (3 possible devices) • camera recognition of the operator through the physiognomy
Validation tools / equipment	Equipment: • LabVIEW acquisition system • Weight sensors • Fixed Vision system and Use of the various sensors of the cell (camera, etc.) • Wearable sensors (smart watch) Tools: • Questionnaire • Smart watch acquisition • AGV movement log • Tracking of robot inverse kinematic
Simplified planning	1. The operator authenticates himself in the cell via smartwatch, badge or is recognized by the camera. 2. The robot sets its working parameters according to the operator's information, either through the database or through recognition of the operator's height with the camera. • **Repeat**: Various tests will be carried out with operators with different builds and strengths. The different operator’s strength, measured through the sensitized handles, will allow us to understand how the system adapts to an iteration with different forces.

Table 6: Overview of Manufacturing Standard Scenario

3.1.7 Summary of additional scenarios

Besides of the Standard scenario a series of additional scenarios have been defined. These scenarios describe events that can occur during the execution of the standard cycle, but are not part of the base sequence of tasks performed by the operator during normal operations. The scenarios listed below are executed in occasional situations and represent adaptive behaviour of the workcell performed occasionally during the execution of the standard scenario when certain situation occur. Besides of these exceptional scenarios, there are the four “Additional events managed during standard execution” described previously in Table 4.

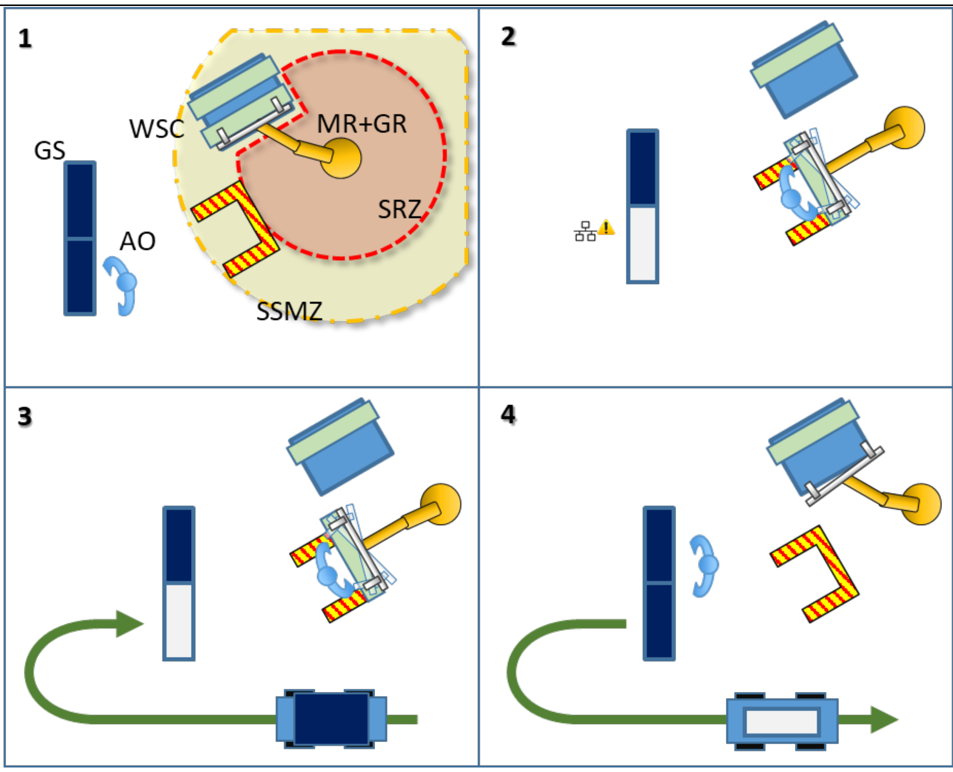
The following table represents an introductory summary of the scenarios that are singularly described later on.

Name	Type of scenario	Notes
Gravity Shelf Refill Scenario	Scenarios for ergonomics and Safety	It is necessary to fill the Gravity Shelf
Windshield Container Refill Scenario	Scenarios for ergonomics and Safety	It is necessary to fill the Windshield Container (only simulated)
Robot Singularity Scenario	Scenarios for ergonomics and Safety	The operator brings the robot close to a singularity point
Slow down zone entrance - SSM	Resilience from Safety zones violation	The operator violates the red zone
Safety Zone Violation Scenario 1 – SMS	Resilience from Safety zones violation	The operator violates the red zone
Safety Zone Violation Scenario 2 - SMS	Resilience from Safety zones violation	The operator violates the red zone

Table 7: Summary of Manufacturing Scenarios

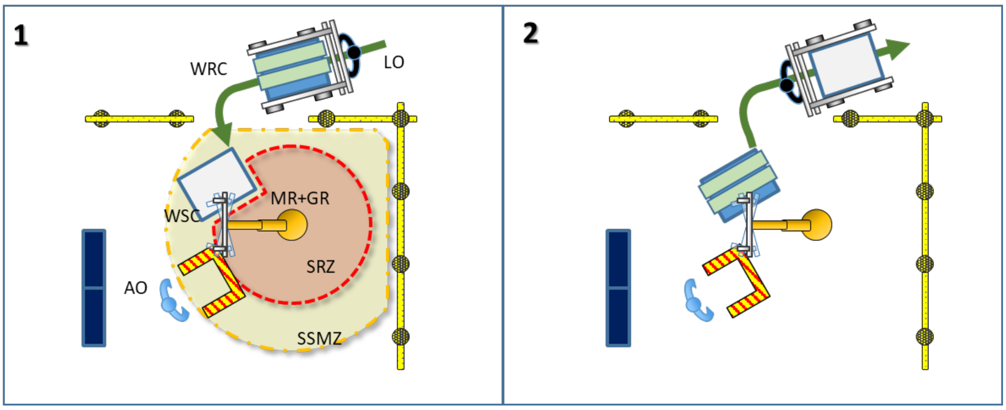
3.2 Additional testing Scenarios

Scenario Name	**Gravity Shelf Refill Scenario**
Related Use Case	Manufacturing
Scenario Description	
Brief Description	The Gravity Shelf Refill Scenario represents the situation in which the components on the gravity shelf are ending and will soon be no longer enough for an assembly
Challenges	The system must be aware of the imminent lack of components in the gravity shelf and communicate it promptly
Assumptions & Pre-Conditions	1. There must be enough components on the gravity shelf and at least one windshield in the Windshields Container 2. The robotic cell is running 3. The AGV must be charged and ready 4. There must be a full gravity shelf, ready for replacement
Involved Actors	Assembly Operator Cell components AGV Gravity Shelf
Scenario Initiation	Gravity Shelf informs the P&S (Planner and Scheduler) that it will soon be empty
Novelty	The system manages to solve an imminent problem autonomously and consciously
Main Flow	

	 *Figure 2-Gravity Shelf Refill Scenario* • SRZ & SSMZ "Violated" upon request: robot stopped without warning generated; restart when SRZ is re-enabled • When the operator is in CWP inside SSMZ: the robot is slower according to SSM standard (from ISO 10218-2) 1) a. Assembly Operator picks up parts from Gravity Shelf b. Manipulating Robot + Gripper picks up Windshield from Windshields Container 2) a. Assembly Operator assembles parts on Windshield, eventually manipulation (orientation) gripper b. Manipulating Robot + Gripper: goes along with the Assembly Operator c. Gravity Shelf informs the P&S (Planner and Scheduler) that it will soon be empty 3) a. The AGV enters the cell with the Gravity Shelf full 4) a. The AGV replaces and takes the empty Gravity Shelf out of the cell
Goal (Successful End Condition)	The replacement must take place in the correct manner and in production times. Besides, the AGV must follow the correct route without entering the forbidden cell area.
Evaluation Criteria	1. Replacement occurred correctly and on time 2. Minimum stock availability guaranteed

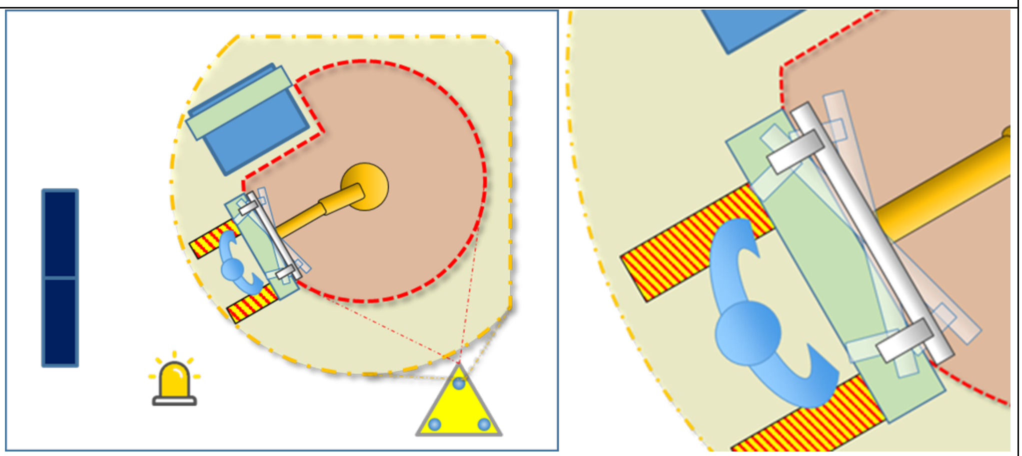
Validation procedure (test methodology)	Criteria 1: • Observation of the refill phase • Time acquisition Criteria 2: • Respect to planned operations (no experimental validation in the scenario)
Desired number of tests/testers	The availability of the AGV is not sure. The scenario is relevant, yet it could be considered only in terms of programming without experimental validation. Eventually the AGV can be substituted by a Cart. Eventual experimental validation: Acquisition over 5 tests.
Validation tools / equipment	Equipment: • AGV • LabVIEW acquisition system • Weight sensors • Fixed Vision system and Use of the various sensors of the cell (camera, etc.) • Wearable sensors (smart watch) Tools: • Questionnaire • Smart watch acquisition • AGV movement log • Weight/presence sensors acquisition on Gravity shelves
Simplified planning	• A weight sensor or Pick to Light system, or direct operator's request through dedicated HMI to the WMS (Warehouse Management System) or simulated analogous function. The simulated WMS generates a request for AGV shelves refill. • A simulated P&S communicates to the AGV the target to reach. 1. The AGV arrives with a full trolley. 2. Full trolley laying in temporary area 3. Pick up empty cart 4. Vacuum installation in a temporary area 5. Withdraws full from the temporary area, places it in the operational logistics area on board the line and releases it 6. Pick up empty and take it away

Table 8: Overview of Manufacturing Gravity Shelf Refill Scenario

Scenario Name	**Windshield Container Refill Scenario**
Related Use Case	Manufacturing
Scenario Description	
Brief Description	The Windshield Container Refill Scenario represents the situation in which the windshields ends and it will be necessary to replace the container
Challenges	The system must be aware of the imminent lack of windshields in the windshields container and communicate it promptly
Assumptions & Pre- Conditions	1. There must be enough components on the gravity shelf and at least one windshield in the Windshields Container 2. The robotic cell is running 3. The logistics operator must be free and ready 4. There must be a full and ready windshield container
Goal (Successful End Condition)	The replacement must take place in the correct manner and in production times. Besides, the logistics operator must cross the forbidden area only for the time necessary for replacement
Involved Actors	Assembly Operator Cell components Logistic Operator Windshield container The Camera
Scenario Initiation	The Camera notifies the P&S (Planner and Scheduler) of the imminent lack of windshield
Novelty	The system manages to solve an imminent problem autonomously and consciously
Main Flow	 *Figure 3-Windshield Container Refill Scenario*

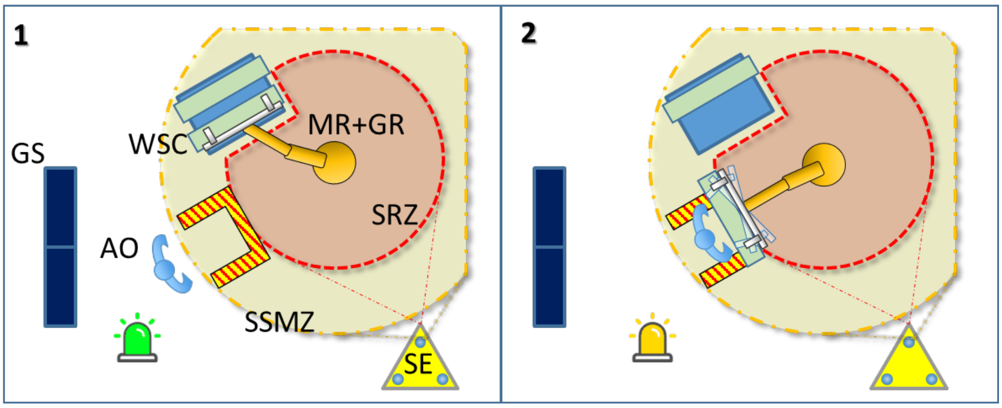
	• SRZ & SSMZ "Violated" upon request: robot stopped without warning generated; restart when SRZ is re-enabled • When the operator is in CWP inside SSMZ: the robot is slower according to SSM standard (from ISO 10218-2) 1) Logistic Operator brings the full WSC into the cell 2) Logistic Operator takes the empty WSC out of the cell **NOTES:** • This Scenario can be simulated but not physically realized in the Laboratory • In a real Scenario also WSC would have an "empty+full" logic like GS in GS refill Scenario
Evaluation Criteria	Replacement occurred correctly and on time
Validation procedure (test methodology)	• Acquisition of accelerations from accelerometers/signal integration • Derivation of inverse kinematic information
Desired number of tests/testers	Acquisition over 30 tests in various situations: • different illuminations of the windshield container Note: This scenario will be simulated, so the tests will also be simulated.
Validation tools / equipment	• Simulation software
Necessary equipment	• Simulation software
Simplified planning	The operator authenticates himself in the cell via smartwatch, badge or is recognized by the camera. The robot sets its working parameters according to the operator's information, either through the database or through recognition of the operator's height with the camera. Various tests will be carried out with operators with different builds and strengths. The different operator's strength, measured through the sensitized handles, will allow us to understand how the system adapts to an iteration with different forces. Meanwhile, the camera communicates to the P&S the imminent lack of windshields. The P&S communicates to the logistic operator the need for his intervention. The logistics operator enters the cell and replaces the empty windshield container with a full one. Once the operation is finished, he leaves the cell. **NOTES:** • This Scenario can be simulated but not physically realized in the Laboratory • In a real Scenario also WSC would have an "empty+full" logic like GS in GS refill Scenario

Table 9: Overview of Manufacturing Windshield Container Refill Scenario

Scenario Name	Robot Singularity Scenario
Related Use Case	Manufacturing
Scenario Description	
Brief Description	Operator guides the robot into a singularity.
Challenges	The system must foresee and prevent the operator from guiding the robot in a singularity.
Assumptions & Pre- Conditions	1. There must be enough components on the gravity shelf and at least one windshield in the Windshields Container 2. The robotic cell is running 3. The AGV must be charged and ready 4. There must be a full gravity shelf, ready for replacement
Goal (Successful End Condition)	After predicting the imminent reaching of an unsafe position of the robot, the system intervenes and stops the operator.
Involved Actors	Assembly Operator Cell components HMI Robot Sensorized gripper
Scenario Initiation	The robot controller informs the PLC that an unsafe position is imminent.
Novelty	The system manages to solve an imminent problem autonomously and consciously.
Main Flow	 *Figure 4-Robot Singularity Scenario*

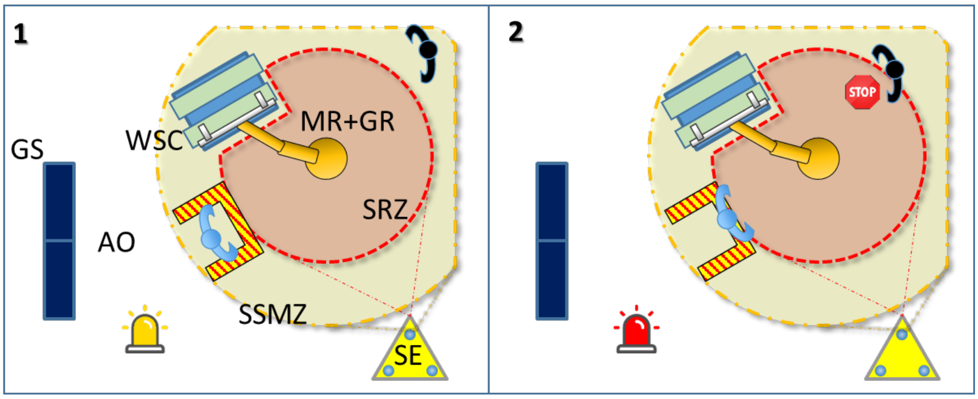
	During HG manipulation the robot adjusts its position to allow the repositioning of the gripper. In case this adjustment risks to bring the robot's motion towards a singularity or a non-allowed configuration (for ergonomics constraints), the system reacts at three stages: 1. Movement becomes stiffer in order to hinder manipulation over the forbidden zone 2. HMI warning are generated 3. Motion is blocked and resumes after direct operator's request
Evaluation Criteria	1. Gripper force feedback measurement. 2. Measurement of the system reaction time.
Validation procedure (test methodology)	Criteria 1: • Observation of the HG phase • Reaction Time acquisition
Desired number of tests/testers	Various tests may be carried out, taking the robot to different unsafe positions. Eventual experimental validation: Acquisition over 5 tests.
Validation tools / equipment	Equipment: • LabVIEW acquisition system • Fixed Vision system and Use of the various sensors of the cell (camera, etc.) • Wearable sensors (smart watch) Tools: • Questionnaire • Smart watch acquisition • Camera acquisition
Simplified planning	1. The operator authenticates himself in the cell via smartwatch, badge or is recognized by the camera. 2. The robot sets its working parameters according to the operator's information, either through the database or through recognition of the operator's height with the camera. 3. The operator, using the sensorized gripper, guides the robot near an unsafe area. 4. The system recognizes the anomaly and: • Movement becomes stiffer in order to hinder manipulation over the forbidden • Zone alerts the operator via the HMIs **Repeat**: Various tests will be carried out with operators with different builds and strengths. The robot will be guided in different unsafe positions.

Table 10: Overview of Manufacturing Robot Singularity Scenario

Scenario Name	**Slow down zone entrance - SSM**
Related Use Case	Manufacturing
Scenario Description	
Brief Description	The Safety Zone Violation Scenario 2 represents the situation in which the logistic operator violates the safety zone.
Challenges	The system must promptly recognize the violation and send the cell to an emergency lockout.
Assumptions & Pre- Conditions	The robotic cell is running.
Involved Actors	Logistic Operator Cell components Safety Eye Light Curtain
Scenario Initiation	The Safety Eye and/or Light Curtain detects the violation and they report it to the controller.
Novelty	The system manages to solve an imminent problem autonomously and consciously.
Main Flow	 *Figure 5-Safety Zone Violation Scenario*  • SRZ not Violated: No warning generated  • When the operator is in CWP inside SSMZ: the robot is slower according to SSM standard (from ISO 10218-2)

	Automatic Execution Mode Speed and Separation Monitoring mode Safety Monitored Stop 1) a. AO is initially out of the SSMZ; MR at full speed b. AO enters the SSMZ (yellow) c. SE detects the entrance and reports it to the controller d. The cell Starts Speed Separation Monitoring state 2) a. MR reduces its speed to a lower predefined safe threshold b. Operations continues as standard assembly 3) When AO exits Slow-down zone, the system resumes the maximum standard speed
Goal (Successful End Condition)	The cell goes into emergency lock almost instantly, the robot stops without injuring the operator.
Evaluation Criteria	No operator injury.
Validation procedure (test methodology)	• Acquisition of accelerations from accelerometers/signal integration. • Derivation of inverse kinematic information.
Desired number of tests/testers	Acquisition over 30 tests in various situations: • Different directions of entry into the cell.
Validation tools / equipment	• Questionnaire • Smart watch acquisition • Vision system • 3 axial Accelerometer acquired by a LabVIEW system • Tracking of robot inverse kinematic • Use of the various sensors of the cell (camera, etc.)
Necessary equipment	• Smart watch for acceleration and/or for identification (or badge RFID) • 3D accelerometer • LabVIEW acquisition system • Safety Eye • Camera etc.
Simplified planning	The operator authenticates himself in the cell via smartwatch, badge or is being recognized by the camera. The robot sets its working parameters according to the operator's information, either through the database or through recognition of the operator's height with the camera. Various tests will be carried out with operators with different builds and strengths. The different operator's strength, measured through the sensitized handles, will allow us to understand how the system adapts to an iteration with different forces. Meanwhile the Safety Eye reveals an intrusion in the pre-alarm zone. The Safety Eye communicates the intrusion to the PLC and the "slow" mode is started. If the intruder also violates the red security zone, the cell is immediately stopped. There are 2 possible ways to resume activity: 1. automatic restart, as soon as the intruder leaves the cell 2. manual restart by the assembly operator

Table 11: Overview of Manufacturing Slow down zone entrance – SSM

Scenario Name	Safety Zone Violation Scenario 1 - SMS
Related Use Case	Manufacturing
Scenario Description	
Brief Description	The Safety Zone Violation Scenario 1 represents the situation in which the logistic operator violates the safety zone
Challenges	The system must promptly recognize the violation and send the cell to an emergency lockout
Assumptions & Pre- Conditions	The robotic cell is running
Involved Actors	Logistic Operator Cell components Safety Eye Light Curtain
Scenario Initiation	The Safety Eye and/or Light Curtain detects the violation and they report it to the controller
Novelty	The system manages to solve an imminent problem autonomously and consciously
Main Flow	 *Figure 6-Safety Zone Violation Scenario 1* • Operator is in CWP inside SSMZ: the robot is slower according to SSM standard (from ISO 10218-2) • SRZ Violated in a non expected moment: robot stopped with warning generated; manually or autonomously restarts when re-enabled Automatic Execution Mode Speed and Separation Monitoring mode Safety Monitored Stop 1) a. LO goes beyond the limits of SRZ b. The SE detects the violation and report it to the controller c. The cell goes into Emergency Block Mode d. MR+GR stop in Safety Monitored (SMS) Stop Mode

	2) a. LO leaves the limits of the safe zone b. Green Light from Safety Eye and Light Curtain c. Assembly Operator restarts the cell or cell restarts automatically 3) a. LO restarts the cell or cell restarts automatically b. The MR+GR resumes program execution and motion restarts
Goal (Successful End Condition)	The cell goes into emergency lock almost instantly, the robot stops without injuring the operator.
Evaluation Criteria	No operator injury.
Validation procedure (test methodology)	• Acquisition of accelerations from accelerometers/signal integration. • Derivation of inverse kinematic information.
Desired number of tests/testers	Acquisition over 30 tests in various situations: • Different directions of entry into the cell.
Validation tools / equipment	• Questionnaire • Smart watch acquisition • Vision system • 3 axial Accelerometer acquired by a LabVIEW system • Tracking of robot inverse kinematic • Use of the various sensors of the cell (camera, etc.)
Necessary equipment	• Smart watch for acceleration and/or for identification (or badge RFID) • 3D accelerometer • LabVIEW acquisition system • Safety Eye • Camera etc.
Simplified planning	The operator authenticates himself in the cell via smartwatch, badge or is recognized by the camera. The robot sets its working parameters according to the operator's information, either through the database or through recognition of the operator's height with the camera. Various tests will be carried out with operators with different builds and strengths. The different operators strength, measured through the sensitized handles, will allow us to understand how the system adapts to an iteration with different forces. Meanwhile the Safety Eye reveals an intrusion in the pre-alarm zone. The Safety Eye communicates the intrusion to the PLC and the "slow" mode is started. If the intruder also violates the red security zone, the cell is immediately stopped. There are 2 possible ways to resume activity: 1. automatic restart, as soon as the intruder leaves the cell 2. manual restart by the assembly operator

Table 12: Overview of Manufacturing Safety Zone Violation Scenario 1 - SMS

Scenario Name	Safety Zone Violation Scenario 2 - SMS
Related Use Case	Manufacturing
Scenario Description	
Brief Description	The Safety Zone Violation Scenario 2 represents the situation in which the logistic operator violates the safety zone
Challenges	The system must promptly recognize the violation and send the cell to an emergency lockout
Assumptions & Pre- Conditions	The robotic cell is running
Involved Actors	Logistic Operator Cell components Safety Eye Light Curtain
Scenario Initiation	The Safety Eye and/or Light Curtain detects the violation and they report it to the controller
Novelty	The system manages to solve an imminent problem autonomously and consciously
Main Flow	

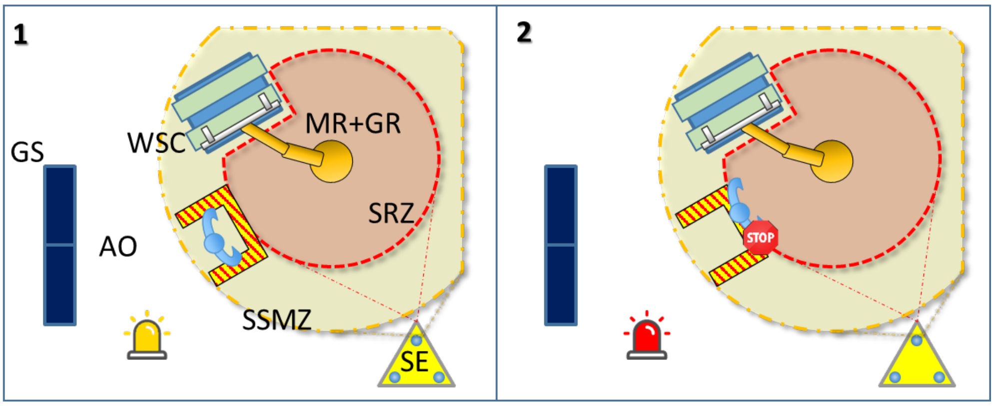


Figure 7-Safety Zone Violation Scenario 2

- Operator is in CWP inside SSMZ: the robot is slower according to SSM standard (from ISO 10218-2)
- SRZ Violated in a non expected moment: robot stopped with warning generated; manually or autonomously restarts when re-enabled

	Automatic Execution Mode Speed and Separation Monitoring mode Safety Monitored Stop 1) a. AO goes beyond the limits of SRZ b. The SE detects the violation and report it to the controller 2) a. AO leaves the limits of the safe zone b. Green Light from Safety Eye and Light Curtain c. Assembly Operator restarts the cell or cell restarts automatically 3) The Manipulating Robot+ Gripper restarts
Goal (Successful End Condition)	The cell goes into emergency lock almost instantly, the robot stops without injuring the operator.
Evaluation Criteria	No operator injury.
Validation procedure (test methodology)	• Acquisition of accelerations from accelerometers/signal integration. • Derivation of inverse kinematic information.
Desired number of tests/testers	Acquisition over 30 tests in various situations: • Different directions of entry into the cell.
Validation tools / equipment	• Questionnaire • Smart watch acquisition • Vision system • 3 axial Accelerometer acquired by a LabVIEW system • Tracking of robot inverse kinematic • Use of the various sensors of the cell (camera, etc.)
Necessary equipment	• Smart watch for acceleration and/or for identification (or badge RFID) • 3D accelerometer • LabVIEW acquisition system • Safety Eye • Camera etc.
Simplified planning	The operator authenticates himself in the cell via smartwatch, badge or is recognized by the camera. The robot sets its working parameters according to the operator's information, either through the database or through recognition of the operator's height by the camera. Various tests will be carried out with operators of different builds and strengths. The different operator's strength, measured through the sensitized handles, will allow us to understand how the system adapts to an iteration with different forces. Meanwhile, the Safety Eye reveals an intrusion in the pre-alarm zone. The Safety Eye communicates the intrusion to the PLC and the "slow" mode is started. If the intruder also violates the red security zone, the cell is immediately stopped. There are 2 possible ways to resume activity: 1. automatic restart, as soon as the intruder leaves the cell 2. manual restart by the assembly operator

Table 13: Overview of Manufacturing Safety Zone Violation Scenario 2 – SMS

4 Conclusions

The deliverable provides the description of some of the testing scenarios, identifies the expected behaviour of the CPSoSAware system in the two use-cases and plans the approach that will be taken during the evaluation phases of the system. The next iteration of the deliverable D6.3 will come up with more elaborated scenarios and Use-Cases that will fully align the Use-Cases and scenarios with the KPIs and requirements presented in D1.2. Each scenario and evaluation criteria is listed along the description of the evaluation procedure. Moreover, the necessary equipment for evaluating each Use-Case is also identified and reported.

Each individual Pilot has described a multitude of scenarios with a different approach, this highlights the deep difference between the 2 Pilots (Automotive and Manufacturing). Each scenario was described schematically to facilitate understanding of the peculiarities of each individual Use-Case. After describing the Use Cases scenarios in this deliverable, the validation tests will be applied and the results will be included in the deliverable D6.5, scheduled for month 36.

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