D1.2 REQUIREMENTS AND USE CASES

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Abstract

This report constitutes the output of task T1.2 "Use Cases Specifications and Use-Case Scenarios for dependable CP(H)Ss" and provides the methodological aspects identified and defined used for deriving the two project use cases, i.e. Connected and Autonomous Vehicles (CAVs) and Human-Robot Collaboration (HRC) in manufacturing.

The Use Cases description has a double purpose: description of functional and operational features of the Use Cases and description of the desired functional features from which the CPSoSaware project will extract and details the architectural features to be implemented in the CPSoSaware system.

The ultimate aim of this document is to provide the list of the main user-requirements coming from the main stakeholders of the applications considered in two project Use-Cases.

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Executive summary

This report represents the output of task T1.2 “Use Cases Specifications and Use-Case Scenarios for dependable CP(H)Ss”. It provides the description of the reference Use Cases and extracts the User Requirements of interest.

The document provides the methodology defined and used for deriving the describing Use Cases, where applicable, as well as the User Requirements.

The definition of the User Requirements is made upon considerations coming from the main stakeholders of the applications in the Use Cases. This document presents the process methodology for the quantification and description of the Use-Case and for the definition of the user requirement. It also provides the list of the main user-requirements or the CPSoSaware project.

More specifically, the document firstly reviews the methodology and tools used for the description of Autonomous driving Use Case scenarios, with a focus on the correct flow that must be followed to identify the three phases: from the Concept Phase (ISO 26262 standard) passing to identify the scenarios for verification and validation.

Secondly, this report reviews the two project Use-Cases: Autonomous driving and Human Robot Collaboration (HRC) in manufacturing field. For the first Use-Case, presentation includes the business objectives being pursued, the technological context in which it develops the activity and subsequently the needs and expectations of the stakeholders are identified. For the second Use-Case, the industrial reference environment will be presented where this type of collaboration between Human and Robot is used, the HRC rules in accordance to ISO standards, the main characteristics of HRC workcell and the structure of this study-pilot. A deeper analysis will be performed with all the details of the operations in D6.3.

Thirdly, the document describes the technical requirement and KPIs for both Use-Cases, with a particular focus on methodology for ADAS design and verification used by PASEU.

1 Introduction

This deliverable is the output of task 1.2 “Use Cases Specifications and Use-Case Scenarios for dependable CP(H)Ss” and presents the methodology defined and used for deriving the detailed Use Cases as well as the User Requirements.
As output of T1.2 this deliverable is formulating the basis of the user-centered design approach that will be followed throughout the project, by focusing on the analysis of the targeted user needs and expectations, in respect of the envisaged holistic solution for reliability and security in connected cars with l3 or l4 level of autonomy and in collaborative robots in large manufacturing facilities.

1.1 Document structure

This document is structured into five major sections:

- Section 1 introduces the document, outlining its structure, and identifying terms and acronyms used across the document.
- Section 2 includes the Use Case scenario description both business and technical point of view for two major pillars involved: Automotive and Manufacturing.
- Section 3 presents relevant methodologies, process and supporting tools for the definition of common taxonomy and categories of requirements of the two Use Cases of the project.
- Section 4 presents the final list of consolidated and prioritized requirements with corresponding metrics of the two Use Cases of the project.
- Section 5 concludes the document.

1.2 Acronyms and descriptions

Below are listed the most relevant acronyms used in the document and recurring definitions:

Acronym / Term	Description
ABS	Anti-Lock System
ACC	Adaptive Cruise Control
AUC	Advanced Urban Cars
AD	Automated Driving
ADF	Automated Driving Function
ADS	Automated Driving Systems
ASIL	Automotive Safety Integrity Level
AVAM	Autonomous Vehicle Acceptance Model
BIW	Body In White
COBOT	Collaborative Robot
CPS	Cyber-Physical System
CPSoS	Cyber-Physical System of Systems
CTAM	Car Technology Acceptance Model
DFMEA	Design failure mode and effects analysis
ESC	Electronic Stability Control
ETU	Elementary Technological Units
ETSI	European Telecommunication Standards Institute
FCW	Front Collision Warning
JPH	Job Per Hours
HG	Hand Guiding
HOV	High-occupancy vehicle
HRC	Human Robot Collaboration
LCA	Lane Change Assist
LDW	Lane Departure Warning
LKA	Lane Keeping Assist
MEC	Mobile Edge Computing
MTM	Methods-Time Measurement
MTM-UAS	Universal Analysing System
NFV	Network functions virtualization
ODD	Operational Design Domain
OEDR	Object and Event Detection and Response
PA	Park Assist
PC5	5G direct communication between vehicle and other devices (V2V, V2I) uses so-called PC5 interface, interferes with WLANp
PDC	Park Distance Control
PFL	Power and Force Limiting by design or control
PPAP	Production part approval process
PRT	Personal Rapid Transit
SAE	Society of Automotive Engineers
SDN	Software-Defined Networking
SMS	Safety-rated Monitored Stop
SSM	Speed and Separation Monitoring
TAM	Technology Acceptance Model
TARA	Threat and Risk Analysis
TT	Takt Time
UTAUT	Universal Theory of Usage and Acceptance of Technology
UMTS	Universal Mobile Telecommunications System
Uu	UMTS air interface
V2V	Vehicle-to-Vehicle

2 Use Case scenario description – business and technical context

In this section an introductory description of the Use Cases of the CPSoSaware project is presented in order to perform the analysis and collection of the system requirements in Chapter 3.

2.1 Methodology and tools used for the description of Autonomous driving Use Case scenarios

The latest version of the ISO 26262 standard from 2016 represents the state of the art for a safety-guided development of safety-critical electric/electronic vehicle systems. These vehicle systems include advanced driver assistance systems and vehicle guidance systems. The development process proposed in the ISO 26262 standard is based upon multiple V-models and defines activities and work products for each process step. In many of these process steps, scenario-based approaches can be applied to achieve the defined work products for the development of automated driving functions. To accomplish the work products of different process steps, scenarios must focus on various aspects like a human understandable notation or a description via state variables. This leads to contradictory requirements regarding the level of detail and way of notation for the representation of scenarios.

Driver assistance systems and automated systems reaching SAE Levels 1 and 2 [1] have already been introduced to the market. Level 3 (conditional automation) and 4 (high automation) systems are announced to follow (Audi traffic jam pilot or Waymo self-driving cars (3) [2]). A challenge for the introduction of higher levels of automation is to assure that these vehicle systems behave in a safe way. For driver assistance systems, this proof is furnished by driving many test kilometers on test grounds and public roads. However, for higher levels of automation a distance-based validation is not an economically acceptable solution [3]. As an alternative to the distance-based validation we introduce a scenario-based approach. The key idea is to purposefully vary and validate the operating scenarios of the automated vehicle. Therefore, the systematic derivation of scenarios and further assumptions have to be documented along the development process to ensure a traceable scenario generation. The ISO 26262 standard is a guideline for the development of safety-critical electric/electronic vehicle systems and thus provides a framework for the development of vehicle guidance systems under the aspect of functional safety. According to the ISO 26262 standard, scenarios can be utilized to support the development process. For instance, scenarios can help to derive requirements, to develop the necessary hardware and software components, and to prove the safety of these components in the test process. When creating test cases, scenarios are necessary for generating consistent input data for the test object in any case. Nevertheless, these different applications of scenarios result in distinct requirements for scenario representation in each development phase of the ISO 26262 standard.

This contribution proposes three abstraction levels for scenarios along a V-model-based development process. In this way, scenarios can be identified on a high level of abstraction in the concept phase and be detailed and concretized along the development process. This allows a structured approach, starting from the item definition according to the ISO 26262 standard, followed by the hazard analysis and risk assessment (HARA), and ending up with the necessary test cases for safety verification and validation. Thus, the authors suggest an extended definition of the term 'scenario' based on the definition of Ulbrich et al. [4] and introduce the abstraction levels of functional, logical, and concrete scenarios.

Go and Carroll [5] pointed out that scenarios have a different use across various disciplines, but the elements utilized to describe a scenario are similar in all cases. Thereby, scenarios can be described in several levels of detail and different forms of notation. Scenarios may be expressed in formal, semiformal, or informal notation [5]. This distinction hints at multiple levels of abstraction of scenarios along the development process for automated vehicles. Bergenhem et al. [6] pointed out that complete requirements for vehicle guidance systems can only be achieved by a consistent, traceable, and verifiable process of requirements engineering in accordance with the V-model. Several publications suggest approaches which utilize scenarios to generate work products along the development process for automated vehicles. Bagschik et al. [7] developed a procedure for the generation of potentially hazardous scenarios within the process step of a hazard analysis and risk assessment, as suggested by the ISO 26262 standard. This procedure utilizes an abstract description of the traffic participants and the scenery in natural language. All possible combinations of scenario elements are analyzed incorporating descriptions of functional failures in a limited Use Case of an SAE Level 4 [8] vehicle guidance system within the scope of the project Unmanned Protective Vehicle for Highway Hard Shoulder Road Works (aFAS2) [9]. Schuldt et al. [10] motivate a scenario-based test process and present a systematic test case generation by use of a 4-layer-model. Bach et al. [11] proposed a model-based scenario representation with spatial and temporal relations as a general scenario notation along the development process of the ISO 26262 standard. This scenario representation is implemented prototypically for scenarios of an ACC-system on motorways and the results are presented. The mentioned publications utilize scenarios with different levels of abstraction for the functional and safety development of vehicle guidance systems. The term 'scenario' has not been defined uniformly, which makes it difficult to achieve a consistent understanding regarding the role of scenarios in the development process.

The ISO 26262 standard from 2016 [12] represents the state of the art for developing vehicle guidance systems regarding functional safety. Scenarios may support the whole development process of the ISO 26262 standard from the concept phase via the technical product development through to the system verification and validation. Hence, it is mandatory to define the requirements on scenarios resulting from the different process steps. These requirements allow a consistent definition of abstraction levels for the use of scenarios throughout the whole development lifecycle. The following sections refer to the work products of the development process defined by the ISO 26262 standard and derive requirements on scenarios for the highlighted process steps.

2.1.1 Scenarios in the Concept Phase

Prior to the technical development, the concept for the item under development is specified. During the concept phase of the ISO 26262 standard the item is defined, a hazard analysis and risk assessment is conducted, and a functional safety concept is developed. The item definition shall include a description of the functional concept, system boundaries, the operational environment, the legal requirements, and the dependencies on other items. Based on this information, possible operating scenarios can be derived. Reschka [13] proposes to identify safe driving states and to specify the nominal behavior based on the operating scenarios. The operating scenarios in this process step shall be described in an abstract level of detail and be represented in a human understandable way (textual description). The next process step defined by the ISO 26262 standard which uses scenarios is the hazard analysis and risk assessment. The hazard analysis and risk assessment consist of two steps: the situation analysis and the hazard identification, and the classification of hazardous events. In the situational analysis, all operational situations and operating modes in which malfunctioning behavior will result in a hazardous event shall be described. Whereby, malfunctioning behavior can be interpreted as deviation from the specified nominal behavior. Afterwards, hazardous scenarios, which include a combination of operational scenarios and malfunctioning behavior, will be rated using the automotive safety integrity level (ASIL). The parameters for the ASIL classification are the exposure of the operational scenario, the possible severity, and the controllability of the hazardous scenario. In order to determine these parameters, the description of hazardous scenarios must include the stationary surroundings (scenery) and all traffic participants which may interact with the automated vehicle.

2.1.2 Scenarios for verification and validation

During the test phase, it is examined whether the implemented system fulfils the requirements specified in the previous process steps. For this verification, the tests must be systematically planned, specified, executed, evaluated, and documented [12]. Each test case specification has to include the following information independently from the test method:

1) a unique identification
2) the reference to the work product to be verified
3) the preconditions and configurations
4) the environmental conditions
5) the input data including their time sequences
6) the expected behavior including acceptable variations

A very challenging aspect of the test case generation is the specification of input data. This data has to include time sequences of each parameter which is essentially affecting the behavior of the test object. At the same time, due to highly connected systems, the input data may not contain any inconsistencies, but rather represent a reliable scenario. Information regarding the operational environment of the system under verification as well as possible operating scenarios are already given in the item definition, which is specified during the concept phase of the development process according to the ISO 26262 standard. Based on this information, consistent input data can be derived for the specification of test cases. The scenarios used in the item definition are expressed by language and formulated on an abstract level of detail. To utilize these abstract scenarios within the scope of a test case, the scenarios have to be specified in detail and concretized. The detailed specification of scenarios can be performed within the scope of the specification of technical safety requirements [12]. The technical safety requirements describe how the item must react to external stimuli which can affect the compliance with the safety goals. In this way, the technical requirements also define for which parameter ranges the functionality of the system under development must be ensured. This parameter space must be tested during the verification process and thus has to be taken into account for the test case generation. In addition, the scenarios must be converted to a formal representation during the step of specifying the scenarios in detail. A formal representation is necessary, to ensure a reproducible test case execution later. The scenarios must define all parameters required for test case execution via different test methods (like simulation or field tests). Thus, in the step of specifying a scenario in detail, a conversion must be conducted from an informal description based on organized terms to a formal description based on physical system state values. To generate the input data included in a test case, discrete parameter values must be chosen from the continuous parameter ranges of a specified scenario in a concretization step.

Schuldt [14] proposed the use of equivalence classes, boundary value analysis, and combinatorial methods for identifying representative samples. This approach provided a systematic generation of test cases but lacks a method to determine a meaningful test coverage. For determining a meaningful test coverage, the test concept, the scenario selection, and the necessary test methods must be taken into account. The scenarios, which are systematically derived during the concretization step and then formally described, represent consistent input data for the item under test. Thus, the derived scenarios can be used in the scope of a test case for the verification of the implemented system. All in all, scenarios must fulfil the following requirements to be utilized during the testing phase (T) of the ISO 26262 standard: T1 Scenarios shall be modeled via concrete state values to ensure their reproducibility and to enable test methods to execute the scenario. T2 Scenarios shall not include any inconsistencies. T3 Scenarios shall be represented in an efficient machine-readable way to ensure an automated test execution. All these scenarios are being discussed in section 3.1 and its subsections.

2.1.2.1 *Functional scenarios*

Functional scenarios depict the most abstract level of scenario representations. These scenarios may be used for the item definition and the hazard analysis and risk assessment during the concept phase of the ISO 26262 standard. They are represented by language to ensure that human experts can easily understand existing scenarios, discuss them, and create new scenarios. In this deliverable we will follow the definition below: Functional scenarios include operating scenarios on a semantic level. The entities of the domain and the relations of those entities are described via a linguistic scenario notation. The scenarios are consistent. The vocabulary used for the description of functional scenarios is specific for the Use Case and the domain and can feature different levels of detail. The representation of functional scenarios on a semantic level includes a linguistic and consistent description of entities and relations/interactions of those entities. For the linguistic description a consistent vocabulary has to be defined. This vocabulary includes terms for different entities (vehicle A, vehicle B) and phrases for the relations of those entities (vehicle A overtakes vehicle B). The required level of detail of functional scenarios depends on the actual development phase and the item under development. Both aspects must be considered during the definition of the vocabulary. For example, a highway pilot requires a vocabulary to describe the road geometry and topology, interactions with other traffic participants, and weather conditions. On the contrary, a parking garage pilot requires a vocabulary to describe the layout of the building whereas weather conditions may be irrelevant. If a comprehensive vocabulary is used for the description of the entities and the relations of those entities, a large amount of scenarios can be derived from the vocabulary. For a generation of consistent functional scenarios, all terms of the vocabulary have to be distinct. Sources for terms that define the entities of a domain are, for example, actual standards and guidelines like road traffic regulations or the German standard for constructing motorways. Fig. 1 shows a functional scenario for a highway pilot on a two-lane motorway in a curve. A car and a truck are driving on the right lane of the road, whereby the car follows the truck. In this example, the road is described with a layout and a geometry. Depending on the item's Use Case and domain, the vocabulary must include additional terms to describe these characteristics like 'three-lane motorway' for layout, and 'straight' or 'clothoid' for geometry. The scenario can be varied by choosing other terms from the defined vocabulary.

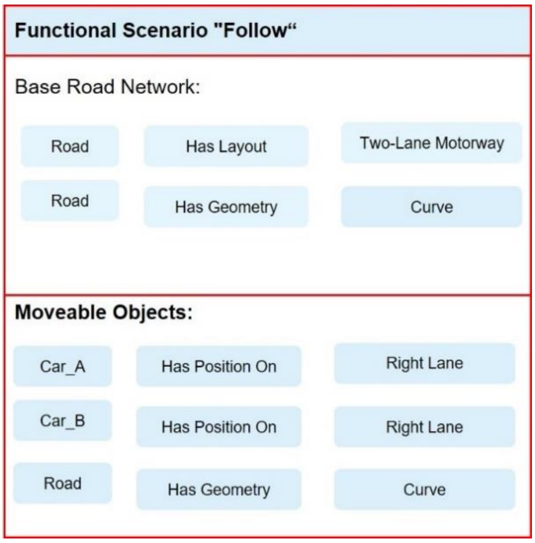

Figure 1: Functional scenario for a highway pilot on a two-lane motorway

2.2 Autonomous driving Use Case

2.2.1 Business goals

Many cars that are being sold today are already capable of some level of automated operation, and prototype cars capable of driving autonomously have been - and continue to be - tested on public roads in Europe, Japan and the United States. These technologies have arrived rapidly on the market and their future deployment is expected to accelerate. Autonomous driving promises many benefits: improved safety, reduced congestion and lower stress for car occupants, among others. Authorities will have to adapt existing rules and create new ones in order to ensure the full compatibility of these vehicles with the public's expectations regarding safety, legal responsibility and privacy. This report explores the strategic issues that will have to be considered by authorities as more fully automated and ultimately autonomous vehicles arrive on our streets and roads. It was drafted based on expert input and discussions amongst project partners in addition to a review of relevant published research and position papers.

Dedicated facilities are occasionally proposed for automated freeway vehicles, but retrofitting existing facilities is likely to be prohibitively expensive and may ultimately prove unnecessary. Separation may be more viable on newly constructed roadways in rapidly urbanising countries, on existing managed lanes (such as those for high-occupancy vehicles) between major employment and residential areas, and on specialised facilities serving exceptionally large numbers of trucks. Vehicle platoons are a particularly promising application for freeways. As typically envisioned, a platoon consists of two to six cars or trucks that are closely spaced and tightly coordinated through both vehicle-to-vehicle communication and some degree of automation. A driver may sit in each vehicle, in only the lead vehicle, or eventually in none of the vehicles. Benefits may include significant fuel savings and, for fleet operators, potentially lower labour costs. Vehicle automation systems and especially automated emergency intervention systems may also have early applications beyond freeways. Automation may be appropriate for low-speed travel during peak periods. Parking facilities may support automated valet functions. Also conventional cars, assigned to car sharing programmes might eventually reposition themselves by traveling at low speeds on particular roads during non-peak periods. Many urban and suburban applications, however, might be realised earlier through an "everything somewhere" strategy of nonconventional vehicles. Passenger shuttles and taxis might operate at low speeds in central business districts, corporate campuses, university campuses, military bases, retirement communities, resorts, shopping centres, airports, and other semi closed environments as well as for first and last-mile transit applications. Delivery shuttles might likewise travel at low speeds along particular routes and at particular times. Depending on their size and purpose, these robotic delivery systems might conceivably use pathways rather than or in addition to roadways. Indeed, the potential proliferation of service robots might bring a new kind of nonhuman user to the urban environment. Some of these urban applications may benefit from specialised infrastructure. Physical infrastructure might include vehicle-to-vehicle and vehicle-to-infrastructure communications equipment, ground-based units for global navigation systems, dedicated facilities comparable to bus and bicycle lanes, on-street parking restrictions, and specific roadway or pavement modifications. Digital infrastructure might include the maintenance of highly detailed roadway maps and pertinent traffic operations data. This specialised infrastructure, if required, could be limited to a manageable set of corridors actually used by a particular urban mobility system. Whereas wealthy consumers and fleet operators are likely to be early adopters of "something everywhere" vehicles, an "everything somewhere" approach might reach a more diverse group of users. Especially if its fuel and labour costs are lower and its usage is higher, an extensive urban mobility system might compare favourably with private vehicle ownership, conventional taxis, and conventional public transit. Residents who cannot afford to buy and maintain a private car or who are unable to drive may be some of the earliest adopters of these shared systems.

2.2.1.1 *Products and services*

Vehicle automation could give rise to consumer-oriented products and services. The "something everywhere" strategy for conventional cars and trucks is likely to rely primarily on a traditional model of selling and especially leasing vehicles to individual consumers or fleet operators. However, manufacturers are likely to be more closely connected to the owners and users of their vehicles through a variety of contractual and technical tools. These may include terms of use, end-user license agreements, and subscription agreements on the contractual side and advanced telematics, driver monitoring, and over-the-air updates on the technical side. Manufacturers might also pursue new revenue streams via automation subscription services, consumer-facing advertising, or the marketing of user data. In addition, companies other than car manufacturers may seek to add, enhance, or customise vehicle automation systems through aftermarket conversions and modifications. Production vehicles already provide a platform for many automated vehicle research efforts, at least one start-up company has announced its intention to add a partial automation feature to certain production vehicles, and legislatures in several US states have expressly limited a car manufacturer's civil liability for injuries caused by a third party's addition of automated driving technology to one of its production vehicles. An "everything somewhere" strategy could more fully embrace a variety of service models. Passenger shuttles, automated taxis, delivery services, and other urban concepts are likely to involve some kind of central ownership, management, maintenance, and dispatch. These services may be public, private, or hybridised, and they may complement or compete with conventional public transit.

2.2.1.2 *Current and future vehicle systems on Level 0 (no automation)*

- Systems beyond human capability to act:
  There are several systems on the market today that intervene beyond the human capability to act. These systems, like ABS (Anti-Lock System), ESC (Electronic Stability Control) and emergency braking are active safety systems that allow higher levels of automation and will facilitate deployment. Future version of these systems will include emergency evasion and emergency stopping.
- Lane Change Assist (LCA):
  The system monitors the areas to the left and right of the car and up to 50 metres behind it and warns the driver of a potentially hazardous situation by means of flashing warning lights in the exterior mirrors.
- Park Distance Control (PDC):
  The Park Distance Control system assists the driver to manoeuvre into tight spaces and reduces stress by communicating distance from obstacles by means of acoustic or, depending on vehicle, optical signals.
- Lane Departure Warning (LDW):
  Lane Departure Warning helps to prevent accidents caused by unintentional wandering out of traffic lanes. It represents a major safety gain on motorways and major trunk roads. If there is an indication that the vehicle is about to leave the lane unintentionally, the driver is alerted visually and in some cases by a signal on the steering wheel.
- Front Collision Warning (FCW):
  The Front Collision Warning monitoring system uses a radar sensor to detect situations where the distance to the vehicle in front is critical and helps to reduce the vehicle's stopping distance. In dangerous situations the system alerts the driver by means of visual and acoustic signals and/or with a warning jolt of the brakes. Front Collision Warning operates independently of the adaptive cruise control or automatic distance control.

2.2.1.3 *Current and future vehicle systems on Level 1 (driver assistance)*

- Adaptive Cruise Control (ACC):
  The cruise control system with "automatic distance control ACC" uses a distance sensor to measure the distance and speed relative to vehicles driving ahead. The driver sets the speed and the required time gap with buttons on the multifunction steering wheel or with the steering column stalk (depending on model). The target and actual distance from following traffic can be shown as a comparison in the multifunction display.
- ACC including stop-and-go function:
  Adaptive cruise control with stop and go function includes automatic distance control (control range 0–250 km/h) and, within the limits of the system, detects a preceding vehicle. It maintains a safe distance by automatically applying the brakes and accelerating. In slow-moving traffic and congestion, it governs braking and acceleration.
- Lane Keeping Assist (LKA):
  Lane Keeping Assist automatically becomes active from a specific speed (normally from around 60 km/h) and upwards. The system detects the lane markings and works out the position of the

vehicle. If the car starts to drift off lane, the LKA takes corrective action. If the maximum action it can take is not enough to stay in lane, or the speed falls below 60 km/h, the LKA function warns the driver, for instance with a vibration of the steering wheel. It is then for the driver to take correcting action.

- Park Assist (PA):
  The Park Assist function automatically steers the car into parallel and bay parking spaces, and also out of parallel parking spaces. The system assists the driver by automatically carrying out the optimum steering movements in order to reverse-park on the ideal line. The measurement of the parking space, the allocation of the starting position and the steering movements are automatically undertaken by Park Assist – all the driver has to do is operate the accelerator and the brake. This means that the driver retains control of the car at all times.

2.2.1.3.1 Urban mobility pathway

This pathway encompasses the types of initially low-speed, fully automated but limited operation vehicles that could be deployed in urban areas. Current high automation systems have been deployed in limited areas or on dedicated infrastructure. This will be the base for going to higher and higher vehicles speeds and perhaps less specific requirements on the infrastructure. Possible Use Cases include:

- Cyber cars, cyber vans, cyber minibuses:
  These are small-to-medium-sized automated vehicles for individual or collective transport of people or goods with the following characteristics: a) They are fully automated on demand transport systems that under normal operating conditions do not require human interaction; b) they can be fully autonomous or make use of information from a traffic control centre, information from infrastructure or information from other road users; c) they are small vehicles, either for individual transport (1-4 people) or for transport of small groups (up to 20 people); d) they can either use a separated infrastructure or a shared space.
- High-Tech Buses:
  These are buses on rubber wheels, operating more like trams than like traditional buses, with the following characteristics: a) They are vehicles for mass transport (more than 20 people); b) they use an infrastructure, which can be either exclusive for the buses or shared with other road users; c) they can use various types of automated systems, either for guidance or for driver assistance; d) they always have a driver, who can take over control of the vehicle at any time, allowing the vehicles to use the public road.
- Personal Rapid Transit (PRT):
  This is a transport system featuring small fully automatic vehicles for the transport of people, with the following characteristics: a) PRT systems operate on its own exclusive infrastructure, so there is no interaction with other traffic; b) they are fully automated systems that under normal operating conditions do not require human interaction; c) they are small with a capacity usually limited to 4 to 6 persons per vehicle; d) PRT offer on-demand service, where people are transported directly from origin station to destination station without stopping at intermediate stations, without changing vehicles and ideally without waiting time.
- Advanced Urban Cars (AUC):
  New city vehicles integrating zero or ultra-low pollution mode and driver assistance such as ISA (Intelligent Speed Adaptation), parking assistance, collision avoidance, stop-and-go function, etc. These vehicles should also incorporate access control coupled with advanced communications in order to integrate them easily into car-sharing services.

- **Dual-mode vehicles:**
  Developed from traditional cars but able to support both fully automatic and manual driving. The first applications of automatic driving will be for relocation of shared cars using platooning techniques, but dual-mode vehicles could become full cyber cars in specific areas or infrastructures. They represent the migration path from traditional cars to automatic driving.

2.2.1.3.2 Automated private vehicle pathway

Figure 2 illustrates a potential pathway for the automation of private individually owned vehicles. This pathway leads from existing commercially-deployed systems to a fully self-driving car in incremental steps.

- **Automated Parking Assistance:**
  Automated parking assistance is available on the market today.
- **Park Assist (Level 2):**
  Partial automated parking into and out of a parking space in a public or private parking area or garage. The process is initiated remotely, e.g. via smartphone or adapted remote key. The vehicle carries out the manoeuvre by itself. The driver can be located outside of the vehicle but has to monitor the system and can stop the parking manoeuvre if required.
- **Parking Garage Pilot (Level 4):**
  Highly automated parking including manoeuvring to and from parking place (driverless valet parking). In parking garages, the driver does not have to monitor the operation and may leave once the system is active. The process is initiated remotely, for instance via a smartphone or an adapted remote key.
- **Traffic Jam Assist (Level 2):**
  The function controls the forward/backward and sideways movement of the vehicle in order to follow traffic flow in low speeds below 30 km/h. The system can be seen as an extension of the ACC with stop-and-go functionality.
- **Traffic Jam Chauffeur (Level 3):**
  Conditional automated driving in congested conditions up to 60 km/h on motorways and motorway-like roads. The system controls the forward/backward and lateral movements of the vehicle up to the threshold speed. The driver must deliberately activate the system, but does not have to monitor the system constantly. The driver can always override or switch the system off. There is no take over request to the driver from the system.
- **Highway Chauffeur (Level 3):**
  Conditional automated driving up to 130 km/h on motorways or motorway-like roads. The Highway Chauffeur operates from entrance to exit, on all lanes, including overtaking movements. The driver must deliberately activate the system but does not have to monitor it constantly. The driver can always override or switch off the system. The system can request the driver to take over within a specific time, if automation reaches the system limits.
- **Highway Pilot (Level 4):**
  Automated driving up to 130 km/h on motorways or motorway-like roads from entrance to exit, on all lanes, including overtaking movements. The driver must deliberately activate the system but does not have to monitor it constantly. The driver can always override or switch off the system. There are no requests from the system to the driver to take over when the system is in its normal operation area on the motorway. Depending on the deployment of vehicle-to-vehicle communication and cooperative systems, ad-hoc convoys of vehicles (platoons) could also be created.
- **Fully automated private vehicle (Level 5):**
  The fully automated vehicle should be able to handle all driving from point A to B, without any input from the passenger. The driver can always override or switch off the system. No consensus exists as to when such systems will become commercially available.

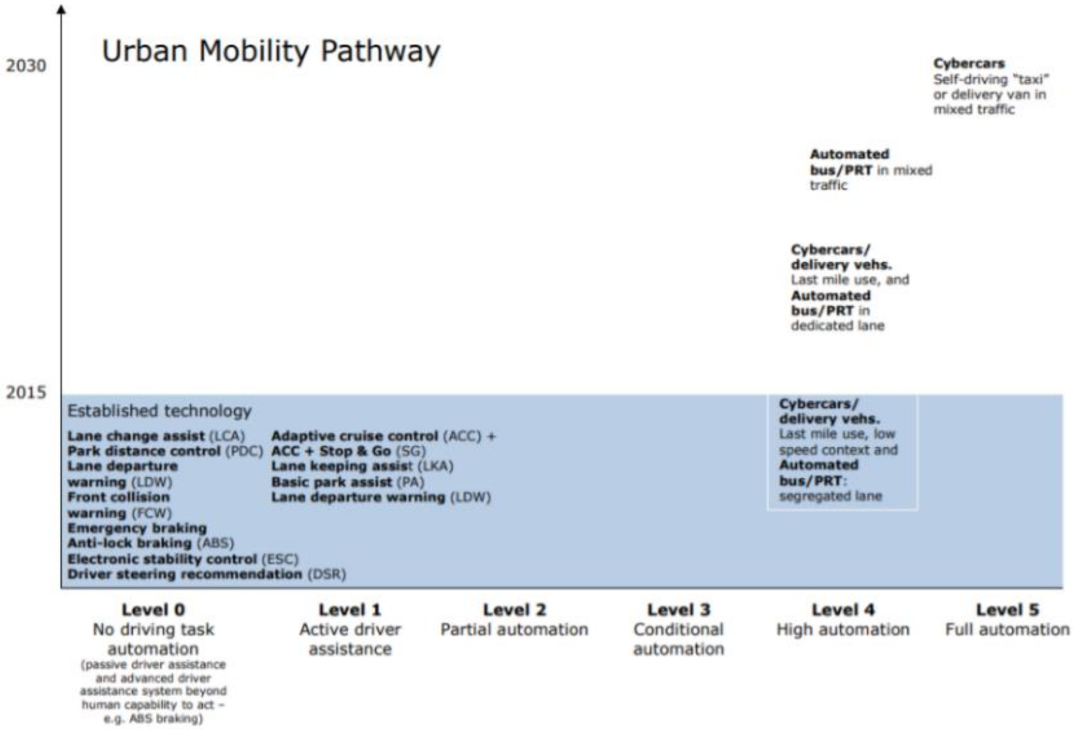

Figure 2: Urban mobility pathway from human to fully automated driving

2.2.2 Technological context

It should be noted that given the emerging and highly competitive nature of Automated Driving Systems (ADS) technology, it is inherently difficult to obtain explicit and complete information about the intended Operational Design Domain (ODD) of an ADS feature as illustrated in Figure 3. In the absence of information about an ODD, engineering judgement was used at times to define the ODD taxonomy and identify the ODD for concept ADS features.

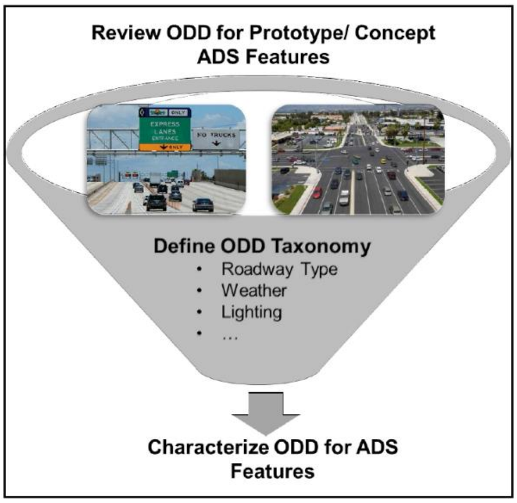

Figure 3: The ODD Prototype Concept

An ODD may include one or more driving modes, as shown in Figure 4. For example, a given ADS may be designed to operate a vehicle only on fully access-controlled freeways and in low-speed traffic, high-speed traffic, or in both driving modes.

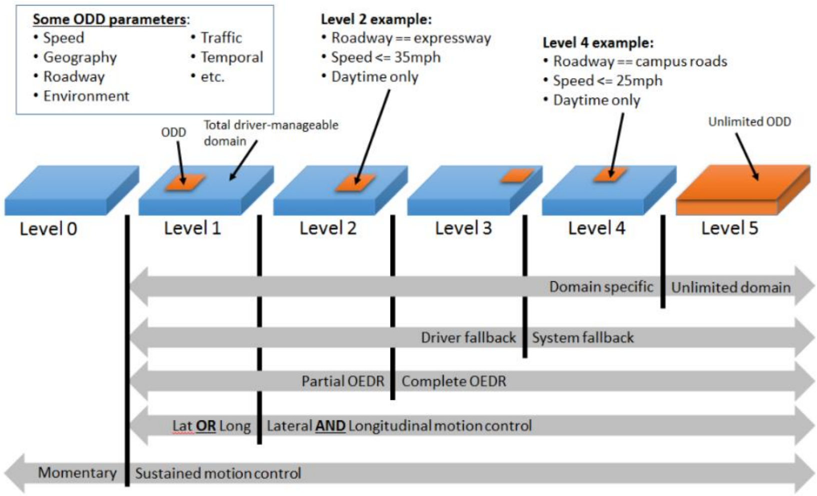

Figure 4: The ODD Defining Process

The operational design domains proposed in SAE 2016 are overly broad and do not adequately reflect the myriad of subdomains a vehicle may be required to enter and exit in the course of a single route within an overall domain.

2.2.2.1 *Guiding Principles*

Several guiding principles were developed based on the literature to identify and characterize the ODDs:

- Need for an ODD taxonomy – A large variety of ODD dimensions exist, and a structure is needed to organize categories and facilitate discussion of system requirements, capabilities and testing.
- Account for variations in operational environments – ODDs may vary in nature. Some can be predetermined (e.g., roadway type), while others change in time (e.g., traffic conditions). Some can be divided into discrete categories (e.g., signage), while others vary along a continuous scale and may be difficult to quantify (e.g., rain, light, fog).
- Define what constitutes "operational scenario" – An operational scenario is described in part by a set of ODD characteristics that describe the environment in which the feature is designed to perform.
- Identify ODD boundaries – ODD defines where the ADS can and cannot operate. ODD limits may vary by sub-trip or operational scenario due to confounding variables (e.g., weather and illumination), non-deterministic software, design and testing, etc. [16].
- Identify Current ODD State (Self-Awareness) – An ADS feature should be able to identify whether it is within the ODD and detect and respond to system engagement and disengagement restrictions. This may include identifying transitions between certain ODD states (e.g., roadway type).

2.2.2.2 *Defining an ODD Taxonomy*

While the literature provided many examples of ODD elements, no classification framework was identified. This work takes an initial step towards developing a taxonomy to organize the many ODD elements identified in research. This ODD taxonomy takes the form of a hierarchy of categories and subcategories, each with definitions and, where appropriate, gradations. This taxonomy is meant to be descriptive, not normative, as it is envisioned that these elements may be organized into several different groupings. The taxonomy offers a structured approach to organize and identify various ODDs for ADS features, especially when there are several different possible combinations. Figure 5 shows the broad range of top-level categories and immediate subcategories.

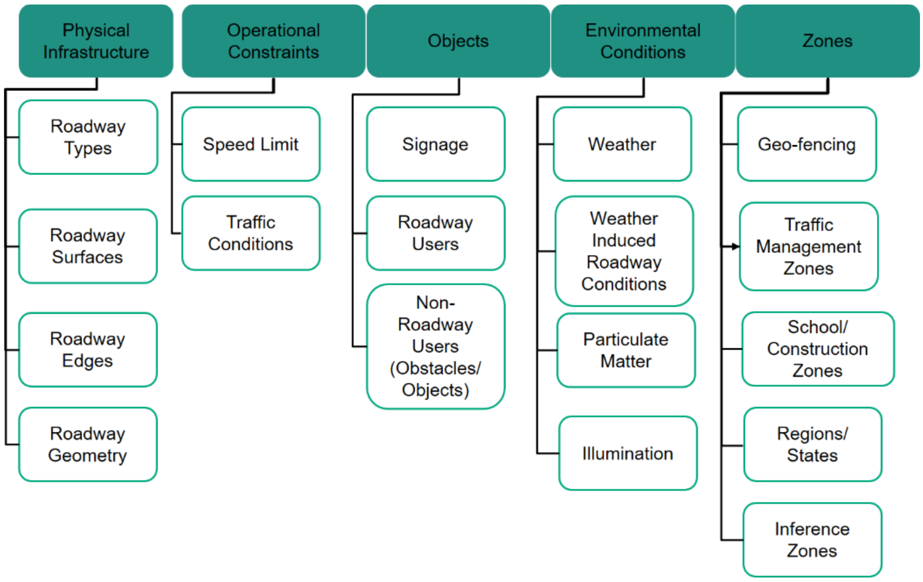

Figure 5: ODD Classification Framework with Top-Level Categories and Immediate Subcategories

The hierarchy extends into multiple sublevels, as shown in Figure 6. The "Environmental Conditions" category was divided into four subcategories: weather, illumination, particulate matter, and road weather. Weather is further subdivided into rain, temperature, wind, and snow. For this research project, it was helpful to further subdivide rain into gradations to capture the data that were collected on ADS features. For example, some ADS features had been tested in light rain, while others had been tested in heavy rain. Although the application of this taxonomy has been useful in the context of this research project, further research and stakeholder engagement would be beneficial in refining and objectively quantifying the categories and gradations.

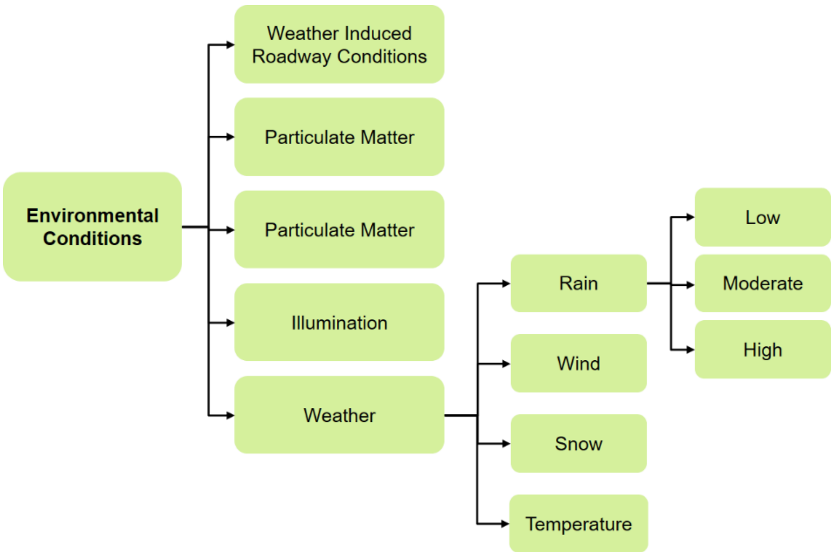

Figure 6: Example of Hierarchical Levels in the Environmental Conditions Category

2.2.2.3 *ODD CATEGORY DESCRIPTIONS*

Physical Infrastructure

Physical infrastructure refers to facilities and systems that serve a country, city, or area and enable its economy to function. Physical infrastructure is typically characterized by technical structures, such as roads, bridges, tunnels, water supply, sewers, electrical grids, telecommunications, etc., that are for the most part interrelated. ADS features may depend on such infrastructure elements, which are a critical part of the ODD environment. Subcategories of the main physical infrastructure elements are listed below [39].

Roadway Types

- Divided highway, undivided highway, arterial, urban, rural, parking, multi-lane, single lane, high-occupancy vehicle (HOV) lane, on/off ramps, emergency evacuation routes, one-way, turn-only lanes, private roads, reversible lanes, intersections (signaled, U-turns, 4-way/2-way stop, roundabout, merge lanes, turn-only lanes, crosswalk, toll plaza, railroad crossing)[17].

Roadway Surfaces

- Asphalt, concrete, mixed, grating, brick, dirt, gravel, scraped road, partially occluded, speed bumps, potholes, grass [18].

Roadway Edges

- Line markers, temporary line markers, shoulder (paved or gravel), shoulder (grass), concrete barriers, grating, rails, curb, cones [19].

Roadway Geometry

- Straightaways, curves, hills, lateral crests, corners (regular, blind corners), negative obstacles, lane width [20].

Operational Constraints

There are several operational constraints that need to be considered when designing and testing ADS applications. These include elements such as dynamic changes in speed limits, traffic characteristics, construction, etc. For example, an ADS entering a school zone is subjected to lower speed limits and must respond appropriately to ensure the safety of its passengers and other road users. Some examples of the operational constraints are listed below.

Speed Limit

- Minimum and maximum speed limit (absolute, relative to speed limit, relative to surrounding traffic).

Traffic Conditions

- Minimal traffic, normal traffic, bumper-to-bumper/rush-hour traffic, altered (accident, emergency vehicle, construction, closed road, special event).

Objects

For an ADS to properly navigate within an ODD, it must detect and respond to certain objects. For example, a pedestrian may be expected at an intersection but rarely on a freeway.

Signage

- Signs (e.g., stop, yield, pedestrian, railroad, school zone, etc.), traffic signals (flashing, school zone, fire department zone, etc.), crosswalks, railroad crossing, stopped buses, construction signage, first responder signals, distress signals, roadway user signals, hand signals [17].

Roadway Users

- Vehicle types (cars, light trucks, large trucks, buses, motorcycles, wide-load, emergency vehicles, construction equipment, horse-drawn carriages/buggies), stopped vehicles, moving vehicles (manual, autonomous), pedestrians, cyclists [21].

Non-roadway User Obstacles/Objects

- Animals (e.g., dogs, deer, etc.), shopping carts, debris (e.g., pieces of tire, trash, ladders), construction equipment, pedestrians, cyclists.

Environmental Conditions

Environmental conditions play a crucial role in the safe operation of a variety of ADS applications, and pose one of the biggest challenges to deployment, particularly early deployment. The environment can impact visibility, sensor fidelity, vehicle manoeuvrability, and communications systems. Today, ADS technologies are tested most often in clear, rather than adverse, weather conditions. On average, there are over 5.7 million vehicle crashes each year. Approximately 22 percent of these crashes—nearly 1.3 million—are weather-related [22]. Weather-related crashes are defined as crashes that occur in adverse weather (i.e., rain, sleet, snow, fog, severe crosswinds, or blowing snow/sand/debris) or on wet, snowy, or icy pavement. Weather acts through visibility impairments, precipitation, high winds, and temperature extremes to affect driver capabilities, vehicle performance (i.e., traction, stability and maneuverability), pavement friction, roadway infrastructure, crash risk, traffic flow, and agency productivity [23]. It is thus important to consider a variety of environmental conditions as part of the ODD.

Weather

- Wind, rain, snow, sleet, temperature.
- On freeways, light rain or snow can reduce average speed by 3 to 13 percent. Heavy rain can decrease average speed by 3 to 16 percent. In heavy snow, average freeway speeds can decline by 5 to 40 percent. Free-flow speed can be reduced by 2 to 13 percent in light rain and by 6 to 17 percent in heavy rain. Snow can cause free-flow speed to decrease by 5 to 64 percent. Speed variance can fall by 25 percent during rain [24].

Weather-induced Roadway Conditions

- Standing water, flooded roadways, icy roads, snow on road.
- Capacity reductions can be caused by lane submersion due to flooding and by lane obstruction due to snow accumulation and wind-blown debris.

Particulate Matter

- Fog, smoke, smog, dust/dirt, mud.
- Low visibility can cause speed reductions. Visibility distance is reduced by fog and heavy precipitation, as well as wind-blown snow, dust, and smoke. Low-visibility conditions cause increased speed variance, which increases crash risk.

Illumination

- Day (sun: overhead, back-lighting, and front-lighting), dawn, dusk, night, street lights, headlights (regular and high-beam), oncoming vehicle lights (overhead lighting, back-lighting, and front-lighting).

Connectivity

Connectivity and automation are increasingly being integrated into cars and trucks with the objective of improving safety, mobility, and providing a better driving experience. Connectivity is an enabling technology that may define where an ADS feature can operate. For example, low-speed shuttles may depend on traffic light signal phase and timing messages to reduce the dependence on sensors alone to detect the signal. Connectivity constitutes a communications link between other vehicles, road users, remote fleet management operators, and physical and digital infrastructure elements. Some of these elements are described below.

Vehicles

- V2X communications (e.g., DSRC, Wi-Fi), emergency vehicles.

Infrastructure Sensors and communications

- Work zone alerts, vulnerable road user, routing and incident management, GPS, 3-D high-definition maps, pothole locations, weather data, data on the cloud, etc.

Zones

- ADS features may be limited spatially by zones. The boundaries of these zones may be fixed or dynamic, and conditions that define a boundary may be based on complexity, operating procedures, or other factors. One example is work zones, which can confuse ADS as the road configuration (pavement markings and new lane alignments) differs from typical conditions. In a work zone, cones may replace double yellow lines, bollards may replace curbs, and construction worker hand signals may overrule traffic lights. These cues designed for human drivers can challenge advanced computer systems.

Geo-fencing

- Central business districts, school campuses, and retirement communities (for example, CityMobil2 is fixed route and includes < 20 mph [15] routes both on-road and off-road on pedestrian walkways).

Traffic Management Zones

- May include temporary lane closures, dynamic traffic signs, variable speed limits, temporary or non-existent lane markings, human-directed traffic, loading/unloading zones.

School/Construction Zones

- Dynamic speed limit, erratic pedestrian and vehicular behaviors.

Regions/States

- Any legal, regulatory, enforcement, tort, or other considerations (e.g., following distance, licensing, etc.).

Interference Zones

- Tunnels, parking garages, dense foliage, limited GPS due to tall buildings, atmospheric conditions.

2.2.3 User needs and expectations

Autonomous vehicle (AV) research is an area of great public interest at present, and vehicles with limited autonomous functionality are starting to be deployed around the world. Autonomous functionality is appearing in currently available consumer vehicles (such as assisted braking and Tesla autopilot [25]), but there is little evidence to suggest that users desire the widespread use of autonomous vehicles; in fact, there is some evidence to the contrary [26]. Most existing studies of public perception of AVs do not use established models of User Acceptance (UA). They are therefore difficult to make comparisons between or interpret in terms of UA [27][28][29][30]. These surveys often use industry descriptions of 'Levels of Autonomy' which may not be clear to participants, and which vary greatly between studies. The Autonomous Vehicle Acceptance Model (AVAM) combines elements of generic technology acceptance models, car acceptance models, and levels of autonomy. Rather than assessing levels of autonomy directly as defined by SAE [32] (one of the more widespread current representations of autonomy levels) concrete examples of vehicles relating to each level are presented. This enables participants to more clearly visualise hypothetical technologies, something which may have resulted in less informed responses in previous studies where scenarios/vehicles are not clearly explained [27][28][29][30].

Autonomous driving could, among other benefits, lead to better inclusion of mobility impaired transport users (that are not able or allowed to drive a car today) by providing cost-efficient, flexible 'on-demand' access to individual motor car traffic that does not require a conventional driver's license. Among a variety of advanced autonomous driving functions that execute navigation as well as longitudinal and lateral control of the vehicle, a variety of 'special features' for autonomous vehicles beyond that are conceivable – e.g. medical and emergency monitoring – that meet specific needs of the mobility-impaired. Certainly, a whole series of questions in this relation is currently unanswered, among them, for example, whether legal driving requirements have to be amended to enable people that are currently not allowed to drive a car could use an autonomous vehicle, or whether only level 5 systems [22] could be given approval for people without conventional driver's licenses. At present, it is hardly foreseeable when (or if) humans in autonomous vehicles will be let off the hook completely. Altogether, the assumption that the mobility-impaired could greatly benefit from autonomous driving has to be considered in a more differentiated way in future. The mobility-impaired do not form a homogeneous group with specific needs and requirements. In fact, different impairments in different age groups, living environments, social classes, etc. require different solutions to meet the mobility needs of these transport users – certainly not only technological ones.

2.2.3.1 *Autonomous Vehicles and Taxonomies of Automation*

Features that can be considered low-level autonomy, such as cruise control and automatic parking, are already technically viable and commercially available. Some leading commercial examples of high-level automation projects include General Motors' Cruise Automation [33], Waymo from Google [34] and the highly publicized Autopilot from Tesla [25]. Many car manufacturers are also incorporating increased levels of autonomous functionality in their vehicles, as well as actively researching high-level autonomy [35][36][37]. More restricted autonomous vehicles confined to specific geographic regions, dubbed automated road transport systems, have also been piloted in a number of cities in Europe; examples include the City-Mobil2 [15] and UK Auto-drive [38] projects. The NHTSA [39] and BASt [40] are two categorizations of AV developed by the US and German governments respectively. These have largely been consolidated into the SAE definition of six distinct levels of autonomy (Levels 0-5) [39]. These levels are intended to be precisely defined categories ranging from no automation to full automation. The categories are defined in terms of the agent responsible for the driving task—the human driver, or the automated driving system—as well as subtasks such as object and event detection and response. While useful for the designers of autonomous vehicles, the SAE definitions can be unclear or even confusing from a user perspective [41]. Since user acceptance of vehicles depends strongly on their understanding of the autonomous functionality present in a vehicle, we argue that it is important to take a user-centered approach in such a definition. A user-centered categorization of AVs will be critical in presenting meaningful descriptions of AVs to users in the future.

2.2.3.2 *Models of User Acceptance*

Various generic models for user acceptance of technology have been developed. These help to quantify the acceptance of various technologies and enable easy comparison within a common framework. The Technology Acceptance Model (TAM) [42] was first described in 1989 and was subsequently expanded to form the TAM2 [43] in 2000. These models heavily influenced the 2003 Universal Theory of Usage and Acceptance of Technology (UTAUT) [44]. The UTAUT unified many existing models of user acceptance, aiming to explain users' intention to use a system and their subsequent usage behavior. There are four key factors within this model:

(1) Performance expectancy, the degree to which an individual believes using the system will aid them.
(2) Effort expectancy, the degree of ease associated with the system.
(3) Social influence, the degree which an individual believes others think they should use the system.
(4) Facilitating conditions, the degree to which an individual believes there is organizational and infrastructural support for the system.

Four further factors make up the remainder of the UTAUT:

(5) Attitude towards using technology, an individual's overall affective reaction upon using a system.
(6) Self-efficacy, a user's belief in their own ability and competence to use the technology.
(7) Behavioral intention, the degree to which the user intends to use the system.
(8) Anxiety, the degree to which a person responds to a situation with apprehension.

The UTAUT factors can be applied almost directly to user perception of autonomous vehicles. For example, the different autonomy levels can be compared in terms of users' effort expectancy (a highly autonomous vehicle might require lower effort to drive), or infrastructure tailored to autonomous vehicles may create facilitating conditions where users are more accepting of higher autonomy levels. The Car Technology Acceptance Model (CTAM) [45] was designed specifically for cars. It introduces one additional factor over and above the eight UTAUT factors:

(9) Perceived safety, the degree to which an individual believes that using a system will affect their well-being.

This factor is not relevant to the more general models aimed primarily at desktop software but is critical for vehicles. CTAM questions are worded to focus particularly on in-car technology, rather than whole car technologies such as AV. These models provide a strong basis for assessing UA but are not directly applicable to AVs. Our model, the AVAM, incorporates these nine key factors of UA into a questionnaire worded specifically for evaluation of AVs.

2.2.3.3 *Studies on the Acceptance of Autonomous Vehicles*

Several studies have investigated public perception of various available autonomous driving technologies, as well as those predicted to become available in the future. Most of these use questionnaires, but do not incorporate formal models that distinguish factors related to user acceptance and experience. International surveys have been conducted but relied on participants conceptualizing the established levels of autonomy [32] based on brief descriptions [27][28][29][30]. Others only used questions with a binary agree/disagree response for a constrained set of statements [46].

2.2.3.4 *The Autonomous Vehicle Acceptance Model (AVAM)*

The AVAM is an adaptation of the UTAUT [44] and CTAM [45] for autonomous vehicle technologies. It incorporates the eight complete factors of the UTAUT—Performance Expectancy, Effort Expectancy, Attitude Towards Technology, Social Influence, Facilitating conditions, Self-Efficacy, Anxiety and Behavioral Intention (to use the system)—as well as one factor introduced by the CTAM [45], Perceived Safety. As in the CTAM, we propose that Anxiety, Self-Efficacy, Attitude Towards Technology and Perceived Safety are direct determinants of Behavioral Intention to use AVs, unlike the UTAUT where only Performance Expectancy, Effort Expectancy and Social Influence are considered as such. The motivation for the inclusion of these additional factors for technologies relating to cars is given by Osswald et al. [45]. A block diagram of the AVAM is shown in Figure 7. Adapting the AVAM from these established models of UA provides a degree of implied validity. While the UTAUT was not developed with AV in mind, the model itself has been validated comprehensively, adapted and applied effectively to a variety of technologies, and been shown to be effective for measuring UA of some AVs [49]. Clearly, the constructs within such a model are transferable to the AV domain, but a standardized adaptation is of critical importance.

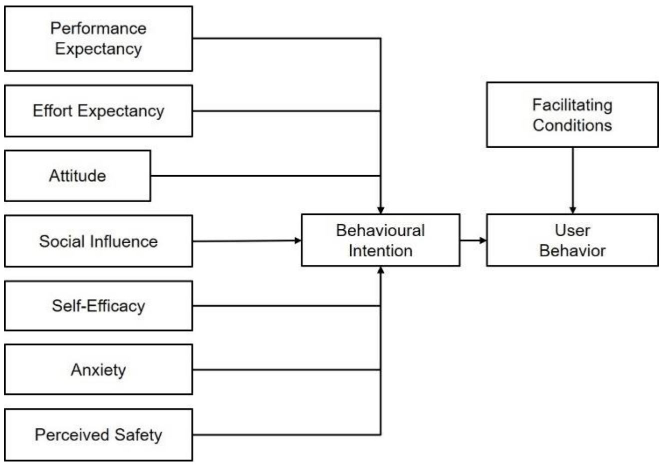

Figure 7: Block diagram of constituent factors of the AVAM

2.2.3.5 *Willingness to Use Autonomous Vehicles*

To gain insights into aspects of acceptance towards autonomous driving, surveys typically record whether their respondents are willing to use an autonomous vehicle. However, the results sometimes differ quite significantly from each other. As already mentioned above, these differences could be ascribed to the fact that autonomous driving is labelled in diverse ways. On the other hand, the results rarely point towards the challenge that a general understanding about autonomous driving, a "general consensus", so to say, does not exist to date, thus making it difficult to assess attitudes and valuations at all – for more details on this topic, see section Autonomous driving – a topic worth noting? as well as Fraedrich and Lenz [38]. Although we could not solve the problem that today's users of the transport system do not have any real-life experience with autonomous vehicles and sometimes only a very marginal knowledge, the discrimination into specific Use Cases facilitated a more differentiated view of how the technology is evaluated by the respondents.

Sociodemographic aspects, actual mobility behaviour, attitudes towards the car, and needs hardly played any significant role to explain the willingness to use an autonomous vehicle – with only a few notable exceptions, as it is described below. In contrast to this the stated willingness to give up specific driving functions and operations to a machine did very well. Respondents who were willing to delegate speed regulation, parking, braking, steering, gear changing, vehicle guidance, pedestrian detection, and vehicle stabilization were also more likely to agree on the potential option to use an autonomous vehicle. When correlated with sociodemographic aspects, the willingness to use an autonomous vehicle only showed significant results in a few cells, and the strength of the correlations was mostly non-existent. Among all the Use Cases, a few notable exceptions for Vehicle on Demand could give interesting hints on how autonomous driving is perceived and evaluated specifically. Being male, having a higher educational background, a higher income, and living in a larger household showed significant influence on the willingness to use Vehicle on Demand. Combined, these aspects seem to correspond well with rather 'typical' characteristics of the so-called 'early adopters' of (mobility) technologies. This points towards the assumption that Vehicle on Demand – potentially more than the other Use Cases introduced in the survey – is seen as tech gadget, thus requiring the tech-savvy users, at least in the first instance. However, in this examination, only univariate analyses were conducted; multivariate analysis could give further information about the interrelations here.

2.2.3.6 *Willingness To Replace Transport Modes*

A question in the first section of the survey addressed the general willingness of respondents to replace their currently preferred mode of transport with an autonomous vehicle, which at this time was not further specified. In a later section of the survey, the respondents were confronted with the question again – this time in relation to a specific Use Case. In summary, and throughout all Use Cases, it becomes clear that specifically a rejecting and therefore sceptical attitude towards autonomous driving increased when it was made more explicit what is meant by such a vehicle.

2.2.3.7 *Emotional responses Towards Autonomous Driving Use-Cases*

Theoretical and empirical research suggests that trust and the intention to use technological innovations such as autonomous vehicles depend on certain attitudes and emotions of users. According to social-psychological frameworks, adoption behaviour results from intentions that are a function of attitudes associated with an object. Attitudes in turn are based on users' related beliefs and feelings. People's cognitive beliefs towards familiar choice options are built on factual information about and earlier experiences with objects. However, in the case of unfamiliar technological innovations where earlier experiences are not available yet, people tend to base their attitudes more on emotional responses [48]. Thus, perceived affects towards autonomous vehicles offer added explanatory and predictive value for the overall attitudes and future behavioural intentions.

2.2.4 Use-case scenarios and Methodology for building secure InterComm Module

To smoothly driving the autonomous vehicle or any ADS, it is essential to have reliable and latency-sensitive networking communication within the overall environment. So that it could help to properly sync between traffic administrator, car owners and service provider for efficiently manage and securely drive the autonomous vehicles. Notably, for addressing some sudden events, avoiding any kind of collisions and find the traffic-less path, it is essential to quickly update/download some software or firmware version or HD Map to the ADS. Thus, for satisfying the low-latency and reliable communication between the service provider and ADS, we have envisioned the LightEdge-powered MEC server [63], which would ensure to bring the cloud facilities near to the end-users by enhancing the end-to-end (E2E) network resources slicing for successfully performing the commissioning/decommissioning of various firmware and software to the ADS and offering better services to address various critical events. Even deploying LightEdge to the system can help to offer better service experiences for providing various kind of infotainment facilities (i.e., video streaming, game streaming, etc.).

However, before building the secure, reliable and latency-sensitive communication model, it is essential to understand the use-case scenarios where an ADS or autonomous vehicle could pass through. Mainly, an ADS or autonomous vehicle can drive within the city, where the high networking facilities are already available; or it can move through a remote area where it can barely communicate with the service provider through the cellular networking facilities. In the following subsections, we briefly explained both use-case scenarios with some diagrams. Eventually, discussing the use-case scenarios could help us to understand the structure of the overall communication model.

2.2.4.1 *Use-case scenarios:*

a) **ADS within the local scope:** In the first use-case scenario, we found that ADS can move around within a city or strong observation area, where many road-side units (RSUs) are deployed to monitoring the traffic state and exchanging some simple messages (e.g., warning message) between vehicles and infrastructure. Whereas individual ADS (cars) using the PC5 interfaces can establish the V2V communication between them. Notably, using the Uu interface and network node (i.e., cellular tower), ADS can be able to establish communication with the nearest Light-Edge empowered MEC server. Interestingly, making a connection with the LightEdge can ensure to get better E2E slicing facilities for the ADS, and facilitate to run various network services close to the vehicles, for addressing different mission-critical events (i.e., car collision). In Figure 8: ADSs passing through the city, we have depicted the scenario. In that figure, we have considered a small piece of code/software (i.e., Agent) essentially needs to be installed in each ADS (i.e., Cars). Importantly, the Agent will enable the facilities for securely identifying the individual ADS.

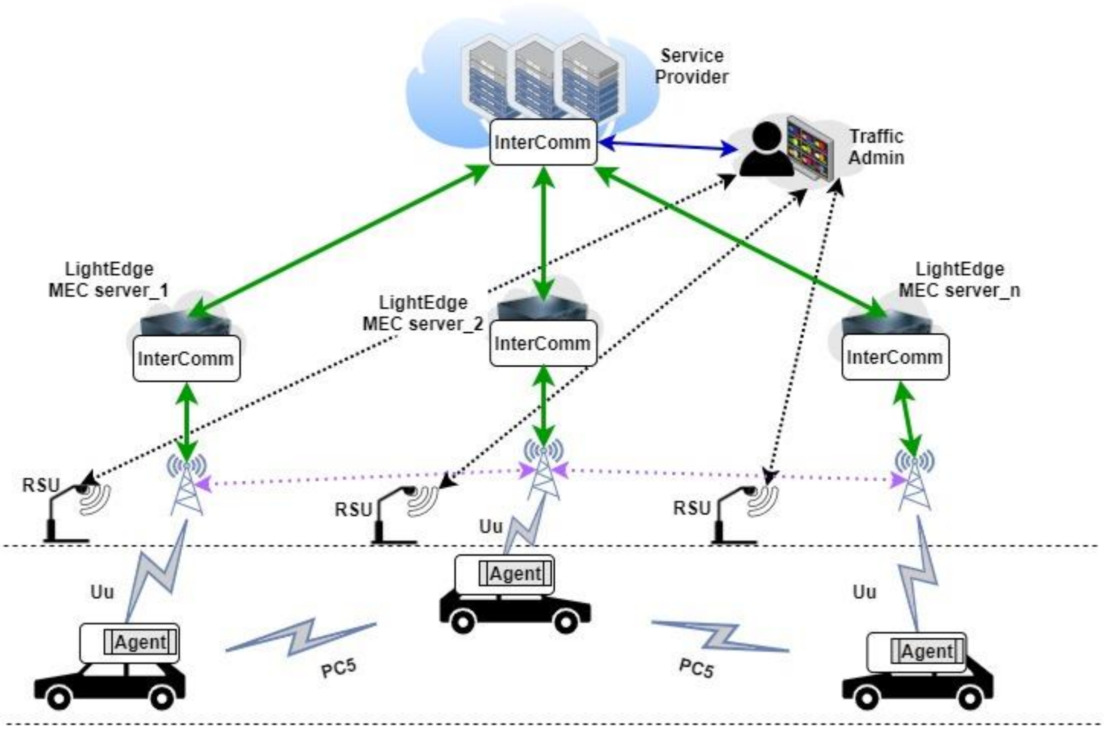

Figure 8: ADSs passing through the city

b) **ADS within the remote area:** Interestingly we found that ADS can move through a remote area, where no Edge server is available near to it. However, in that case, two scenarios may happen. In the first case, ADS can move through a path, where RSUs are already deployed to follow and surveillance the traffic. Whereas, in the second case the ADS can pass through a completely remote area, where neither RSUs nor MEC servers are available. In both cases, ADS (i.e., Cars) can communicate with the service provider using cellular communication technology. However, using the PC5 interface the ADS can communicate with other ADS for transmitting some warning message. For the sake of better understanding, we have already depicted both use-case scenarios in Figure 9.

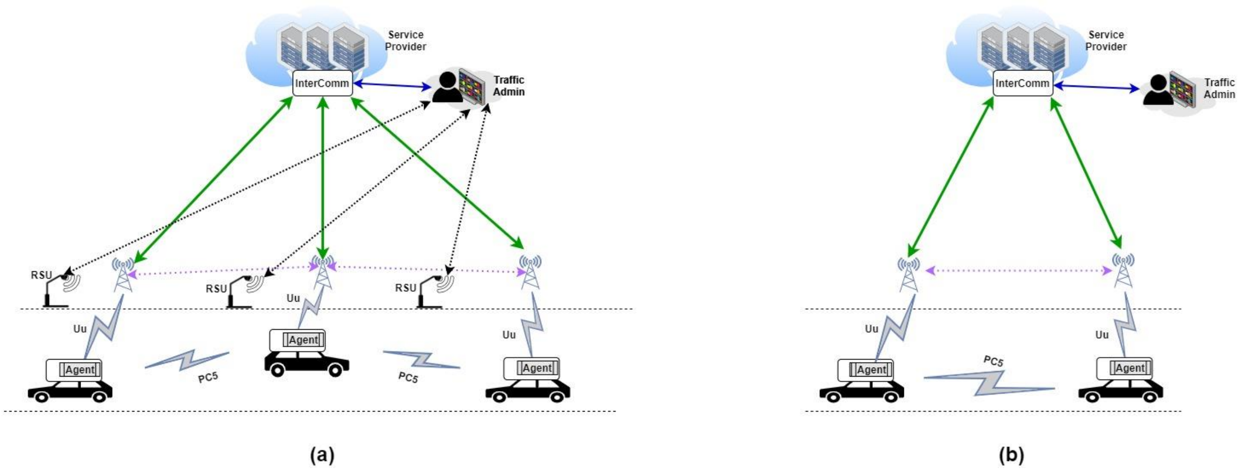

Figure 9: (a) ADS passing through a semi-remote area; (b) ADS passing through complete remote area

2.2.4.2 *Methodology for developing Intercommunication model:*

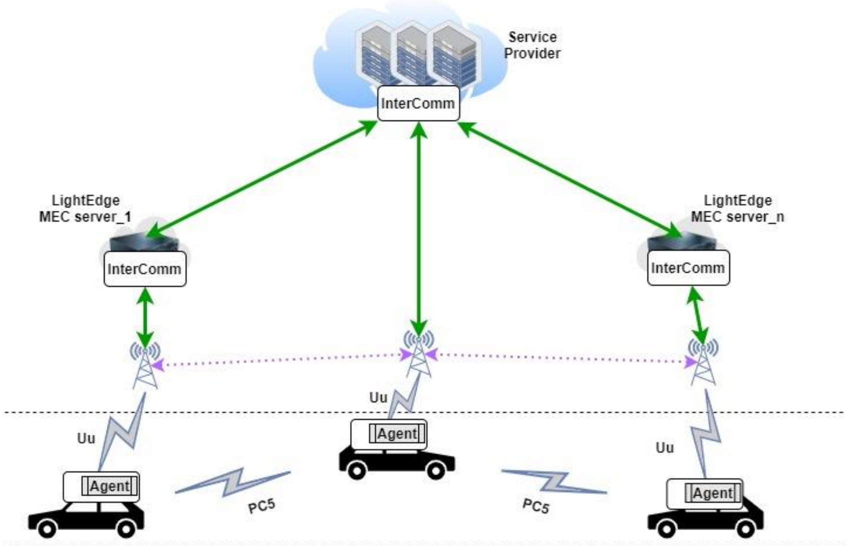

Figure 10: Simplified diagram of our LightEdge empowered agent-based intercommunication model

In Figure 10, we have already simplified our overall proposal for developing the LightEdge empowered agent-based intercommunication model. Importantly, in that figure, we have introduced a new component named 'InterComm' module. The core of this module will be constituted based on the SDN and NFV concept. Significantly, with the help of the InterComm module, it is possible to ease the whole process for ensuring the E2E slicing and offer better service facilities among the ADSs. Notably, deploying the LightEdge empowered MEC server can provide a huge advantage to the existing system.

As the LightEdge offering the ETSI-compliant MEC solution for existing 4G and 5G networks, therefore it can help to the ADS to smoothly access the 5G core facilities. Also, deploying the LightEdge empowered MEC server in the system can help to reduce the service latency for providing the mission-critical services (i.e., software/firmware update, emergency breaking, etc.).

LightEdge empowered server does not only ensure to offer better service facilities for addressing various mission-critical events but also to improve the journey of the passengers it can offer better service facilities for running different infotainment applications (e.g., video streaming, online gaming, etc.) in the ADS. However, in some cases, for offering better service facilities among the end-users, it may require effective scaling the network resources of the MEC layer as well as the centralized core layer. Thus, to address this issue and successfully design network resource scaling mechanism, we will constitute our research work within the scope of this project. i2CAT plans to emulate the same kind of use case scenarios by using some standardize emulation tools (i.e., TATA ELXSI V2X [64]). The primary focus of our future research work is to define an intelligent mechanism for scaling the networking resources effectively for offering better service facilities among the end-users, without comprising the QoS factors. Thus, for developing such an intelligent mechanism we are planning to adopt the federated learning concept. Adopting the federated learning concept will not only help us to bring the intelligence capabilities near to the verge of the network but also it will ensure the strengthening of data privacy policies. Also, for securely identifying each individual ADSs is a big challenge. Thus, to address this issue, we are planning to deploy an agent (i.e., a piece of software/code), which could help to solve the identification-related issue.

2.3 Manufacturing Use Case

2.3.1 Industrial reference environment

The industrial organization considered in the CPSoSaware project refers to automotive Industry (described by CRF, which is the main Research Centre of FCA in the EMEA region and is expert in the FCA manufacturing process). Automotive manufacturing organization is mainly reflected on serial production and assembly lines system. It means that the final product is obtained through a scientific serial organization of the work: the production system is divided in elementary standardized operations with a specific execution time. Each operation is then strictly dependent on the previous one and on the next one.

The automotive industry, follows the assembly line production system. The production of the vehicle starts with the development of the car body through the joining of the printed metal sheets. Once the skeleton is ready, after the cataphoresis process, it is painted and finally, the engine, the electrical cables and internal parts are assembled. In order to improve the efficiency of the whole process, the suppliers of components (engine, wheels, trims) are located in strategic positions with respect to the specific Plant. Based on the type of product (premium brand or mass-market brand) and number of vehicles produced, the plants have different predetermined time frame (Takt Time). The automotive production process is divided in four main areas (or Operating Units):

- Stamping shop floor: steel sheets stamping of all parts
- Body in White shop floor (BiW): welding and joining of the stamped parts to form the full chassis and movable parts before painting
- Paint shop floor: cleaning, degreasing, sealing, painting and polishing of the chassis
- Assembly shop floor: assembly of parts and component (comprised engine) on the chassis. Final testing for full compliance

BiW, Presses and Painting shops have a high rate of automation; BiW is the shop floor with the highest concentration of robots: it is equipped with robots and numerous fully-automated welding and adhesive application stations operated by highly-skilled personnel. The Paint Shop, like BiW, is also an area that is highly automated. The final area of the production process, the Final Assembly, guarantees high flexibility in product mix and customization models; that's why in this area the presence of humans is fundamental.

CRF use-case is based on an industrial Use-Case in the assembly shop floor of a medium Takt Time[1] automotive manufacturing of Premium Vehicle.
Assembly shop is mainly based on human workforce the penetration of automation is less than 7-10% of the total operations in the assembly shop floor. In the assembly shop floor, the engine, all the interiors, all active devices (actuators/sensors control units), cables, harnesses, trims, upholsteries, glasses and wheels are put together, assembled, connected and tested to build the full vehicle (made of more than 50.000 components).
The work activity is mainly organized in line with a sequence of operations that can reach more than 200 workstations per line.
Automotive production characteristics depend on the desired throughput: big differences are present from cases of low to high throughput. It is possible to have variety ranging from mainly manual assembly (e.g. Bugatti, Pagani, or similar supercars: few vehicles per year), to production in the range of 1 vehicle

[1] Takt time is the average time between the start of production of one unit and the start of production of the next unit, when these production starts are set to match the rate of customer demand.

per hour (e.g some Maserati, Ferrari…), middle throughput (1 vehicle/5-10 minute – Maserati Levante, Maserati Ghibli) or high throughput (1 vehicle/minute – mass production vehicles).
The use of the assembly line is obviously more convenient and thus the tendency is to make flexible lines with more vehicles produced in the same line. Assembly production lines like those of the supercars are more related to artisanal production methods.
The throughput, besides of the production rate, indicates the time a vehicle is present in the workstation: normally low throughput means often a "Stop and Go" production, while high throughput means continuous moving production in line.
The difference also generates a different impact on the production methodologies, as a fact:

- High throughput means
    - shorter, more frequent operations
    - higher ergonomics workload for the operators due to repetition
- Low throughput means:
    - higher time per vehicle
    - less frequent operations
    - lower ergonomics workload
    - higher time per operation resulting in more time to ensure the quality.

The solution identified is always an economic tradeoff between the number of workstations, the amount and type of equipment, the number of operators that saturate the workstation, the ergonomics and safety for the operators, the Takt time and the achieved quality.
All workstations activities need to be planned in order to guarantee a constant cycle time (cycle time longer than the Takt Time cause the line to stop and represent an economical damage), the quality requirements and the safety and ergonomics constraints for the operators. Similarly, planning considers the need to distribute the activities in adjacent workstations guaranteeing the correct sequences of assembly.
Considering high level productivity KPIs, the number of operations per cycle performed by the operators (saturation of the operators) and the amount of active usage time per cycle of any equipment (saturation, availability…) has to be analyzed, planned and quantified.
Based on the above assumptions, the recent introduction of Human Robot Collaboration, as a method and a set of available technologies, is defining new work approaches, allowing a potential increase of productivity, ergonomics and quality in the assembly lines.
The CRF use-case within the CPSoSaware project is based on a Human-Robot collaboration 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 reference Use-Case is inspired from a line workstation. Nevertheless, the direct application in plant production would not be feasible for safety reasons until the full system is not validated and tested.
For this reason, CRF is implementing the Use-Case in a laboratory Pilot in which the main aspects of the application can be reproduced. The physical workcell of the pilot itself is under construction in the framework of another European Project (CoLLaboratE: Co-production CeLL performing Human-Robot Collaborative AssEmbly - grant agreement No 820767)[2]. The approach in the two projects is different and the developed concepts differ in the two contexts, but CRF will base the application on the same physical application in order not to duplicate costs.
In the following text, we will give an introductory description of the factors that characterize the reference Use-Case, the general Use-Case and the main aspects that affect the Human-Robot interaction in the work application.

[2] https://collaborate-project.eu/

2.3.1.1 *Human Robot Collaboration (HRC) application: main aspects description*

Collaborative robots, or COBOTs [50], represent an extension of traditional robot and can solve existing challenges in manufacturing and assembly tasks, as they allow for a physical interaction with humans in a shared workspace; moreover, they are designed to be easily reprogrammed even by non-experts in order to be repurposed for different roles in a continuously evolving workflow [51]. Collaboration between humans and COBOTs is seen as a promising way to increase productivity while decreasing production costs.

Behind this expectation there is the possibility of exploiting the physical capabilities of the robot such as precision, repeatability and strength together with the human cognitive operator (intelligence, problem solving, improvisation, immediate vision) and physical (manipulation, dexterity) skills. In additional it is possible to:

- reduce the non-*ergonomic tasks* using the robots to:
  - carry over heavy operations;
  - execute high frequency repetitive operations;
  - substitute the operator in awkward positions;
- improve *quality* by:
  - robot's characteristic repeatability;
  - the introduction of controlled adaptive constraints in the operator's activity;
  - the direct use by the robot of tools for measurement and objectivation (to perform an objective measurement/control that certifies and tracks the result of the measurement or the effective completion of an operation for traceability and later controls);
- improve *productivity* using the robot to perform "Non Value-Added Activities" (NVAA: percentage KPI describing the sum of duration of the operations times that are not creating value for the product over the total execution time) instead of the operator;
- give *support to elderly* or *reduced work capacity operators* and reintroduce them in the workforce, and so on.

The introductory description in paragraph 2.3.2 and 2.3.3 analyses the collaborative applications, workspace and actors in the field, in order to highlight criticism in the definition of the work-application and highlights/describes the features to be considered in the description of collaborative Use-Cases.

The analysis is focused on the explanation of the elements to be taken into account in design and description phases of the workcell. The purpose is twofold: to obtain a description that fulfils the end-user[3] requirements about the definition of new production cells, and to enable the extraction of the references to:

- Functional description
- Human-robot coordination with Roles assignment
- ISO Regulation minimum requirements toward the risk-assessment
- Required hardware and so on.

While identifying, designing and setting up a collaborative workcell it is always fundamental to keep in mind which collaboration level is strictly necessary for the application. Collaboration levels are defined in ISO 10218-2 and are detailed later in paragraph 2.3.2. For example:

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[3] The industry or party which utilizes the robotic technology into its premises. The end-user is the owner of the robotic workcell; it covers the costs of its installation and is legally responsible for any consequence of the workcell.

- If the contact or the proximity are not necessary, it is possible to use SMS (Safety-rated Monitored Stop) or SSM (Speed and Separation Monitoring) mode with lower costs, higher speed.
- If the proximity and the contact are requested it is necessary to further evaluate the nature of the contact (e.g. HG Hand Guiding to take control of the robot's end-effector; possibility to stop and resume the motion of the robot by a simple touch…)

It is furthermore important to:

- Evaluate which operations are attributed to the Human and which to the Robot.
- Determine execution times and saturation (MTM with Robot Timing Analysis).
- Determine available room.
- Analyze constraints (architectural, logistic, quality, ergonomics, cycle time…).

2.3.1.2 *Automotive main organizational approach*

In order to guarantee the productivity goals of each product, each Operating Unit (Press Shop, Body In White, Paint Shop and Final Assembly) is divided in Elementary Technological Units (ETU), autonomous and independent production cell. The rigidly vertical structure of the traditional plant is replaced by decentralization. Overall, the production models usually follow the structure of the lean production.

In detail, the structure of our production plants can be divided into 5 levels: Plant Manager, Area Manager, Supervisor, Team Leader and Operators.
Focalizing the attention regarding the structure with a "bottom-up approach", we can find the level of the Operators (inside which we can find for example the assembly line worker, conductors, maintenance workers), going forward we find the level of the Team Leaders. Both of these two levels are called as Blue Collars.
Moving towards the third level we can find the first category that include under the White Collar: the Supervisors, who interface directly with the Area Managers (one for four main areas or Operating Unit) and subsequently with the Plant Manager.

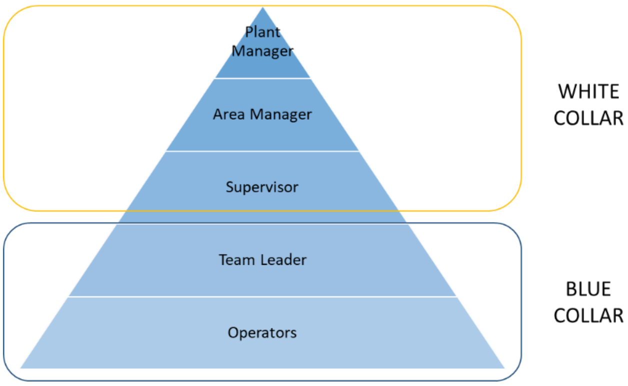

Figure 11: Simplified organizational structure of production plants

Always according to the production needs (determined by the JPH – *Job Per Hours* – which defines the number of vehicles produced per hour) the production can be organized in shifts (from 1 to 3 of the duration of 8 hours). Eventually each shop floor can organize the number of shifts differently.

The introduction of HRC technologies impacts the organization at different levels and strengths. When considering appreciation of the technology at different stakeholder level, there is the need to consider what different roles expect from the technology itself. All the levels in Figure 11 are stakeholder in relation to the introduction of the HRC technology with different motivation and expectations. The analysis of Stakeholder's structure from the perspective of user requirements and expectations will be made later on.

2.3.1.3 *Process quality*

Another aspect of great importance for the business goals is Quality: not only when it pertains to product value but also to product compliance to safety standards. Depending on product system, internal control strategies are integrated within the production phases (Intrinsic quality and safety). The quality control of products and processes is carried out at all stages of development and production, from the technological concept to the industrialization phase. Visual quality controls are performed most of the times within the different operations, so human presence is essential.
In automotive industry quality control is part of the product development process. In fact, quality can be ensured through the identification and the elimination of the root causes and not only through final controls and deliberates. In the Final Assembly Operating Unit, in particular, where the level of automation is low, the workers are responsible in guaranteeing the quality in each operation. Poke Yoke (simple devices/solutions that prevent mistakes in the human operations) solutions are used when possible. Whenever quality impacts on product safety, objectivation of performed operations is done. In some cases the assembly operations are defined specifically to obtain the desired quality. Dedicated personnel make the quality controls and, at the end of the line, all completed vehicles are then subjected to a “Dynamic Performance Test” over a mixed driving route.
The use of robotics can support quality both by the repetition rate and grade achieved by robots in comparison to operator, and by the capability to automate qualification processes (autonomous check of correctness of the components assemble). Automatization of the above factors strongly improves assembly inherent quality, while reducing time execution and efforts assigned to the operators.

2.3.2 Human Robot Collaboration rules according to ISO Standards

Human Robot Collaboration (HRC) is a new work approach whose implementation and use is allowed by a newly available technology (COBOTs) and new ISO Standards for the safety in industrial environment. HRC in manufacturing impacts on aspects related to Human performance (ergonomics), productivity and inherent quality and it is more and more used worldwide.

The ISO regulatory framework for Human Robot Collaboration nowadays is properly defined and any application at industrial level needs to consider it. It is important to underline that the use and application of standards is voluntary in most countries. Technical standards only become mandatory if they are referred to in contracts, laws or regulations. In addition, contract partners may choose to make the use of a standard binding. Standards are often used to settle legal disputes, especially in product liability cases. Courts use standards to help decide whether or not the manufacturer has followed the acknowledged rules of technology and thus has exercised "due diligence". Standards are thus recommendations which, when followed, provide legal certainty. Standards become thus a technical reference that end-users have to consider as a best practice. It is not compulsory to follow the technical standards, but in case of accidents involving Human Operators, the end-user has to demonstrate that he applied any reasonable know-how and existing solution to guarantee operator’s safety. If the end-user decides not to use existing ISO-Standards, he has to explain and demonstrate that the solutions he took are sufficient to guarantee full operator’s safety and laws conformity. On the contrary, although the use of standards which are referred to in legislation does not absolve one of liability, the "presumption of conformity" principle applies. This means that when a manufacturer or end-user complies with legal provisions laid down in a directive or law by applying the relevant standards, it can be presumed that the product (the workcell in case of Human-Robot Collaboration) is in conformance with these provisions and can thus be placed on the market.

The CE Marking (defined and regulated in the “Machine Directive 2006/42/EC” which a mandatory European regulation) demonstrates conformity with the essential safety requirements laid down in EU legislation. The CE mark has to be applied by the manufacturer or exporter, or their representative. Some directives require conformity assessment by a neutral third party, called a "notified body", before the marking can be applied. By applying the CE mark a manufacturer declares on his/her sole responsibility that the product meets all the legal requirements and can thus be placed on the EEA market.

The CE mark on Robots should not be applied since robots are considered partly completed machinery. Partly completed machinery are almost machinery but cannot in itself perform a specific application. They are only intended to be incorporated into or assembled with other machinery or other partly completed machinery (or equipment, thereby forming machinery or assemblies of machinery) and must thus undergo further construction in order to become final machinery that can perform its specific application.

Partly completed machinery alone cannot comply fully with the essential health and safety requirements since certain of the risks may result from the fact that the machinery is not complete or from the interface between the partly completed machinery and the rest of the machinery or assembly of machinery into which it has to be incorporated (this is the case of the collaborative “safe” robot with a gripper, handling a dangerous part: the whole system cannot be safe and thus certified). However, the manufacturer of partly completed machinery must state, in a *Declaration of Incorporation*, which of the essential health and safety requirements he has fulfilled.

Similarly, assemblies of machinery (with or without partly completed machinery) are subject to the Machinery Directive as machinery themselves because their safety depends not only on the safe design and construction of their constituent units but also on the suitability of the units and the interfaces between them.

If the new unit (machinery or assembly of machinery) is constituted by partly completed machinery accompanied by a Declaration of Incorporation and assembly instructions, the person incorporating the partly completed machinery into the assembly is to be considered as the manufacturer of the new unit. In case of assembly of machinery the CE-marking will thus be applied only to the whole assembly.
The main HRC regulatory technical framework is mainly based on the following standards:

- EN ISO 10218-2:2011 [53] that sets the allowed behaviour of the COBOT in Human Robot Collaboration applications, through the definition of the collaborative modes and the rules for the integration in the collaborative workspace (targeted to integrators);
- EN ISO 10218-1:2011 [52] that sets the hardware and functional safety characteristics that a collaborative robot has to fulfil (targeted to robot’s constructors);
- ISO/TS 15066:2016 [54] sets the numerical limits for the physical KPIs (velocity, force, power…), and the methodologies for the workplace safety in Human Robot Collaboration (HRC) applications.

For those parts of the whole workcell that don’t have a specific technical standard for regulation (e.g. AGVs, AMRs or Grippers for manipulating COBOTs), the references is the Machine Directive (in Europe), or any other technical standard related to the specific device depending on functional and safety similarities.
The main reference standard is the ISO 10218-2:2011 that defines the rules for the System integration of collaborative robots. According to ISO 10218-1 [52], *collaboration is a special kind of operation between a person and a robot sharing a common workspace. It is only:*

- *used for predetermined tasks;*
- *possible when all required protective measures are active;*
- *possible for robots with features specifically designed for collaborative operation complying with ISO 10218-1 [52].*

Furthermore, due to the potential reduction of the spatial separation of human and robot in the collaborative workspace, physical contact between the human and the robot can occur during the operation. Protective measures shall be provided to ensure the operator's safety at all times.

The collaborative workspace is the space where the Operator(s) *can interact directly with the robot, and shall be clearly defined (e.g. floor marking, signs, etc.). Persons/operators shall be safeguarded by a combination of protective devices and compliance with robot performance features allowed in ISO 10218-1 [52]. The design of the collaborative workspace shall be such that the operator can easily perform all tasks and the location of equipment and machinery shall not introduce additional hazards.*

A complete risk assessment is required for any application involving collaborative operation specifying collaborative methods, physical parameters (power, force…), ergonomics, additional tools and so on. The whole robot system and application shall be included in the risk assessment and certified for safety. ISO 10218-2:2011 [53] gives the fundamental definition of the collaborative operations in the collaborative workspace.

When designing a collaborative operation, the standard define four possible collaborative modes, each characterized by its own specific functionality and safety requirements.
Any detected failure of the selected safety features of the collaborative operation shall result in a protective stop. After the stop, autonomous operation shall not be resumed until the reset by a deliberate restart action outside the collaborative workspace. The allowed Collaborative modes are the following:

- Safety-rated Monitored Stop (SMS): If there is no person in the collaborative workspace the robot operates autonomously. If a person enters the collaborative workspace the robot shall stop moving and maintain a safety-rated monitored stop in order to eventually allow direct interaction of an operator and the robot (e.g. loading a part to the end-effector); the robot's operations can resume after the person leaves the collaborative workspace.

- Hand Guiding (HG): Hand guiding operations are a manual guidance of the end-effector of the robot performed by the operator. For HG:
    - the task is carried out by manually actuating guiding devices located at or near the robot end-effector;
    - the operator uses a hand-operated device to transmit motion commands to the robot system;
    - when the robot reaches the hand-over position, a safety-rated monitored stop, must be set;
    - the operator shall have clear visibility of the entire collaborative workspace;
- robot systems used for hand guiding can be equipped with additional features, such as force amplification, virtual safety zones or tracking technologies.

- Speed and Separation Monitoring (SSM): The Robot system is designed to maintain a safe separation between the operator and the robot in a dynamic manner (considering position and speed of both the Human operator and the Robot). Robot speed, minimum separation distance and other parameters shall be determined by risk assessment. In SSM mode:
    - The robot system and operator may move concurrently in the collaborative workspace.
    - During robot motion, the robot system never gets closer to the operator than the protective separation distance (or the robot system stops).
    - Speed and separation monitoring shall apply to all persons within the collaborative workspace.
    - For constant values of speed and separation, the maximum permissible speed and the protective separation distance shall be determined through the risk assessment as worst cases over the entire course of the application.

- **Power and Force Limiting by design or control (PFL):** The Robot systems are designed to control hazards by power or force limiting to specific values depending of the type of possible contact and risks related to them. Parameters of power, force, and ergonomics shall be determined by risk assessment. Some important requirements in PFL are:
    - PFL collaborative operation requires robot systems specifically designed for this particular type of operation.
    - Physical contact between the robot system (including the workpiece) and an operator can occur either intentionally or unintentionally;
    - Risk reduction is achieved, either through inherently safe means in the robot or through a safety-related control system
    - Risk reduction shall consider means by which possible contact between the operator and robot system would not result in harm to the operator (soft layers around the robot);
    - Objects with sharp, pointed, shearing or cutting edges, such as needles, shears, or knives, and parts which could cause injury shall not be present in the contact area.
    - Contact exposure to sensitive body regions, including the skull, forehead, larynx, eyes, ears or face shall be prevented whenever reasonably practicable.
    - In any clamping event between the collaborative robot system and human body the person shall be able to escape independently and easily from the clamping condition.
    - If robot motion can result in clamping or pinning a body area between a part of the robot and another item in the robot cell, the robot speed shall be limited
    - For frequent contacts or other special cases, the applicable threshold limit values can be further reduced to an ergonomically acceptable level.
    - Parameters of power, force, and ergonomics shall be determined by risk assessment.

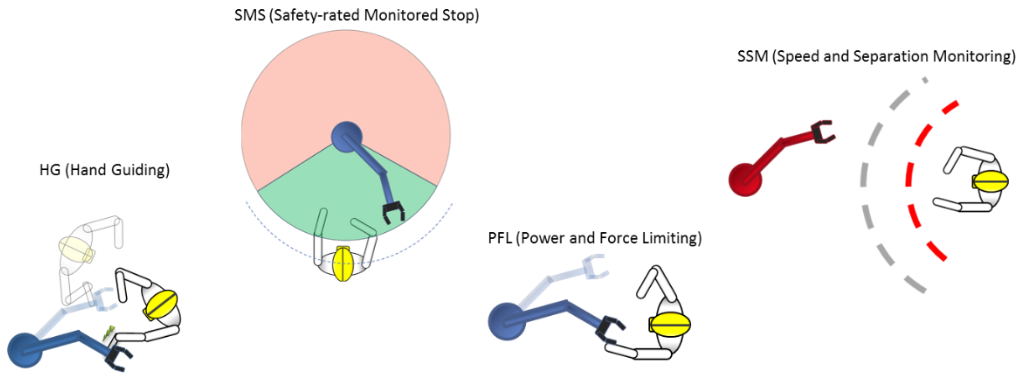

Figure 12: Collaborative Operating Methods

Any HRC application has to be defined by one or more collaborative modes and the change point between autonomous and collaborative operations shall be designed so that the robot cannot endanger personnel. Any robot or safety device used in a collaborative workcell shall comply with ISO 10218-1 [52].

The ISO 10218-1 [52] defines the Hardware safety requisites of the robot and devices in the collaborative workspace, their Performance Level (PL) and Structure Category (control redundancy requisites). For collaborative robots, and in general for safety related devices in a Collaborative Workspace a PL “d” with Safety category 3 is required (Figure 13).

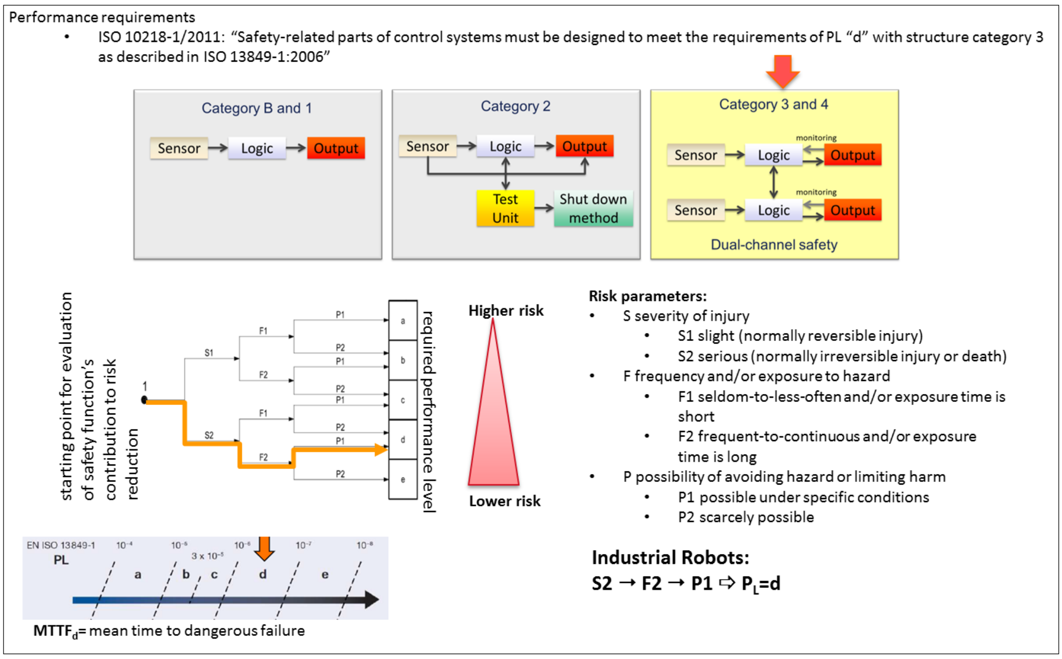

Figure 13: Safety requirements for Collaborative Robots

ISO 10218-1 [52] defines also all the functional behavior and characteristics of any protective devices to be used in the four collaborative modes.
In 2016 the ISO/TS 15066 [54] was released. This technical specification defines the details for the safety in HRC work-places and work-applications, and gives numerical values for the calculation of Speed, Force and Power limits to be used in the design of HRC work-cells.
The general rules for the realization of a collaborative workcell can be thus summarized as:

- *The requirements for the design of the collaborative robot operation are provided in ISO 10218-2:2011, 5.11.*
- *The operating methods (SMS, SSM, HG, PFL described after) may be used singularly or in combination when designing a collaborative application.*
- *Transitions between methods of collaborative operation or between non-collaborative operation and collaborative operation shall be designed such that the robot system shall not pose unacceptable risks to the operator*
- *If a collaborative robot system relying upon safety-rated limiting functions is used without an enabling device, then these functions shall always remain active.*
- *Any detected failure in the safety-related parts of the control system shall result in a protective stop and in this case operation shall not resume until reset with the operator outside of the collaborative workspace.*
- *All people within the collaborative workspace shall be protected by protective measures.*
- *During collaborative operation the operator shall be able to:*
    - *stop robot motion at any time by a single action OR have an unobstructed means of exiting the collaborative workspace*
    - *transitions between collaborative operation or between non-collaborative operation and collaborative operation shall not pose risks to the operator*
- *A visual indicator to identify transitions between collaborative and non-collaborative operations can be used.*

It is important to understand that the risk assessment requires the application to be precisely specified with all its constraints and components. The result is the assessment of risks in the overall application. If the risk is too great, measures have to be used to minimize the risk of the application to an acceptable residual risk (e.g. safely reduced velocity in combination with collision detection. In accordance with EN

ISO 10218-1:2011 [52]). The CE mark may only be affixed if the modified risk assessment confirms a sufficiently low residual risk.

2.3.2.1 *Collaborative Workspace (Layout considerations and constraints) in ISO standards*

Whenever describing a Human Robot Collaboration, it is fundamental to consider the whole Collaborative Workspace. The complete description of the workplace requires different considerations that will be detailed afterwards, nevertheless this paragraph, describing shortly the concept of the collaborative workplace, aims at introducing the issue and its importance. The ISO 10218:2 [53] introduces and defines the Human Robot Collaboration as (text in *Italic* is directly from the Standard):

Collaboration is a special kind of operation between a person and a robot sharing a common workspace. It is only:

- *used for predetermined tasks;*
- *possible when all required protective measures are active; and*
- *for robots with features specifically designed for collaborative operation complying with ISO 10218-1.*

In the General Requirements paragraphs it is further underlined that:

Due to the potential reduction of the spatial separation of human and robot in the collaborative workspace, physical contact between the human and the robot can occur during the operation. Protective measures shall be provided to ensure the operator's safety at all times. The following requirements shall all be fulfilled.

a) The integrator shall conduct a risk assessment as described in 4.3 (see Annex E for examples of applications). The risk assessment shall consider the entire collaborative task and workspace, including, as a minimum:
1) robot characteristics (e.g. load, speed, force, power);
2) end-effector hazards, including the workpiece (e.g. ergonomic design, sharp edges, protrusions, working with tool changer);
3) layout of the robot system;
4) operator location with respect to proximity of the robot arm (e.g. prevent working under the robot);
5) operator location and path with respect to positioning parts, orientation to structures (e.g. fixtures, building supports, walls) and location of hazards on fixtures;
6) fixture design, clamp placement and operation, other related hazards;
7) design and location of any manually controlled robot guiding device (e.g. accessibility, ergonomic, etc.);
8) application-specific hazards (e.g. temperature, ejected parts, welding splatters);
9) limitations caused by the use of necessary personal protective equipment;
10) environmental considerations [e.g. chemical, radio frequency (RF), radiation, etc.];
11) performance criteria of the associated safety functions.
b) Robots integrated into a collaborative workspace shall meet the requirements of ISO 10218-1 [54].
c) Protective devices used for presence detection shall meet the requirements of 5.2.2.
d) Additional protective devices used in a collaborative workspace shall meet the requirements of 5.2.
e) The safeguarding shall be designed to prevent or detect any person from advancing further into the safeguarded space beyond the collaborative workspace. Intrusion into the safeguarded space beyond the collaborative workspace shall cause the robot to stop and all hazards to cease.
f) The perimeter safeguarding shall prevent or detect any person from entering the non-collaborative portion of the safeguarded space.
g) If other machines, which are connected or attached to the robot system and present a potential hazard, are in the collaborative workspace itself then the safety-related functions of these machines shall comply, at a minimum, with the requirements of 5.2.

Besides of the specific content of the cited paragraph 5.2 of the ISO Standard, all the above text underlines the importance to describe and plan all the actors in the collaborative workspace.
Considering the ISO/TS 15066:2016 we have:

§ 5.3 Design of the collaborative workspace:

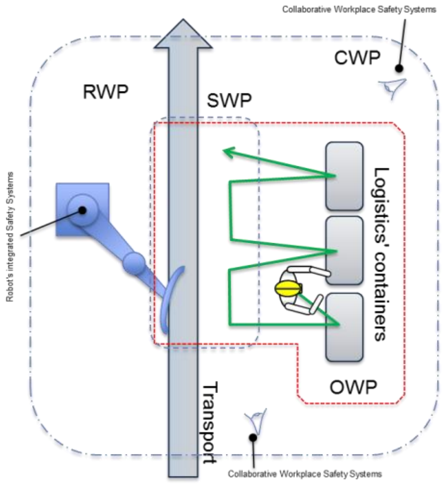

Figure 14: Collaborative workspace detailed

The design of the collaborative workspace shall be such that the operator can perform all intended tasks. Any risks introduced by machinery or equipment shall be sufficiently mitigated by the measures identified in the risk assessment. The location of equipment and machinery should not introduce additional hazards.

Figure 14 describes the concept of the Collaborative Workspace; it is all the space interacting with the Human-robot collaboration. The importance in its description is related to the Safety contents of all the active and passive actors in the workplace; even though not represented in the figure, passive "actors" like architectural elements (columns, walls…) or furniture (tables…) represent a risk, and as such need to be analyzed and included in the Workplace description. Considering the presence of passive risk elements, the ISO standard (10218-2:2011[53]) states that:

The robot system should be installed to provide a minimum clearance of 500 mm (20 in) from the operating space of the robot (including arm, any attached fixture and the workpiece) to areas of building, structures, utilities, other machines, and equipment that allow whole body access and may create a trapping or a pinch point. Where this minimum clearance is not provided, additional protective measures to stop robot motion shall be taken to provide protection while personnel are within 500 mm of the trapping or pinch hazard in a static environment. If there is dynamic motion (e.g. line tracking), special considerations may be needed. (See ISO 13854)

The figure above introduces further concepts in relation to the possible type of interactions:

- OWP: Operator's Work Place (zone of movement of the operator)
- RWP: Robot Work Place (robot + gripper + component reachability envelope)
- CWP: Collaborative Work Place (according to ISO/TS 15066 [54])
- SWP: Shared Work Place (zone with where both robot and operator work)

This differentiation is introduced in [55] considering the specificity of the playing actors in order to classify the different possible HRC applications in relation to the collaborative modes defined in the ISO standards.

Referring to above, it is possible to make an analysis and classification of the type of collaborative application, considering the spatial superposition, the time simultaneousness of OWP and RWP and the action of operator and robot on the same application or not. It is important to remember that both the RWP and OWP are envelopes of time dependent functions and as such can be considered as fixed objects (envelopes) or dynamic objects in case of time overlapping. The description of the Use Cases requires different levels of layout definition. The most important considerations are those related to the Collaborative Workplace. It is important to consider and highlight every element in the layout description that can influence the collaborative workplace. This analysis and consideration has to be performed recursively along every design phases. A second consideration to be performed is that in HRC the position of the actors is dynamic; in this framework the layout must obviously consider every movement foreseen for the operator and the robot in any moment of the collaborative operation. The layout of the workspace can be done as usual with 2D or 3D CAD models, but its full evaluation and dimensioning requires a recursive analysis of the application to be performed together with the task analysis and risk assessment.

2.3.3 Main characteristics of Human Robot Collaboration workcells

When designing or analysing any collaborative application, it is important to consider some descriptive factors that impact strongly both the performances and the safety of the workcell.

Taking into consideration the collaborative nature of the application the most important aspects are:

- Human factors (time and task planning, MTM, ergonomics, fatigue correlated aspects and so on)
- Used hardware (type of robot, its performances, the end-effector, Safety systems, logistic interfaces, any other active device…)
- Human Machine Interfaces (HW/SW tools and design that allow the system to dialog with the operators

All these points need to be considered in terms of the Safety requirements deriving from the ISO standard and in terms of the application and its main KPIs. In the following a deeper description of the above aspects is given, in general terms, for those features that deserve a specific attention; in the following paragraph "2.3.4 Human Robot Collaboration Pilot", that describes the specific Use Case pilot, these aspects will be described for the specific application in the pilot.

2.3.3.1 *Human Factors*

The Human operator and the robot are the main actors of the collaborative workspace; because of this the human factors are at the center of a proper design of HRC workcells.
For the Human operator different levels of design and analysis are required. It is thus fundamental to include in the analysis different characteristics of the operator's planning that directly or indirectly influence the workcell performances, characteristics and design.
The main characteristics affecting or describing the performances of the workcell are:

- the task analysis with relative timings (e.g. MTM Task analysis)
- the type of operation to be performed (e.g. NVAA/VAA see next section),
- the ergonomics,
- the distance traveled by the operator in the workstation (through the spaghetti chart).

2.3.3.1.1 NVAA (Non Value Added Activities) and VAA (Value Added Activities)

Every operation performed by the operator in its application can be classified in two main groups related to the product value creation chain. NVAA (Non Value Added Activities) and VAA (Value Added Activities) are two complementary percentage KPIs describing the sum of times over the total execution time of operations that are not creating value or that are creating value respectively. The value chain contains all the operations performed to create the product's features that the final client is willing to pay for, or that are compulsory for the realization of the product. Other operations are nevertheless necessary for the realization of the product itself without concurring to perception of value.
VAA is thus the sum of the times used for:

- Product transformation (handling, screwing, gluing, welding, assembly …)
- Quality check
- Traceability or similar (those that ensure regulation compliance of the product)

NVAA, on the other hand is the sum of times executed for:

- Logistics (going to pick up sub-assemblies is necessary but not perceived as a value buy the buyer of the final product)
- Waiting (sometimes necessary in case automation and human operator are misaligned in time)
- Walking in general (to pick up tools, parts…)

For a proper productivity planning and optimization the minimization of NVAA in the design phases of the application is necessary.
Figure 15 shows an example of the NVAA minimization process in order to create value by the use of a collaborative robot.

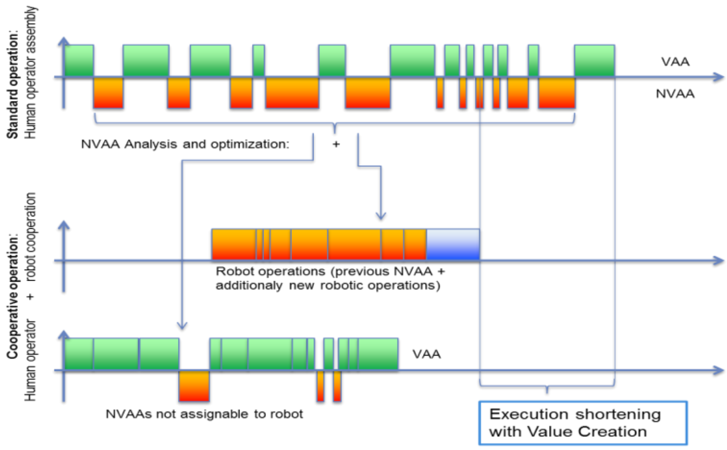

Figure 15: NVAA Analysis for value creation

2.3.3.1.2 Ergonomics

Ergonomics is the science that applies the physiological (and psychological) principles to the engineering and design of products, processes, and systems. Ergonomics can be defined like the science of designing the job to fit the worker, rather than physically forcing the worker's body to fit the job [56]. In manufacturing operations human operators can often be exposed to many non-ergonomic movements/actions such as:

- Heavy loads manipulation
- Blind and awkward postures
- Repetitive and cycling movements

It is a standard procedure to design the workplace in order to reduce the ergonomics workload on the human operators. The aim is to fulfil the goals of occupational health and safety and productivity.
Ergonomics is nowadays faced by a preventive (and on the field) simulation and analysis of the positions, postures and actions performed by the operators. In case ergonomics issues are foreseen, workplaces can be redesigned to eliminate the issue or reduce the impacts to the operators. Proper job rotation planning is needed in order to keep the exposure to ergonomic risk below the acceptable level (defined by the law).
Often mechanical solutions are used to support the operator's activities, such as adjustable seats, workstations and tables, or eventually proper devices and tools can be used such as dampening devices for vibration control, semi-autonomous or passive manipulators and lifters and so on.
The solution to ergonomics issues often represents a cost for the end-user and sometimes, if the optimized solution is not achievable, there is the need to plan job rotation among operators which is expensive and often complicate. COBOTs, thanks to their inherent flexibility, force and safety in interaction with humans, are an optimal candidate for ergonomics improvements, in particular for those workstations in which both management (job rotation) and mechanical solutions are difficult to apply.
Nonetheless HRC and, generically speaking, any form of human-robot interaction (e.g. exoskeletons) introduce some issues in the ergonomics evaluation. Ergonomics is usually optimized according to standard tools which, up to now, are based on evaluation of a static environment.

2.3.3.1.3 Spaghetti chart

During assembly tasks, the operator has the necessity to walk inside its workcell. These walking phases are classified as NVAA since they are not related to the direct production of the value of the product,

but they refer to the workplace organization. For this reason, the Spaghetti Chart is a powerful tool in all the Lean Manufacturing methodologies, for the walking phase representation and analysis.
The Spaghetti Chart draws on the layout and quantifies the length of the expected walking path of the operator. As such it allows to highlight un-optimized workcells, wrong disposition of the logistics containers and so on. The Spaghetti Chart has an impact on both productivity (time losses in high NVAA) and ergonomics (km walked per day). There is no "optimal value" for this KPI since the disposition of logistics and parts depends on many factors and often the Spaghetti Chart Value can be really high even if the path itself is optimized for the specific plant and application. However, the tool is important to optimize the workcell layout, the logistics planning and the working operations. In some cases the Spaghetti charts can show possible risks for the operator of crossing and cross-disturbance.

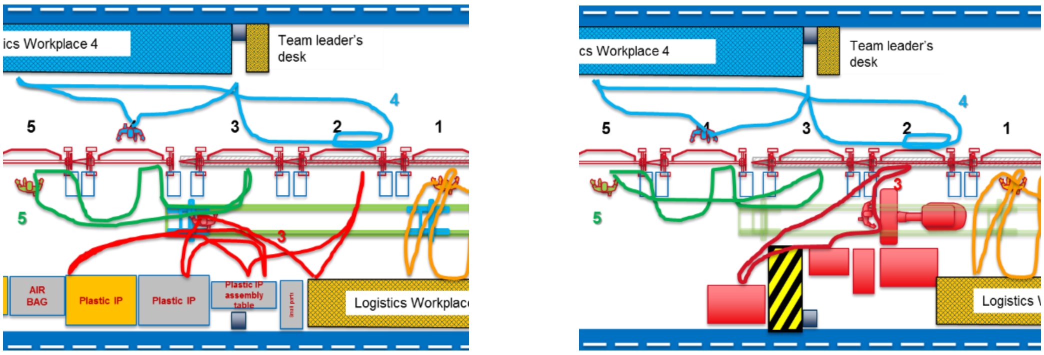

Figure 16: Spaghetti Chart before and after planning a Collaborative Robot introduction

In Figure 16 the modification of a Spaghetti Chart before and after planning a collaborative Robot introduction is shown. The COBOT application affects the operator 3 Spaghetti Chart (red line) and reduces the risk of interference with operator 5.

2.3.3.1.4 Task Analysis and MTM (Methods – Time Measurement)

In order to plan the activities of the operator both in terms of time and in terms of required equipment, spaces and so on, a task analysis is required. This task analysis can be performed in different ways and have different content according to the target. One of the most known and powerful methodology for the task analysis is the MTM.

In Assembly, all processes are manual and the Takt Time (TT) is determined according to the production needs; it can eventually be limited if technological bottlenecks are present.

The MTM (Methods-Time Measurement) analysis is used to organize, on the basis of the tack time, the activities and saturation of each single operator (cycle time). New developments have led to the MTM-UAS (Universal Analysing System) aiming at the continuous improvement of:

- cost-performance ratio (function, quality);
- delivery reliability (short-term, on time deliveries);
- human and motivating work design.

For the specific use to plan, describe and analyze Human Robot Collaboration applications, CRF has developed a specific task analysis representation based on the MTM methodology. This representation puts together a simplified MTM analysis for the operator's tasks and a robot task analysis. The operator's analysis is less detailed than the MTM analysis, but contains references to the interaction with the robot, approximate evaluation of distance from the robot and indication of the collaborative methods (according to ISO/TS15066) used during each specific task. Furthermore the analysis at task level highlights and classifies the characteristics of the task executed in terms of the value/Non Value Added activities.

This tool allows the estimation of tasks with functional and system requirements on a single tool. The level of evaluation of functional system requirements is preliminary but it efficiently highlights HMI functional requirements, robot modes, and the need for additional safety tools in the workcell.
The details of the analysis for the CRF use-case in CPSoSaware project are being presented in deliverable D6.3 "Preliminary Evaluation and assessment of CPSoSaware Platform" in paragraph 3.1.3 "Human operator planning – Task analysis".
A detailed description of the tool used is represented in Annex 1.

2.3.3.2 *Robot and related hardware identification*

The components and devices, as well as their interaction and architectural organization affect heavily any application and, of course, all HRC application design. The categories of components that affect more heavily the application of HRC are listed below.

- COBOT model identification. It affects the functionality, the level and type of safety and the possibilities of interaction. It is the second main actors together with the operator in Human-Robot Collaboration.

- End-Effectors: it is the tool on top of the robot. It is the part of the active system that creates and personalizes the effects that the robot performs during the process. ROBOTs are party completed machinery, as such they functionality require an end-effector that, applied to the robot's flange, performs the operation itself. It can be made for different applications: Welding (welding guns, torches…), manipulation (grippers, flexible grippers, suction cups…), gluing, riveting, sanding and polishing, cameras for vision and so on.

- Safety System: Safety in a collaborative workcell is seldom achievable only through the use of the collaborative robot alone. Though the COBOTs have inherent tools and characteristics that reduce the risk of harming the operator a full Risk assessment must be done. Elements like the end-effectors, the parts transported by the robot (if any) or the processing tools must be analysed as well. The safety system is composed by all the elements (cameras, controllers, PLCs, robots…) that together define the safety in the workcell. Besides of the devices, the safety system comprises software and procedures as well.

- Interactions and logistics: all the tools that bring the component toward and away from the process (made by the human and the operator). The organization and choice of the logistic organization is fundamental for a proper automation of the processes.

- Full architecture: the system is composed by a plethora of sub-systems connected together by industrial networks (both in terms of software and physical network connections). The identification of the proper and best technology can affect the performances and safety of the workcell as a whole. The architectural representation of the workcell is thus fundamental for a proper understanding of the system as a whole.

2.3.3.3 *Interfaces requirements & Information exchange*

Finally, it is fundamental to define the connectivity of the Robot with its world. Inside the workcell many interfaces are required to achieve a proper working ability. In standard manual cells, the system acts often at a too high level to be conveniently aware of all the events occurring in the workcell. The complexity of the motion of the operators and their unpredictability is such that the system cannot perform any automatic monitoring of the tasks. In order to have a proper feedback from the operator, often the system relies only on voluntary feedbacks coming through an HMI (Human Machine Interface). For a very limited set of operations (e.g. screwing in automotive lines) the tools are "intelligent" and give a feedback of the performed operations (torque profile in time, number of turns,

pressing force, time profile in absolute time…). Besides these kind of "intelligent" tools are expensive and are normally used only when more restrictive quality or traceability requests are done.
In the Human-Robot Collaboration, on the other side there is the new "robot" element that can interact with the operator. The Robot is inherently a connected machine: normally most of the operations are programmed inside the robot controller which is interfaced to the cell or line's PLC. This situation creates a normal and complimentary bridge for the information to the higher level Manufacturing Systems like the MES (Manufacturing Execution System). On the Human side, the robot needs to have a certain level of awareness of the situation in order to fulfil the safety requirements of the workcell.
For HRC applications it is possible to highlight the minimum level of requirements that are:

- SMS systems require the presence of a safety sensor (environmental sensing) in order to stop the motion;
- SSM systems need to know the position and speed of the persons in the workzone to regulate its own speed in real time.
- In HG the robot needs to have a specific handle capable to detect the action request and to understand whether it is voluntary or not;
- In PFL the robot needs to have an advanced and safe force feedback in any time.

Besides of the functional specifications, the interaction with the robot generates new risk situations that can distract the operator. Proper signaling of the working conditions (besides being requested by the standards in same specific cases) are useful for the operator to act safely and properly.
The robot in the workcell is in a central position to manage most of the knowledge flow related to the system defined in the workcell. It is possible to separate three main level of information:

1. High level interaction toward logical fluxes of plant management;
2. Workcell management, coordination and know-how of the workcell; awareness of the environmental situation (number of operator, position…)
3. Operative information which can be divided into:
    a) Devices information (process sensors…)
    b) Operator information (what he is doing, when…)

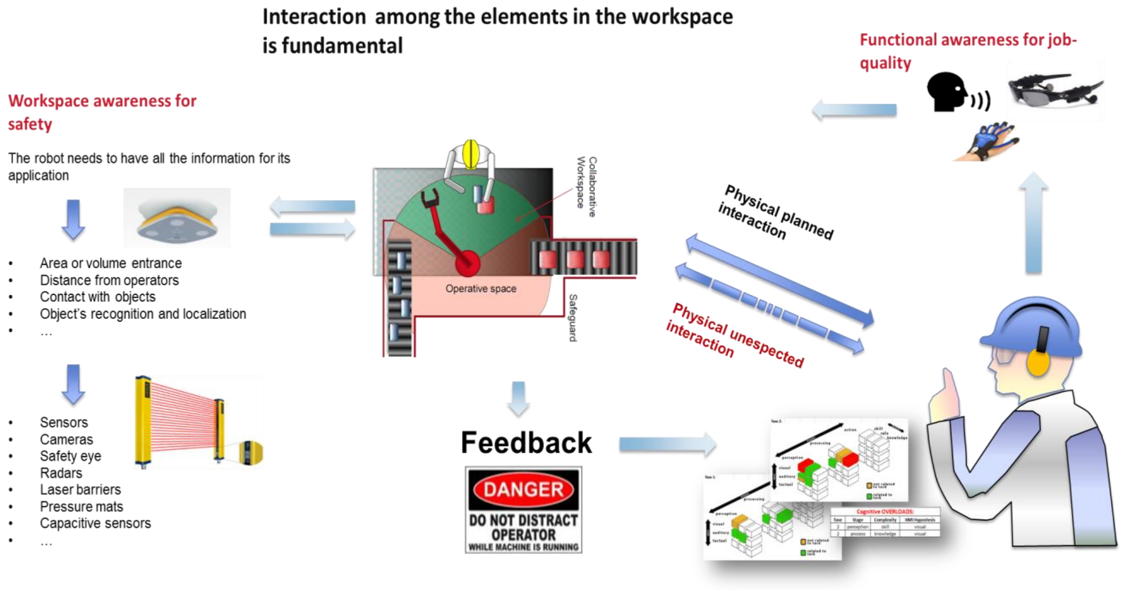

Figure 17: HRC Information flow around the Collaborative Workplace

For the specific purposes of the HRC the information flow acts around the workspace and can be detailed as:

- Safety sensors for workspace awareness

- HMI for communicating with the operator; these are bidirectional HMI and can be acting at visual, acoustic or haptic perception level
- Sensory devices and actuators for process specific purposes.

All this information flow is fundamental for the proper execution of the activities and thus needs to be properly represented and defined. As for the flow towards the operator, it is important to highlight that the operator is already concentrated onto its own operations and for the detection of the robot's motion (to avoid collisions). This situation can be already generating cognitive stress; for this reason the optimization of the HMI with the operator should take into account procedures to lower the risks related to cognitive ergonomics.

2.3.4 Human Robot Collaboration Pilot

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 CRF workcell is the following concepts can be implemented:

1. a front windshield is picked up and manipulated by the robot;
2. the front windshield is placed in front of the operator;
3. the operator can perform visual quality check for cleanness, existence of cracks and so on while interactively manipulating and repositioning the gripper holding the windshield;
4. a series of manual assembly phases is performed on the windshield in a collaborative way while the robot reposition itself according to the specific workphases required;
5. the robot completes the assembly of the windshield on the chassis (gluing if necessary, positioning).

The Use Case won't perform experimental tests of the "As Is" situation in plant since the pilot layout cannot be complete in reference to the in-plant layout (no conveying line and chassis are present in CRF premises), but the initial requirements and some constraints are based on the real in-plant workcell. The developed workcell is intended as a green field planning of the operation. As stated the reference application is for low JPH. In these conditions the use of full tradition automation is not suitable given the high costs, and a mixed Human-Automation solution with a separate Robot is used. In real manufacturing, the precision of positioning of the windshield on the chassis is critical for the quality and the safety of the vehicle, and considering the weight and dimensions of the windshield, a robot is always used for the final stages of the assembly. The following figure gives a representation of the line reference workcell.

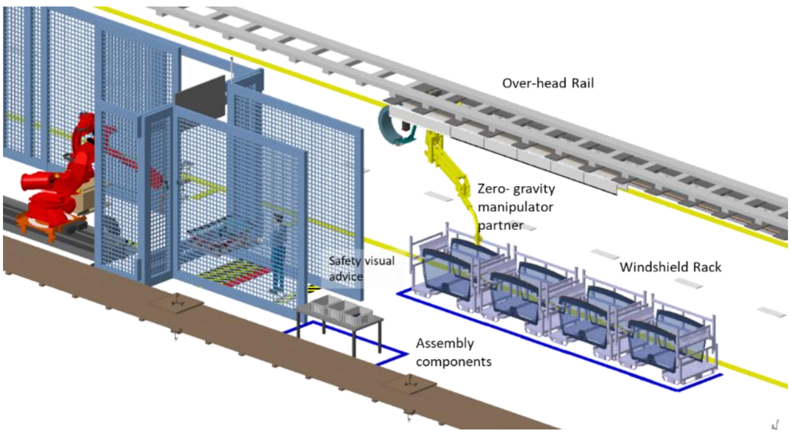

Figure 18: Tools and logistics set up in the reference layout

The simplified sequence of tasks in the line workcell is as follows:

1. The chassis enters the workcell (in continuous motion).
2. The operator places on the chassis, from the near side line, some positioning, anti-slippery jigs.
3. The operator returns to the assembly workzone.
4. The operator takes a partner manipulator and picks up a windshield from the rack.
5. He moves the windshield to a rotating table with the inner part above.
6. He puts back the manipulator.
7. He takes a cleaning towel and cleans the windshield.
8. He takes components to be assembled on the windshield (3 sensors, 1 cable harness and the internal rear view mirror).
9. He starts to assemble the parts (cycles of picking cleaning towels, cleaning, assembly, disposing used towel).
10. He exits from the assembly zone.
11. The table rotates.
12. A robot picks up the assembled windshield from the outer face, goes under a glue dispenser and puts a uniform glue path; assembles the windshield on the chassis.

In the workcell, other operations are performed, but they are not of interest for the collaborative part of the application. The only operations that are reproducible on the CRF pilot are those from 4 to 12, were the use of the collaborative robot modifies the sequence as follow:

	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

Table 1: Collaborative windshield assembly main expected phases

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. Figure 19 gives a representation of the aimed layout with safety zones. More details are provided in D6.3.

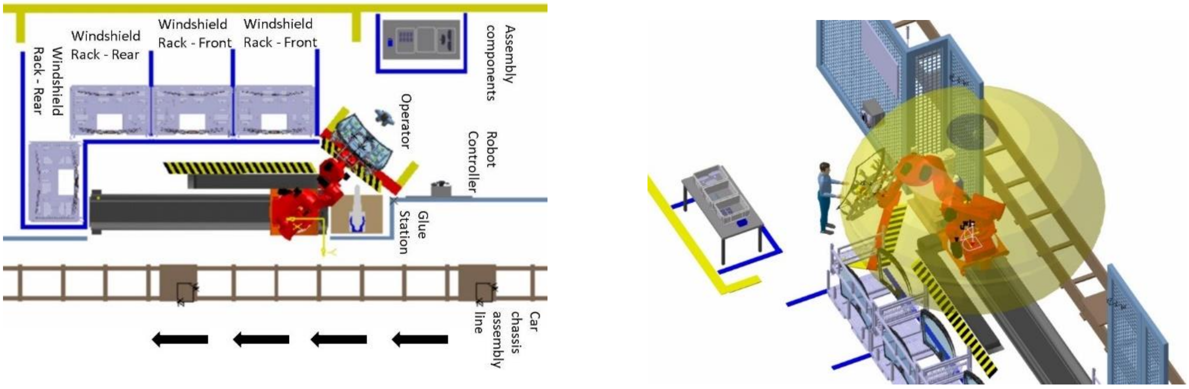

Figure 19: Challenge 2: Collaborative Layout

In the reference workstation, the operator needs accessibility to the inner side of the windshield, so the windshield is positioned on a rotating table so that the operator accesses one side and the robot can access the other side after a rotation. Due to the automation present in the workstation, a Safety zone is introduced and monitored with laser scanners so that the operator cannot be nearby the windshield during the rotation phases and the movements of the robot. In order to further limit the accessibility to the dangerous zone, safety fences are positioned to create a corridor which is easily monitored for safety accesses. A safety visual advice is placed on the ground at the limit of the accessible zone (see Figure 20 left).

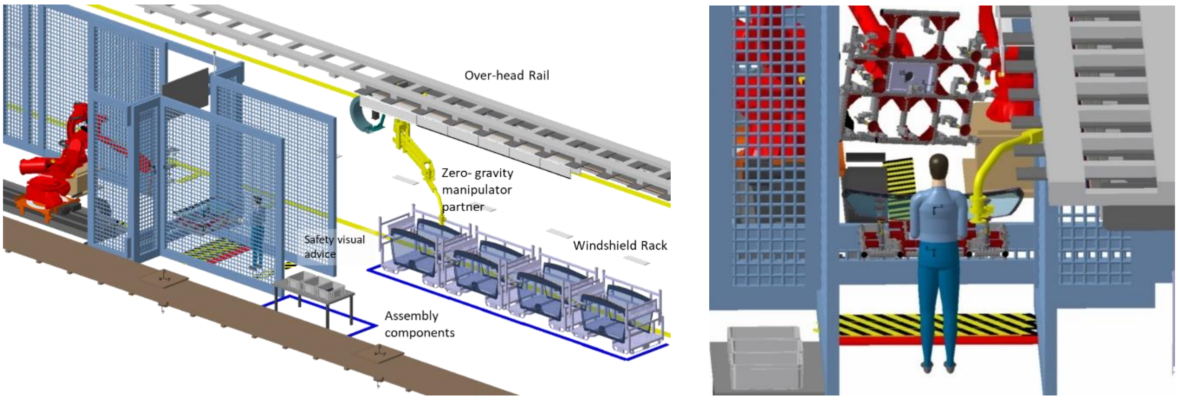

Figure 20: Tools and logistics set up in the reference layout (left) and Human operator inside the assembly station (right)

With such layout the racks containing the windshield and all the logistics containers and gravity shelves are out of the safety delimited zone. A manipulator (mounted on an overhead rail) depicts the zero gravity material handling system which aids the operator to transfer the windshield from the rack to the rotating table system. These rails ensure the reachability from the source (rack) to the assembly station.

An HMI monitor updates the operator with the current variant of the product to be assembled. The operator chooses appropriately the components to be assembled.

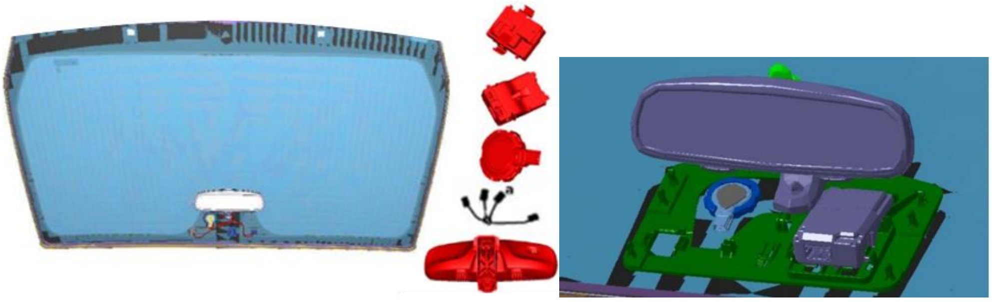

Figure 21: Windshield before assembly and components to be assembled

The rotating table acts as an interface between the human workplace and the robot workstation. The current layout is clearly depicting a traditional layout where humans and robots work in complete isolation, this leads to a very long layout consuming more factory space and also more energy expenditure for the operator to move from one point to another.

As in Figure 21 there are 4 sensors and parts to be assembled; and a cable harness has to be placed. The operator cleans the windshield before every optical sensor assembly and picks up the sensors in a sequence. The coexistence of the safety zone and the quality requirements creates a Spaghetti chart which is extremely long (Figure 22).

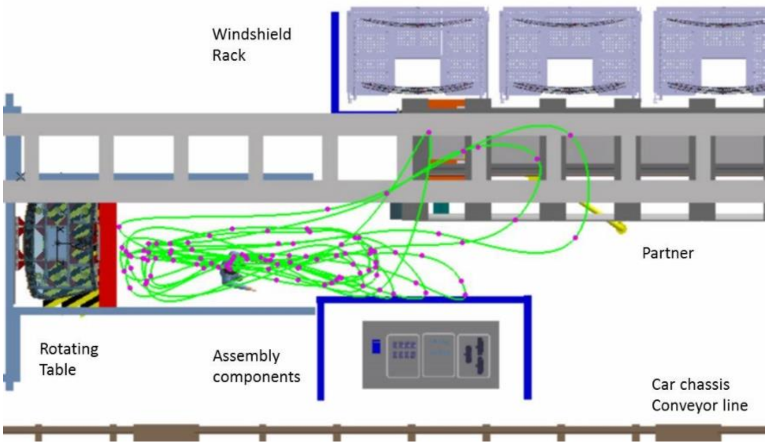

Figure 22: Operator's Spaghetti chart

From the ergonomics point of view the main issues are a long spaghetti chart, the anthropometrics limitations introduced by the fixed equipment, some awkward position that may occur depending on the anthropometry of the operator and the pushing/pulling actions performed on the manipulator that affect the overall operator's fatigue but are not considered in the overall ergonomics indexes.

While for most of the cases the handled parts are small or relatively small, that means that the operation is easy to be performed manually, in some cases the operation requires the handling of cumbersome or heavy parts to be performed with the aid of manual supports (also known as *partners*: zero weight support manipulators). In these cases the operation becomes difficult and requires awkward positions to be performed or eventually the presence of additional fixed supports like table, fixtures and so on. The windshield, weight is ~10 kg and thus it requires a support for the manipulation and the operator may need asked to perform a visual inspection of defects. A deeper analysis is performed with all the details of the operations in D6.3.

2.3.4.1 *Ergonomics*

In the AS IS situation the workcell is considered green without turning. Nevertheless, it is possible to note that some of the working positions of the operator can generate awkward positions in other people at the queues of the anthropometrics percentile distribution. The fixed table, currently used, is placed at a fixed position correspondent to the optimal position for the 50 percentile at a 0° angle from the ground. These factors generate a non-optimal position for many operator and the pushing angle doesn't allow to exert the maximum pressure at the minimum possible fatigue. Similarly, the extensive use of the partner, requested for safety and for the extension of the warehouse with one full and one empty rack for both the windshield and the rear window, causes many push-pull actions. It is a standard procedure to minimize this kind of actions, which on the other hand are not considered in the standard procedures for the determination of the ergonomics class. The use of the robot as an adaptive collaborative platform enables the full adaptability to the operator's anthropometrics and thus strongly improves ergonomics in the workcell.

As stated, the reference workcell is a green workcell, and thus no ergonomics risk is existing if all the operations are performed in the planned way. Nevertheless, minor factors exist that can be further improved. The following table summarizes the situation related to the workcell and the planned operations in the reference case and in the collaborative workcell. It is evident that the ergonomics achievable by the use of the collaborative adaptable worktable is improved for all the main characteristics affecting the overall ergonomics performance.

Table 2: Ergonomics improvements

Specific metric	Reference workcell	HRC adaptive workcell
Ergonomics classification	Green	Green
Spaghetti Chart	High	-68%
Awkward positions	Depending on operator's percentile	Not existing
Golden Zone	Depending on operator's percentile	Always obtained
Worplace personalition	Not Possible	Allowed
Parts insertion angle during assembly	0°	45 ° (Optimal)
Horizontal loads pushing/pulling	Yes, due to the manipulator with high load	Non existing

The overall application and the end effector design are designed in order to reduce the ergonomics impact and optimize all operator's activities. Details on the application and on the end effector design are given later.

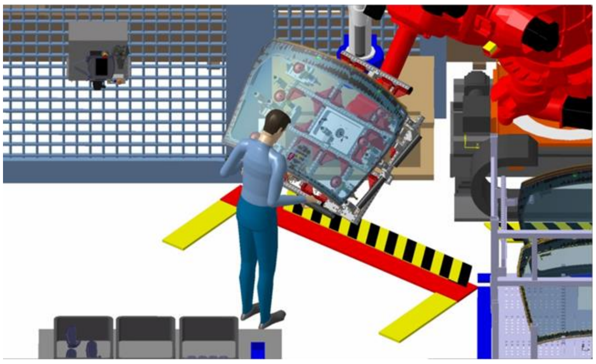

Figure 23: Visual evaluation of golden zone

2.3.4.2 *Spaghetti chart*

The total covered distance per cycle required for the operator (spaghetti chart) is reduced by 68% using the collaborative workcell and the layout enabled by the new configuration. Further reduction in direct human involvement with a further reduction of the spaghetti chart and removal of potentially risky operations can be obtained by automating the windshield rack retainer mechanism.

2.3.4.3 *HRC Collaborative Operating Methods*

As described in Figure 47, the third part of the modified task-MTM analysis provides details of the collaborative modes in the planned robot tasks. The full tables related to CRF Use Case are represented in D6.3, nevertheless the corresponding figure from D6.3 will be copied in this context for further clarity (Figure 24). The approach for the definition of the collaborative methodology has been based on the four collaborative methods as highlighted by the standard ISO 10218 part 2. As stated in the standard, any application can be split into a sequence of the four collaborative methods SSM, SMS, PFL and HG.

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 24: Task analysis of CRF Use Case. Detail of tasks and interactions: robot's phases

2.3.4.4 *Demonstrator's set-up*

The workcell is based on the previously described in-line workstation, and the design of the application was made considering a potential substitution of the technology in-line. This analysis was made in order to define the proper sequence of tasks and to identify the main actors and layout considerations for the demonstrator set-up.

The final setup will be made in CRF premises, adapting an existing robotic cell laboratory. Details on the Layout, functionality and testing scenarios are in D6.3. The following figure (taken from D6.3) represents the 3D simulation of the Workcell with a representation of the main actors involved in the system.

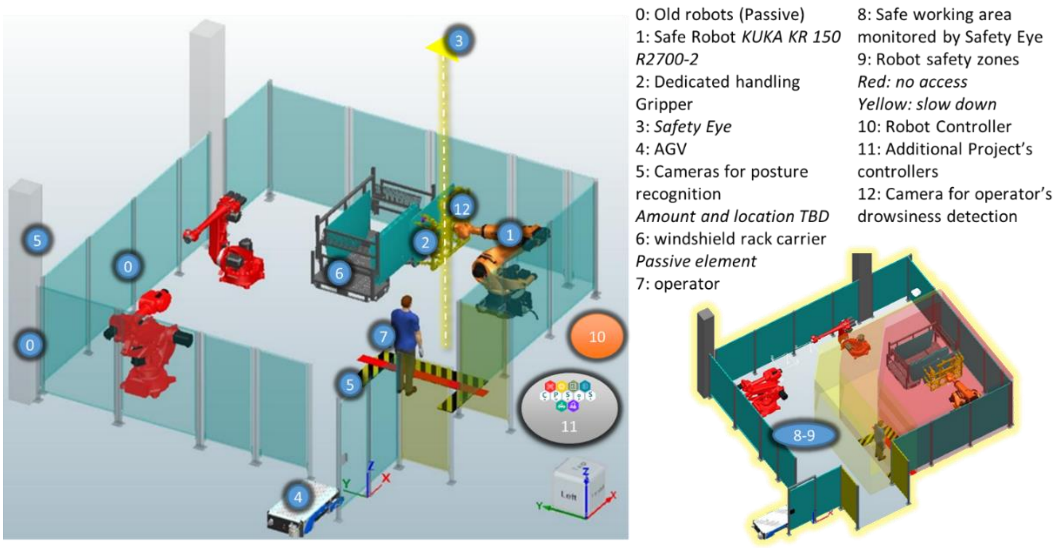

Figure 25: Main Actors in CRF's Pilot

The workcell will comprehend a series of elements necessary for the Use Case functionality and safety implementation. It is important to note that CRF will make a double layer safety on the cell given the high payload of the robot. Figure 25 shows the position of the most relevant elements and actors of the finally implemented system. The overall system architecture is represented in paragraph 2.3.4.5.4.

2.3.4.5 *Robot and related hardware identification*

2.3.4.5.1 ROBOT

Considering the weight of the windshield to be on the order of 15 kg, a first hypothetical design of the gripper end-effector was made with a preliminary weight evaluation of 60-80 Kg. Based on payload requirement, the identified robot is a KUKA KR 150- 2700, with in-built safe feature. The main criteria for the robots selection have been the payload, the reach and the integrated safety. Both robots are PLd Category 3 robots ensuring thus a safe control and stop capability. This kind of robot is inherently safe for the SSM and SMS modes and can be considered safe for the HG mode depending on the gripper safety properties. The full safety in the workcell will be achieved with the supervision of a vision based safety system (Safety Eye by PILZ). The safe control of the robot, together with the Safety management of the operating zones by the Safety Eye, will allow safe operations for some kind of interaction. The end-effector is designed to allow the operator to perform a slight orientation of the windshield (namely ±20° of angle in most directions, while it is retaining it into a safe position ensuring a "no-fall" behaviour of the windshield itself. In the overall application, it is possible to achieve the required safety. The system will be equipped with an additional load cell for the safe detection of forces exchanged between the gripper and the robot. The addition of the load cell is made for additional safety and control during the Hang Guiding phases.

2.3.4.5.2 End-Effector

A customized gripper is designed for the interaction and comes from the previous project. The robotic manipulator needs to pick the windshield from the rack and grasp it during the assembly and visual inspection check. Existing industrial solution involves using vacuum-based gripping and zero-gravity manipulators for transporting the windshield. Similar grasping methodology is adapted for the new custom gripper. The existing gripper has six vacuum cups to cater to picking both the front and rear windshield of the car chassis. For challenge demonstration purpose, the focus would be on the front windshield, hence a minimal 3 vacuum cup model is proposed.

Figure 26: CAD Model of Rack with windshields

Further, due to the design of the rack shown in Figure 26, a near vertical handling of the vacuum gripper is proposed, where the robot with the gripper (Figure 27) on its wrist approaches the windshield in a direction nearly perpendicular to the shop floor.

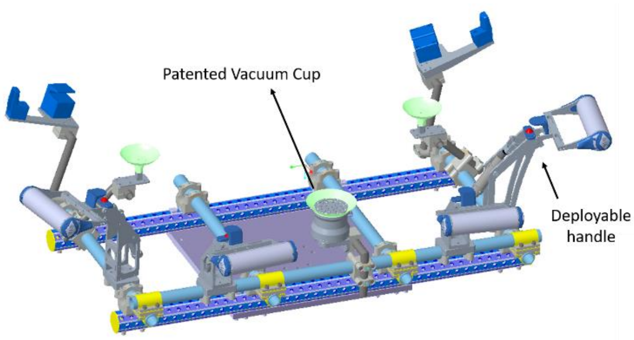

Figure 27: Detailed view of the Custom Gripper

The gripper is optimized to enable human-robot interaction phases in Hand Guiding - HG – mode. The gripper is equipped with retractable handles, mounted on a deployable structure, which are made available only during HRI.

2.3.4.5.3 Safety System

It is important to note the implementation of the Safety EYE system from PILZ for a safe monitoring of the workcell: the Safety Eye is a commercial Safety system that monitors a volume in space using two redundant sets of stereo cameras placed on the ceiling. The System can run multiple Safe parallel programs that can be selected during the project execution. In the Use-case this is requested to ensure safe activities in the workcell by the researchers and will run “above” the demonstrator’s system to monitor and ensure the safe coordination of the robots and the logic of the interlocked doors.

The Safety Eye system is composed by the redundant vision system, the controller industrial PC (for the vision information interpretation, and a Safety PLC to interface with workcell Safety control. Figure 28 represents the Safety Eye commercial system with its active volume and two different types of implementation.

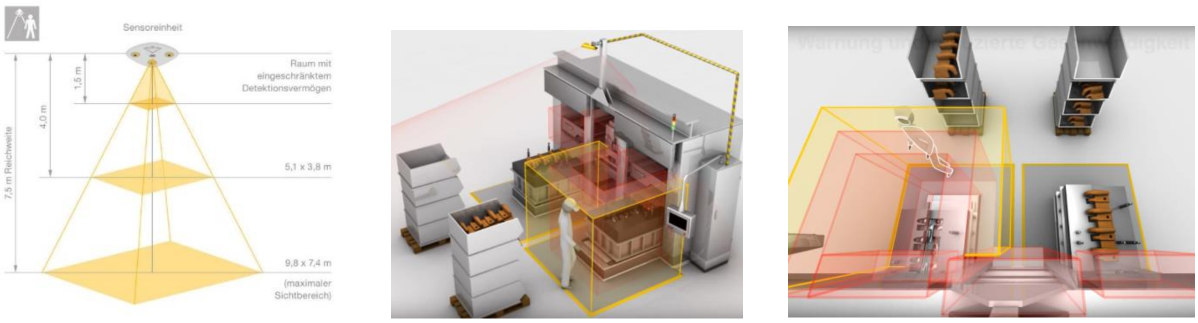

Figure 28: PILZ Safety Eye cone of View and examples of detection volumes

Safety zones are preliminary defined at the ground in three levels (yellow, orange and red) to identify two slow-down zones and one safe Stop zone. Following the requested ground footprint evaluation the field of view and a possible implementation of the vision control zones with red (Safety Stop) and yellow/orange (Warnings) volumes have been analyzed as a function of the Safety Eye height from the ground.

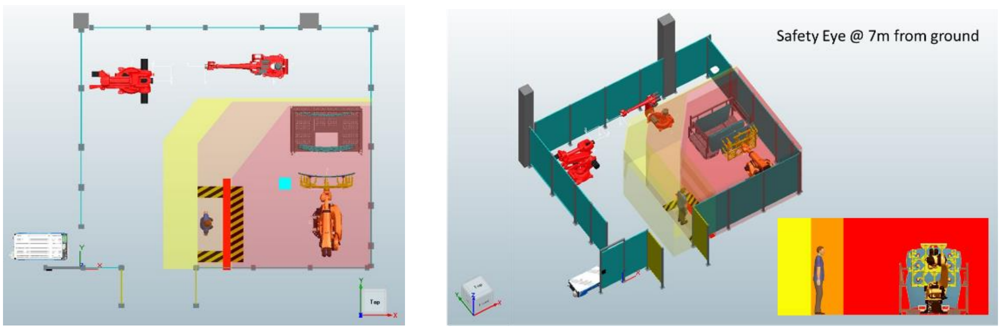

Figure 29: Safety zones in laboratory demonstrator – Ground Footprint safety zones and volumetric representation

During all workcell assembly operations, the operator is capable to interact with the robot only from the front part of the windshield or using the sensitive gripper acting as a spatially distributed HG input device. In the workcell, there is no physical barrier separating the operator from the robot, a fixed visual with a sensor barrier is made.

2.3.4.5.4 Overall system architecture

As described in Figure 30, there is the simplified representation of the overall system architecture of the Pilot workcell.

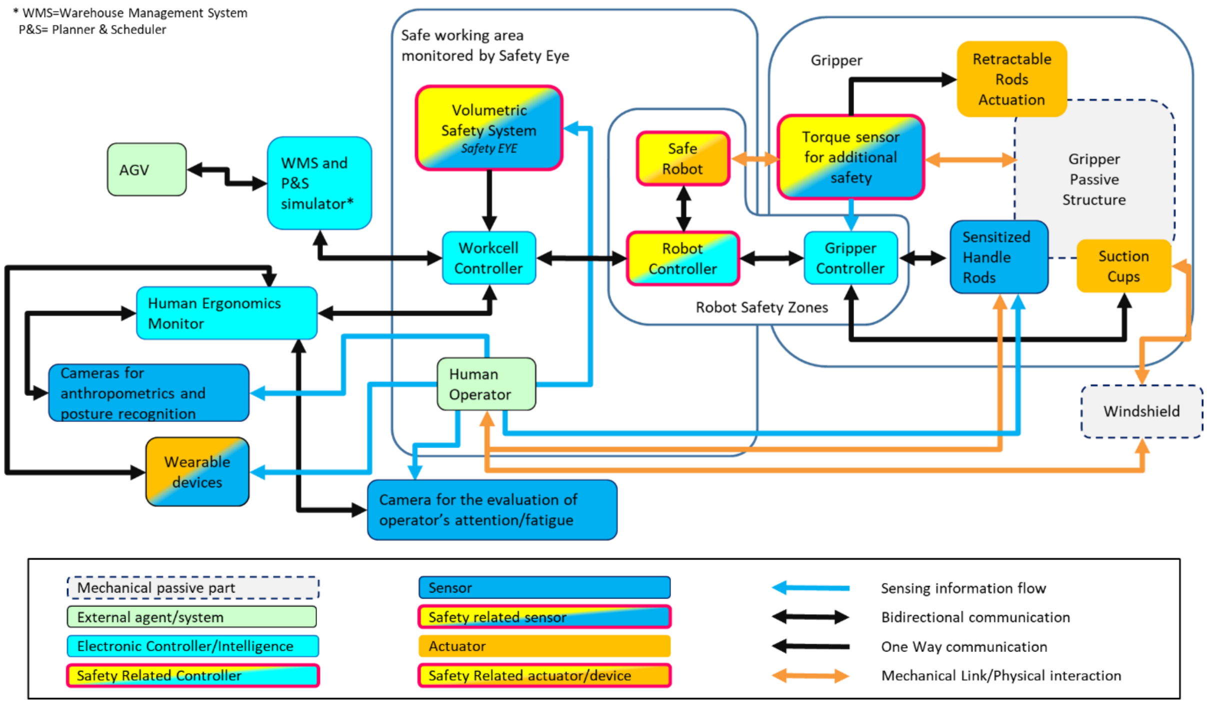

Figure 30: Overall system architecture representation

2.3.4.6 *Interactions and logistics*

The collaborative robotic system is composed of two independent systems: (i) a collaborative robot manipulator: which directly interacts with the human operator to do the main visual assembly and inspection tasks, and (ii) mobile robot: which acts as a secondary unit to bring assembly components to the workcell. The presence AGV is still to be defined in the final pilot solution.

The proper flow of product and its availability in the workstation is of prime importance. In Challenge 2, the product to be processed "Windshield" is constantly made available through a windshield rack and its position is pre-determined in advance, to make it easily accessible to the collaborative robot for manipulation and grasping. Hence, the robots can grasp with required precision and repeatability since the rack design are standardized. The assembly components such as the rear view mirror, wire harness and sensors can be constantly supplied into the shop floor using a mobile robot. In this complete case, the logistics ensures an ease of collaborative operation and tries to minimize the spaghetti chart of the human footprint.

2.3.4.7 *Interfaces requirements & Information exchange (HMIs)*

The necessary HMI in the Use-Case derive from the physical Human Root interaction (for HG mode) with the addition of wearable and fixed information systems that can be defined from the CPSoSaware Project. The operator needs for sure to have a guaranteed flow of information available, yet the final effective solution is still to be defined.

Furthermore, in the scenarios identified for the use-case the presence of additional actors is foreseen. These additional human actors introduce variants of which the operator has to be advised. Also, the additional actors may require identification wearable tools such as smartwatches.

2.3.4.8 *Testing scenarios*

In the current Pilot some scenarios are identified in which the interaction between human operators and equipment is foreseen. See details in D6.3.

3 Technical requirements and KPIs

In Chapter 3, the methodology adopted for the extraction and description of the requirements is presented. The methodological approach presented can be different in the two Use Cases as a consequence of the differences in the business and the applicative approach. Because of this the initial paragraphs will present the description of the approach used in two separate sections: one for the Automotive ADAS application, and the other for the Manufacturing HRC one.

Part of the tools that are used will be described in the specific sections of description of the Use Case to favour the contextualization of the presentation of the tools (e.g. the MTM adapted task analysis for HRC used by CRF).

3.1 Requirements from the Autonomous driving Use Case

Automated Driving Systems (ADS) are a class of cyber-physical systems (CPS) that increase car safety and driving comfort. ADS represent a collection of key technologies for future self-driving vehicles. As a class of CPS, ADS design is a complex task that naturally involves teams of engineers with different specialties such as requirements modelling, control design, software/hardware development, etc. With the increasing adoption of ADS towards truly autonomous vehicles, this task is made even more complex by the importance of taking into account domain-specific requirements and concerns, such as rules and laws, which can be seen as functional and legal requirements for the technology to be put in operation. This includes demonstrating conformance to standards (e.g., safety), considering cultural differences across regions in terms of, e.g., infrastructures and driver behaviour, etc. On this last point in particular, Lindgren et al. [59] state that not taking these differences into account when designing ADS increases the risk of ending up with a product that is not only unusable but also potentially dangerous.

As the complexity of ADS design increases, a holistic methodology is required that is underpinned by formal modelling for all domain-specific concerns and encompasses the whole design process at system level. Systemic modelling naturally accounts for multiple viewpoints, as represented in Figure 31. The system engineering approach based on formal models allows accurate evaluation of multiple candidate designs according to many facets, such as system performance, safety, reliability, autonomy, energy consumption, etc. This, in turn, brings crucial competitive advantage for adopters, since it enables early-stage evaluation of design choices, keeps the development costs low and the time-to-market short.

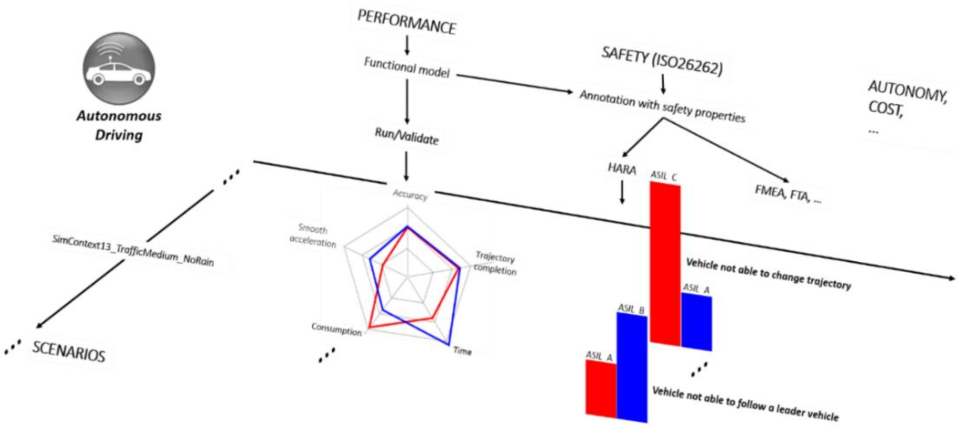

Figure 31: Holistic methodology enables thorough assessment of multiple ADAS design criteria

Safety and security engineering both focus on system-wide features and need to be integrated adequately into the existing process landscape. Safety engineering is already an integral part of automotive engineering and safety standards, such as the road vehicles functional safety norm ISO 26262 [60].

3.1.1 Methodology for ADAS design and verification

The first step concerns the modeling of requirements and vehicle end-missions. At this stage, the customer specifies the requirements for what concerns safety, performance and quality aspects. The system engineers use SysML [61] and PhiSystem [62] to define the stakeholders and the associated requirements for each stakeholder. Examples of such requirements are conformance to civil code and traffic laws, and to ISO26262 standard [12][60] for road vehicles functional safety. The main vehicle's capabilities are identified as well, such as *mobility*, *navigability* and *livability*. Models of vehicle's end-missions are conceived, and the stakeholder requirements are allocated to the end-missions.
In the second step, system engineers model the vehicle's key functions in the so-called *Logical Solution Definition*. The system's functional architecture is represented at a high level of abstraction as a set of interconnected functional units. Examples of such functional units are *motion and navigation*, which are made of sub-units such as *perception*, *localization* and *vehicle guidance*. Other examples include *energy management* and *thermal comfort*. Test scenarios are defined as well, according to required Use Cases. Automated tools process the high-level functional and test scenario (SysML) models and generate a Simulink model which is used by simulation engineers to prototype and validate control strategies and algorithm ideas at the early phases of design process. Unsatisfactory performances from simulation verdicts may trigger design iterations, where, e.g., end-mission requirements or their allocation to vehicle's key functions are refined.
The frameworks for functional safety, Automotive SPICE, and cybersecurity standards all assume a structure analysis of system, subsystem, hardware, and software architecture for new product development as well as an engineering V-model evaluation (see Figure 32 for an example of structure analysis). Each of these elements has its own project plan (APQP) and more specific functional safety, cybersecurity, and software project plan. Both ISO 26262 Functional Safety (FS) and ISO 21434 Cybersecurity (security) have a concept phase where a risk analysis is conducted to identify the ASIL level or CAL of the product. The ASIL or CAL are safety or cybersecurity related hazards and/or requirements that are the output of the Hazard and Risk Analysis (HARA) and the Threat and Risk Analysis (TARA). These requirements are identified in the Functional and Cybersecurity Safety Concept.
The new automotive standards do not address manufacturing process design for the system, subsystem, or hardware elements of the structure. The focus is solely on product design, with no mention of the production part approval process (PPAP), where the testing is performed using production parts made in the production environment. Automotive SPICE or software processes don't enter the discussion on the concept phase. The system requirements which are the result of the concept phase are the start of AUTOMOTIVE SPICE standards.
Following structure analysis is the engineering V-model that links the design of the system, subsystem, hardware, and software via functions and requirements. The design flows down on the left side of the V-model and is complemented by testing as the product is recursively tested upward on the right side of the V-model (see Figure 32). The engineering V-model requires features and requirements from stakeholders to flow down and incorporate into functions and requirements at the system, subsystem, hardware, and software levels. It is a more detailed evaluation in that there is an interim architectural requirement that focuses on interfaces. Those familiar with design failure mode and effects analysis (DFMEA) can think in terms of a block diagram, but the engineering V-model goes even further. Each requirement has a unique ID, and the incorporation is traced into each level or element of the structure. For software there is system, module, and unit-level incorporation based on the software's structure.

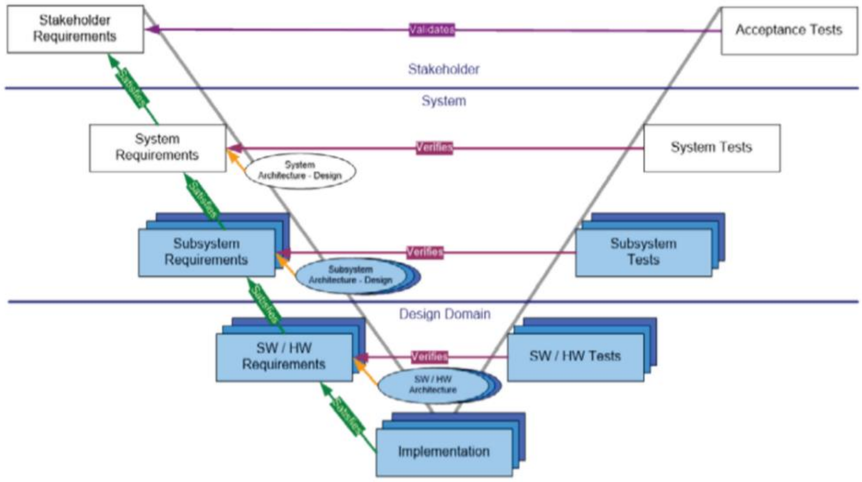

Figure 32: Engineering V-model

In CPSoSaware the observation of user behaviour in automated driving is expected to impact in eight areas; Safety, Mobility, Efficiency, Environment, Acceptance & Awareness, User Experience, System Performance, and Socio-economic. These impact areas are used to create a two-dimensional research question framework (or matrix) in which each research question is allocated to a specific Evaluation area/Impact area combination (Table 3). The use of a two-dimensional research question framework allows the researcher to ensure that a research question is contributing to a specific evaluation area, and under which impact area it is doing so. The allocation of a research question to a specific cell (or cells) of the matrix also allows for identification of overlap and thus allows for more efficient division of workload amongst analysts at the evaluation stage.

		Evaluation Areas			
		1.Technical & Traffic Evaluation	2.User & Acceptance Evaluation	3.Impact Evaluation	4.Socio-Economic Impact Evaluation
Impact Areas	a.Safety				
	b.Mobility				
	c.Efficiency				
	d.Environment				
	e.Acceptance& awareness				
	f.User experience				
	g.System performance				
	h.Socio-economic				

Table 3: Research Question Searching Framework

The research question setting process was started by a thorough review of the existing literature to identify main factors related to different impact areas and knowledge gaps relating to user or driving behaviours when using automated driving functions. In addition, repeated cycles of 'research question generation – review – edit and addition' were conducted to ensure coverage of all major topics with the potential to affect future knowledge, society or business. The first stage of research question setting focussed on high- level questions that need to be answered per evaluation area, are displayed below, categorised per evaluation area (RQ Level 1) (Table 4).

Technical and Traffic Evaluation
• What is the system's technical performance? • What is the impact on the driving behaviour? (Considered during manual driving and AD) • What is the impact of ADF on the interaction with other road users? • What is the impact of the ADF on the behaviour of other traffic participants?
These questions focus on the readiness of the ADF for implementation and on impacts of the ADF on driver behaviours, such as speed and headway distribution, and interaction with other road users
User and Acceptance Evaluation
• What is the impact on user acceptance and awareness? • What is the user experience?
These questions focus on facets of the user experienced including use, transfer of control, interaction.
• What is the impact on safety? • What is impact of ADF on environmental aspects? • What is the impact of ADF on travel behaviour? (Exposure)
These questions focus on the potential wider impacts of ADFs on safety, environment and mobility.
Socio-Economic Impact Evaluation
• What are the socio-economic impacts of ADF?
These questions focus on the scaling up of the impacts of the ADFs to the Europe level, and the cost-benefit analysis of their use on European roads.

Table 4: Research Question Level 1

The second stage of research question setting involved development of these into more detailed questions relating to specific components of the higher-level questions (e.g. different aspects of user acceptance (RQ Level 2), before going one step further to ask questions about specific Use Cases, driving situations or performance indicators (RQ Level 3), where appropriate.

RQ Level 1	RQ Level 2	RQ Level 3
What is the impact on user acceptance & awareness?	Are drivers willing to use an ADF?	Are drivers willing to use an ADF?
	How much are drivers willing to pay for the ADF?	How much are drivers willing to pay for the ADF?
	What is the user acceptance of the ADF?	What is the perceived safety of the ADF?
		What is the perceived comfort of the ADF?
		What is the perceived reliability of the ADF?
		What is the perceived usefulness of the ADF?
		What is the perceived trust of the ADF?
		How is user acceptance influenced by system behaviour in unexpected Use Cases?
	What is the impact of the ADF on driver state?	What is the impact of ADF on driver stress?
		What is the impact of ADF on driver fatigue?
		What is the impact of ADF on driver workload?

	What is the impact of ADF use on driver awareness?	What is the effect of ADF use on driver attention to the road/other road users?
		What is the impact of ADF on driver risk perception?
	What are drivers' expectations regarding system features?	What are drivers' expectations regarding system features?

Table 5: An example of the three-level approach to setting Research Questions

3.1.1.1 *Hypothesis Generation*

From the more detailed research question (RQ Level 3), specific hypotheses were generated to guide the 'Evaluate' stage. This process led to the generation of greater than 100 detailed hypotheses. The output of this process was a spreadsheet of Research Questions and associated hypotheses defined by Evaluation area, Impact area, and AD function. This process has the effect of increasing the depth of questions asked within the project, and linking hypotheses to specific ADFs and Use Cases.

3.1.1.2 *Identifying Use-Cases*

In order to test the hypotheses, requirements for objective data have to be determined for the pilot studies. In this section we present the methodology for identifying requirements, then the logging needs for the pilot are presented and linked to the Research Questions (and their associated hypotheses) in subsequent section. The next step after hypothesis generation is to derive the requirements for each hypothesis. For this process, a distinction is made between subjective and objective data, which have to be collected during the pilot. Whereas subjective data will be collected by questionnaires that are evaluated in the User and Acceptance Evaluation, objective data will be extracted mostly from the data logging systems in the vehicle, from additional cameras mounted on the vehicle, and where required, from external data sources as well (e.g. weather information, road type etc.). This data is afterwards analysed in the Technical and Traffic Evaluation and the User and Acceptance Evaluation (where appropriate). A list of signals for logging in the vehicle will be derived from the hypotheses defined previously, (see Table 6). For the evaluation areas the Research Questions are specified on three levels. Based on these the hypotheses are defined. In this context, the indicators necessary for answering the hypotheses are identified. Finally, the requirements in terms of signals to be recorded are derived based on the formulas for calculating the indicators

Evaluation Area	Technical & Traffic
RQ level 1	What is the impact of the ADF on driving behaviour?
RQ level 2	What is the impact of the ADF on driven speed in different scenarios?
RQ level 3	What is the impact of the ADF on driven speed in driving scenario X?
Hypothesis	e.g. 1: There is no difference in the driven mean speed for the ADF compared to manual driving. e.g. 2: There is no difference in the standard deviation of speed for the ADF compared to manual driving.

Evaluation Area	Technical & Traffic
Performance indicators required	Mean speed, standard deviation of speed, max speed, plot (speed/time)
Logging requirements / sensors available	CAN bus of vehicle: Ego speed in x-direction

Table 6: An example of how logging requirements were defined per hypothesis.

In order to establish a structured process for deriving the requirements, a table containing all Research Questions and their associated hypotheses for the respective evaluation areas (Technical and Traffic, User and Acceptance, Impact and Socio-economic Impact Evaluation) should be prepared. Within this table, all Research Questions have an individual RQ-ID. The preliminary hypotheses derived for each RQ are also ascribed the same RQ-ID. As shown in Table 7, the requirements are added to the table by linking them in a matrix structure with hypotheses. With this structure, all relevant requirements, e.g. lateral acceleration, could be linked to a hypothesis, and thus to a Research Question. For quantitative analyses, the hypotheses will often include the required performance indicator in its phrasing. In this case, the selection of the required performance indicator and desired logging needs is rather simple. In other cases, the hypotheses are less prescriptive in terms of the required performance indicator, and thus surrogate measures need to be identified from past research. Following the definition of these surrogate measures, the logging needs for these hypotheses can be defined. In the latter example, it is often necessary to define and measure a new performance indicator, especially in situations where the research is novel i.e. the first on-road test of a L3 ADF.

						Requirements			
						Vehicle Data			
Evaluation area	RQ-ID	RQ Level 1	RQ Level 2	Hypotheses	Performance indicators	Throttle position	Brake pressure	Longitudinal velocity	…
Technical & traffic	$RQ\text{-}T_1$					0	0	0	1
	$RQ\text{-}T_2$					0	0	1	1
	$RQ\text{-}T_3$					0	0	1	0
	$RQ\text{-}T_4$					0	0	1	1
	$RQ\text{-}T_5$					0	0	1	1
	….					0	0	1	1

Table 7: Framework for allocation of requirements to research questions

This process of deriving requirements will be carried out for all defined hypotheses. We will summarize, requirements linked to their higher-level research questions (RQ Level 2) for ease of presentation. In the subsequent sections, we will present a stepwise progression from Research Questions to hypotheses to performance indicators, then logging needs has been followed in this work.

3.1.1.3 *List of Requirements for Autonomous Driving Sensing*

The requirements are derived by using the method described in above. In order to structure these, data categories were introduced. These 'types of data' with their description are introduced in Table 8.

Type Of Data	Description
General information on vehicle	General information on attributes of the vehicle, e.g., wheelbase, length and width of vehicle. No continuous signals.
Ego vehicle data	All signals, which give information on the current state of the ego vehicle, e.g., speed of ego vehicle in x-direction, steering wheel angle.
Information on system	Here, all signals giving information about the state of the evaluated ADF, e.g. whether the ADF is active.
Object data, information for relevant objects	All signals referring to relevant dynamic and static objects, e.g., distance to relevant object in x-direction.
Lane marking data	In order to detect if a vehicle enters the lane of the ego-vehicle, information on lane markings is necessary, e.g., distance to left lane marking.
Other environmental information (e.g. from map)	In order to know the number of lanes or the road type the vehicle is driving on, additional data is necessary.
Traffic sign data	Here, all signals giving information on traffic signs are represented, e.g., speed limit of current road section.
Video	All video signals for investigating relevant situations in detail, e.g., front video data.

Table 8: Types of Data Requirements and their description

The project requires a series of different data streams to test the diverse range of hypotheses across the four evaluation areas. This necessitates a range of sensors with the ability to measure a vast array of driver, vehicle and environmental factors.

3.1.1.4 *Linking Research Questions with Captured Data and KPIs*

This section lists Research Questions per Evaluation area. The top two levels of research question are displayed, with their associated data. In all cases, research questions have been further developed and linked to an Impact area under which their effects will be evaluated. Note that where data exists for a meaningful analysis of between human related factors such as age, gender, personality, and driving experience, these covariates will be considered. In addition, where the experimental design allows, possible longitudinal effects of system interaction will be considered. For this reason, the effects of these factors are not listed as separate Research Questions in this chapter. Note that where vehicle data is listed as the logging requirement, this includes alternative external data sources in instances where the required data is not available from the vehicle. For example, if weather information cannot be extracted from vehicle sensors and video annotation, external sources of this data will be sought.

3.1.1.4.1 Technical & Traffic Evaluation

RQ-ID	RQ Level 1	RQ Level 2	Logging requirements	Key Performance Indicators (KPIs)
RQ-T$_1$	What is the system's technical performance?	How reliable is system performance in a given driving and traffic scenario?	Vehicle data	System status, distribution of longitudinal velocity per driving scenario and situation variables
RQ-T$_2$		How often and under which		System status, distribution of longitudinal velocity per driving scenario and situation variables

RQ-T$_{3}$		circumstances do the ADFs issue a takeover request?	Vehicle data	System status, distribution of longitudinal velocity per driving scenario and situation variables
RQ-T$_{4}$	What is the impact on the own driving behaviour?	Are there any traffic violations while using the ADF?	Vehicle data	Distribution of difference between speed and speed limit, distribution of distances to other objects, frequency of overtaking manoeuvres in overtaking prohibitions
RQ-T$_{5}$		How do take-over requests affect driving?	Vehicle data	Distribution of lateral and longitudinal acceleration and velocity
RQ-T$_{6}$		What is the impact of ADF on the driving comfort?	Vehicle data	Distribution of longitudinal acceleration
				Distribution of lateral acceleration
RQ-T$_{7}$		What is the impact of ADF on the accuracy of driving?	Vehicle data	Distribution of longitudinal and lateral position at defined time positions
				Distribution of position in lane
RQ-T$_{8}$		What is the impact of ADF on the driven speed?	Vehicle data	Distribution of velocity
RQ-T$_{9}$		What are the impacts of ADF on energy efficiency?	Vehicle data	Distribution of fuel consumption and speed
RQ-T$_{10}$		What is the impact of ADF on the frequency of near crashes / incidents?	Vehicle data	Frequency of harsh braking
				Frequency of unintended lane departures
RQ-T$_{11}$		What is the impact of ADF on the frequency of certain events?	Vehicle data	Frequency of detected driving events
RQ-T$_{12}$	What is the impact of ADF on the interaction with other road users	What is the impact of ADF on the interaction with other road users in a defined driving scenario?	Vehicle data	Distribution of THW, encroachment time, proportion of stopping distance, post encroachment time, initially attempted post encroachment time
			Vehicle data	Distribution of velocity and acceleration of other road users
				Distribution of velocity of other road users, Frequency of incidents caused by pedestrians
				Distribution of TTC
RQ-T$_{13}$		What are the impacts of ADF on traffic efficiency	Vehicle data	Distribution of longitudinal velocity, crossing time, waiting time, longitudinal acceleration

RQ-T$_{14}$		What is the impact of ADF on the number of near-crashes / incidents with other road users?	Vehicle data	Frequency of near crashes
				Frequency of near crashes with VRU
RQ-T$_{15}$	What is the impact on the behaviour of other traffic participants?	How does the ADF influence the behaviour of subsequent vehicles?	Vehicle data	Distribution of longitudinal acceleration of other road users
RQ-T$_{16}$		How does the ADF influence the behaviour of preceding vehicles?	Vehicle data	Frequency of passive cut-in manoeuvres
RQ-T$_{17}$		What is the impact of ADF on the number of near-crashes / incidents of other traffic participants?	Vehicle data	Frequency of harsh braking of subsequent vehicles

3.1.1.4.2 User & Acceptance Evaluation

RQ-ID	RQ Level 1	RQ Level 2	Logging requirements	Key Performance Indicators (KPIs)
RQ-U$_{1}$	What is the impact on user acceptance & awareness?	Are drivers willing to use an ADF?	Proportion of driving time in automated mode, interview/questionnaire for parking function	• Proportion of driving time in automated mode. • Questionnaire for parking function • Annual survey • Site-specific questionnaire
RQ-U$_{2}$		How much are drivers willing to pay for the ADF?	Questionnaire	Willingness to pay

RQ-U3		What is the user acceptance of the ADF?		ADF specific questions to participants (pre, post use at each site); based on pre-existing acceptance questionnaires, tailored to suit automated driving functions Annual survey: non-participants
RQ-U4		What is the impact of ADF on driver state?	Questionnaires & interviews	ADF specific questions Online physiological measurements possible. Hand position on the steering wheel can be used as a proxy for stress, and could be obtained from video
			Videos and eye-tracking	Subjective data/video coding. Rating of driver video, subjective rating, eyelid-based indicators
			Questionnaires	Post-trip workload questionnaires
RQ-U5		What is the impact of ADF use on driver awareness?	Eye tracking, questionnaires	Eye-tracking - percent road centre, proportion of time spent looking at specific regions of interest (e.g. mirrors), number of glances and mean/max/SD glance duration would also be useful if eye-tracking available. Some of these could potentially be coded from video - simplistic coding of glance location may be useful as a compromise.
				Participant questionnaire on perceived risk (does this differ from safety)? Response time to hazards e.g. brake reaction time to lead vehicle or pedestrian-related events
				General questionnaire on detection of objects in scene during automated mode and nonautomated mode. This would require some 'scripting' of events
RQ-U6	What is the user experience?	How often and under which circumstances do drivers choose to activate/deactivate the ADF?	Video (coded for system activation deactivation, therefore codebook required asap)	Video coded for environment variables: road type, VRU presence, speed limit, traffic density, weather, lighting conditions.

3.1.1.4.3 Socio-economic Impact Evaluation

RQ-ID	RQ Level 1	RQ Level 2	Logging requirements	Key Performance Indicators (KPIs)
RQ-S_1	What is the socio-economic impacts of ADF?	What is the net welfare gain in a certain societal scenario?	Input from the previous safety & environmental impact assessment Additional information: Cost of functions and vehicle (other sources), Cost of injuries (other sources) / repair, benefit due to additional gain spare time, society data (other sources), Cost due to traffic today (other sources)	Input from the previous safety & environmental impact assessment Additional information: Cost of functions and vehicle (other sources), Cost of injuries (other sources) / repair, benefit due to additional gain spare time, society data (other sources), Cost due to traffic today (other sources)
RQ-S_2		What is the overall socioeconomic impacts for different groups?	Input from the previous safety & environmental impact assessment Additional information: Cost of functions and vehicle (other sources), Cost of injuries (other sources) / repair, benefit due to additional gain spare time, society data (other sources)	Input from the previous safety & environmental impact assessment Additional information: Cost of functions and vehicle (other sources), Cost of injuries (other sources) / repair, benefit due to additional gain spare time, society data (other sources)

3.1.1.4.4 Next Steps & Recommendations

Research questions and hypotheses developed and presented in this document are the starting point for the work that will follow in the next iteration of the deliverable. Based on this work, the next will be:

- Developing the experimental design needed to answer the Research Questions. Due to the variability of research areas a mixture of different experimental procedures will presumably be needed; Datasets from previous projects National and EU projects will also be considered to determine whether they can offer useful (baseline) data for the AD functions evaluation.
- Collecting and describe methods to be used for answering the Research Questions and introducing mathematical formalizations that quantify the output. A range of methods will be needed to effectively answer Research Question covering technical aspects (e.g., change of vehicle behaviour compared to manual driving), user-related concepts (e.g. acceptance), and impact of the ADFs (e.g. on safety, environment, and general societal effects).

3.1.2 Requirements Analysis for the Automotive Use Case

As discussed above, autonomous driving systems must meet expectations from various stakeholders such as the internal engineering teams, passengers, regulatory authorities, and commercial fleet operators. The system must also meet multiple types of requirements Table 9. While requirements are typically developed based on stakeholder expectations, factors such as the concept of operations, enabling support strategies, the measure of effectiveness, and the industry safety standards is mandatory to be considered. For example, the requirements should follow the safety standards such as ISO/PAS 21448 (or SOTIF)[14] and ISO 26262 [12] to produce the intended functions that could be declared safe and minimize risks in case of system and component failures, respectively.

	Types of Requirements
Requirements that service as input to technical requirements	• Functional • Performance • Interface • Safety • Comfort • Reliability • Sustainability
Technical	• System • Subsystem • Component

Table 9: Concepts of requirements for Autonomous Vehicles

An analysis of the requirements into the afore mentioned categories and a subsequent discussion on the importance of each of them and the impact that they produce regarding safety, performance and refinement of the societal impacts will be performed.

3.1.2.1 *Statistical Processing of the Requirements*

This subsection aims at revisiting the description and the analysis of the user and system requirements of the CPSoSaware platform in the automotive use-case. From an overview analysis of the outcomes the distribution of URs according to their functionality is presented in the following graph.

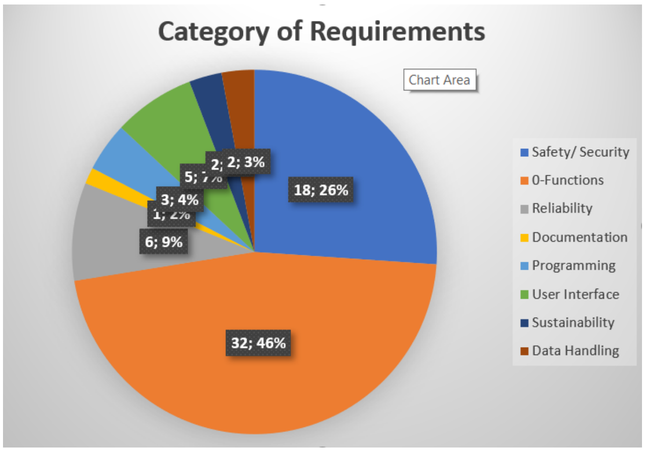

Figure 33: Distribution of Requirements Categories

Figure 33 shows that, besides the functional requirements, the higher attention in the use-case is toward system requirements (0-functions), which actually comprise basic functionalities dictated by existing Standards and protocols, which are mandated to be followed. Safety and security requirements follow as the fulfilment of the latter are crucial to align with the promised impact of the CPSoSaware project. The detailed analysis of the functional requirements will be made in the following text.

Another clustering of the user requirements has been made according to the field "**Complexity in CPSoSaware**" in the table ***User Requirements – PASEU*** described before. This field describes the preliminary complexity estimation for the implementation in CPSoSaware. It is a preliminary analysis considering if the specific UR will be implementable, complex to implement (to the level to require additional dedicated efforts) or "automatic". Automatic means that the UR is important, but it is already achieved by the purchased hardware/software that will be implemented on the pilot. The unfeasible UR refers to user-requirements that are requested in the use-case, but that are unfeasible in the CPSoSaware Pilot because of pilot's constraints. Due to the high safety standards prevailing in automotive safety testing we don't have any such requirements as their satisfaction would not be allowed to be tested.

Figure 34 represents the frequency distribution of User & Systems Requirements considered in the Automotive Use Case.

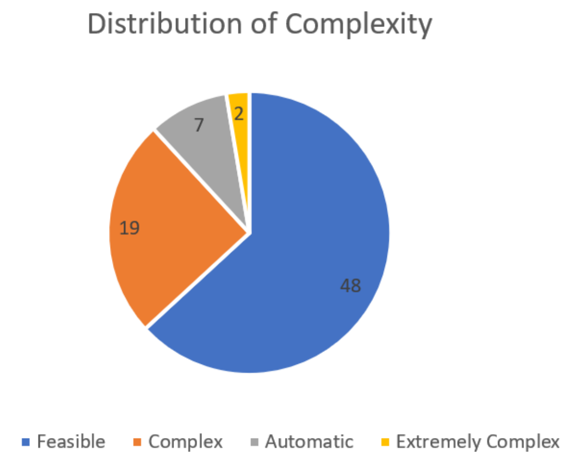

Figure 34: Distribution of the *complexity of Requirements for the Automotive Use Case*

As it is apparent some part of the requirements that need to be full filled fall in the categories complex/ extremely complex field, mainly due to the fact that in the automotive use case CPSoSAware aims at providing complex solutions embodying features from the environmental modelling, the intercom and the driver monitoring fields. Moreover, part of the requirements fall into the "Automatic" field. These are mainly system requirements that are mandated to be followed by the ISO 26262 [12] standard.

In addition to this preliminary analysis, D1.2 also performs high level analysis of the 74 Requirements, the most relevant 25 have been selected identifying the top ranked ones.

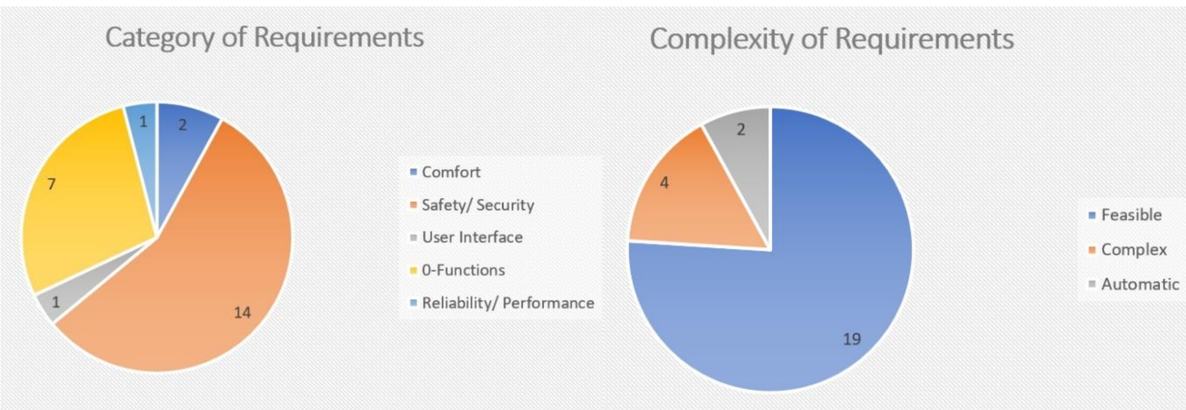

Figure 35: Category and Complexity of the top 25 Requirements

From the list of requirements, a first level distinction of Functional and non- Functional requirements have been done. In the functional distribution, the percentage of functional requirements in the automotive use case is significantly higher than the number of non-functional requirements. This perfectly aligns with the promised impact that CPSoSAware will deliver in the automotive pillar in terms of enhancing safety/ security indexes along with the excellence that the project will bring in launching state of the art technologies in the field of co-operative awareness and driving monitoring. As being expected the non-feasible or the highly complex URs are not listed within the top ranked 25.

3.1.2.2 Analysis of Functional Requirements for the Automotive Use-Case

Throughout this subsection some of the functional requirements of the CPSoSaware platform for the automotive use-case will be revisited. The URs (see Annex 3) have been renamed according to the (see Annex 3) "F-Req-nn" form with the numbering in order of ranking. The F-Req-01UR is thus the more relevant Functional UR of the list. The "*automatic*" type of URs are listed in details since no further development is expected on them.

Table 10: Functional Requirement 1, corresponding to UR_01

ID	F-Req-01 (UR 01)
Name	The system shall detect a moving pedestrian (normal adult's size with normal walking speed) who has 6m of lateral offset vertically to driving tube of Ego vehicle and crossing the driving tube of Ego vehicle (with moving speed of maximum 20 kph) in daytime and at enough lighting conditions at night time.
Requirement Type	Functional
Description	The perception engine needs to be able to detect moving pedestrians on the vicinity of the ego-vehicle (at distances as those mentioned above and at speeds relevant to those mentioned above). The pedestrian detector needs to be robust to a wide diversity of human appearance and postures.
Fit Criterion (Measurable)	The function needs to be able to perform at either 10Hz or at 30Hz at the front and rear camera of the ego-vehicle.
Conflicts	-
Constraints (Attainable)	The moving pedestrians needs to be within the area of capture of the camera excluding the blind spots.
Author	PASEU
Revision	V1.3.5, 31st of March, 2021

Table 11: Functional Requirement 2, corresponding to UR_16

ID	F-Req-02 (UR 16)
Name	The system shall detect a moving cyclist (normal adults size with normal cycling speed) who is moving if font of the vehicle (in middle) and with a speed less than ego vehicle (vehicle speed is less than 20 kph). The system shall first warn then activate AEB system
Requirement Type	Functional
Description	The Automated System must detect cyclists on the vicinity of the ego-vehicle (at distances as those mentioned above and at speeds relevant to those mentioned above). The detector must be robust across a wide diversity of human appearance and postures.
Fit Criterion (Measurable)	The function needs to be able to perform at either 10Hz or at 30Hz at the front and rear camera of the ego-vehicle and should deliver accurate results when the ego vehicle is either static or moving.
Conflicts	-
Constraints (Attainable)	The moving pedestrians needs to be within the area of capture of the camera excluding the blind spots. Also the cyclists should be detected irrelevantly of the part of the image where the cyclist moves on (Camera axis or perpendicular to it)
Author	PASEU
Revision	V1.3.5, 31th of March, 2021

Table 12: Functional Requirement 3, corresponding to UR_30

ID	F-Req-03 (UR 30)
Name	While the vehicle is in Auto-Parking mode and approaches the parking space in reverse gear (with speed of maximum 6 kph), it should detect a stationary sitting child in middle of the parking slot in daylight.
Requirement Type	Functional
Description	The Automated Driving function should perform scene understanding and collision avoidance, when it is in parking mode as well, not only on driving. The object of interest (child) should be detected accurately, independently of the appearance/ pose etc…
Fit Criterion (Measurable)	The function needs to be able to perform at either 10Hz or at 30Hz at the front and rear camera of the ego-vehicle and should deliver accurate results when the ego vehicle is either static or moving.
Conflicts	-
Constraints (Attainable)	The object of interest could be at any part of the image (camera axis, sides etc) excluding the blind spots.
Author	PASEU
Revision	V1.3.5, 31th of March, 2021

Table 13: Functional Requirement 4, corresponding to UR_38

ID	F-Req-04 (UR 38)
Name	The Auto Parking Module shall apply it's own safety margins to the detected obstacles to be sure that safety distance to the objects will be applied
Requirement Type	Functional
Description	The Parking Function follows some specific margins for allowing distances between the ego vehicle and neighboring obstacles while parking.
Fit Criterion (Measurable)	The Parking function needs to park on parking areas and maintain specific distances from all the surrounding obstacles.
Conflicts	-
Constraints (Attainable)	No constraint
Author	PASEU
Revision	V1.3.5, 31th of March, 2021

3.1.2.3 *Non Functional Requirements*

In continuation to analysing the functional requirements, this subsection will present the structure and the constraints of some basic non-functional requirements of the CPSoSaware platform for the automotive use-case. Table 14 summarizes some of the most important non-functional requirements. The requirements related to safety have been inserted in the list of detailed URs given the critical importance even is classified as "automatic".

Table 14: Overview list of the non-functional requirements

ID	Original ID	Type	Requirement name
I-Req-01	UR 52	User Interface	The driver of the vehicle should be able to cancel the parking maneuvers of Auto parking system at any time.
I-Req-02	UR 41	User Interface	The Auto Parking Module shall provide the requested motions of the vehicle as a single package assigned with an ID. To ensure the expected behavior of the vehicle.
I-Req-03	UR 61	User Interface	An Android device with an API higher than 28 and a front camera available shall be present within the vehicle.
I-Req-04	UR 62	User Interface	An Android application shall be implemented to provide the DSM functionality.
I-Req-05	UR 63	User Interface	The Android DSM application shall notify through proper alerts the driver if the DSM detects high level of drowsiness or lack of attention.

C-Req-01	UR 40	Configuration	The APM should not request higher speed than for safety limit defined in it's "config" file.
DH-Req-01	UR 68	Data Handling	The system will preserve adequate levels of data integrity.
DH-Req-02	UR 69	Data Handling	The system will preserve adequate levels of data availability.
R-Req-01	UR 66	Reliability	The system will be robust to deterioration of LIDAR quality.
R-Req-02	UR 70	Reliability	The system will preserve adequate levels of system availability/continuity of operations.
S-Req-01	UR 71	Sustainability	The system will preserve adequate levels of accountability.
S-Req-02	UR 65	Sustainability	The system will be robust to deteriorated image quality in a way that can be either inspected or not by HVS.
P-Req-01	UR 57	Programming	The SW architecture should be designed with an appropriate management of shared resources.
P-Req-02	UR 56	Programming	The SW architecture should be designed with restrictions on size and complexity of software components.
P-Req-03	UR 55	Programming	The SW architecture should be designed with an appropriate hierarchical structure of the software components.
D-Req-01	UR 47	Documentation	The vehicle controller shall report its failures to the Auto Parking Module.

As it is apparent from the table above, the matching of shortcuts to terms is as follows in Table 15:

Table 15: Matching of shortcuts to requirements terminology

I-Req	User Interface Requirement
C-Req	Configuration Requirement
DH-Req	Data Handling Requirement
R-Req	Reliability Requirement
S-Req	Sustainability Requirement
P-Req	Programming Requirement
D-Req	Documentation Requirement

3.1.2.3.1 User Interface Requirements

Table 16: I-Req-01

ID	I-Req-01 (UR 52)
Name	The driver of the vehicle should be able to cancel the parking maneuvers of Auto parking system at any time.
Requirement Type	Non-functional - User Interface
Description	The driver should be able to cancel the parking maneuvering. This is an HMI feature that also serves as a comfort feature. The driver should not follow the directions of the automated system if he does not feel convenient.
Rationale	The driver should approve the automated functions for safety/ comfort reasons.
Fit Criterion (Measurable)	The interface achieves high usability score during testing by the drivers.
Conflicts	-
Author	PASEU
Revision	V1.3.4, 25th of March, 2021

Table 17: I-Req-02

ID	I-Req-02 (UR 41)
Name	The Auto Parking Module shall provide the requested motions of the vehicle as a single package assigned with an ID. To ensure the expected behavior of the vehicle.
Requirement Type	Non-functional - User Interface

Description	The Auto Parking Module presents to the driver the available routes for the destination parking position and the driver needs to select one of them in order the vehicle to move along the designated route.
Rationale	The function needs to select one amongst the proposed paths for parking. These proposals correspond to parking positions that guarantee a high level of safety. High distance between the ego vehicle and surrounding vehicles.
Fit Criterion (Measurable)	The proposed parking positions are those that can be accessed by the vehicle in less than 3 strokes and where the safety margin between the ego-vehicle and all surrounding obstacles at the target position is higher than 20cm
Conflicts	-
Author	PASEU
Revision	V1.3.6, 5th of April, 2021

Table 18: I-Req-03

ID	I-Req-03 (UR 61)
Name	An Android device with an API higher than 28 and a front camera available shall be present within the vehicle
Requirement Type	Non-functional - User Interface
Description	The Android device and a camera with specific API is used to assess the driver's awareness and provide the alerts.
Rationale	The usage of more than one resources is very critical for both the assessment and the awareness
Fit Criterion (Measurable)	The maturity and applicability of the function will be evaluated based on module and unit tests. The accuracy needs to be higher than 80%
Conflicts	-
Author	PASEU
Revision	V1.3.6, 5th of April, 2021

Table 19: I-Req-04

ID	I-Req-04 (UR 62)
Name	An Android application shall be implemented to provide the DSM functionality
Requirement Type	Non-functional - User Interface
Description	The DSM application will also be hosted in the android device in order the alert to be more efficient.
Rationale	The mobile device needs to be used in order to stabilize the assessment of driver's awareness and provide more efficient alerts.
Fit Criterion (Measurable)	The system must be able to assess the awareness of the driver and raise alerts. There are unit tests used to assess the accuracy.
Conflicts	-
Author	PASEU
Revision	V1.3.6, 5th of April, 2021

Table 20: I-Req-05

ID	I-Req-05 (UR 63)
Name	The Android DSM application shall notify through proper alerts the driver if the DSM detects high level of drowsiness or lack of attention
Requirement Type	Non-functional - User Interface
Description	The system should accommodate alerts when the driver's attention, detected through drowsiness, is very low.
Rationale	The DSM application needs to alert the driver if his attention is low. This happens in order the safety level to be enhanced.
Fit Criterion (Measurable)	The interface must contain at least 90% of the functionality in graphic form and not in words.
Conflicts	-
Author	PASEU
Revision	V1.3.6, 5th of April, 2021

3.1.2.3.2 Configuration Requirements

Table 21: C-Req-01

ID	C-Req-01 (UR 40)
Name	The Automate Parking Module (APM) should not request higher speed than for safety limit defined in it's "config" file.
Requirement Type	Non-functional - Configuration
Description	There is an upper limit of speed (safety margin) for the Automated Parking Module. This is defined in the configuration files and the driver cannot request above it.
Rationale	The upper limit of speed for the automated parking module has been defined through extensive testing and the driver cannot ask to go beyond it.
Fit Criterion (Measurable)	The higher velocity for Automated Parking is 15kph. The driver cannot go beyond it
Conflicts	-
Author	PASEU
Revision	V1.3.6, 5th of April, 2021

3.1.2.3.3 Data Handling Requirements

Table 22: DH-Req-01

ID	DH-Req-01 (UR 68)
Name	The system will preserve adequate levels of data integrity
Requirement Type	Non-functional - User Interface
Description	Sanity check of the data need to be performed before the data are fed to the sensing functions.
Rationale	After the data recorded, sanity check runs on the data in order to guarantee data integrity. e.g: alignment in terms of timestamps, synchronization between the sensors, frame drops, sensors not provided input etc.....
Fit Criterion (Measurable)	The data recording checks whether the synchronization discrepancy between sensors is lower than 0.4msec
Conflicts	-
Author	PASEU
Revision	V1.3.6, 5th of April, 2021

Table 23: DH-Req-02

ID	DH-Req-02 (UR 69)
Name	The system will preserve adequate levels of data availability
Requirement Type	Non-functional – Data Handling
Description	All data that the sensing functions need to work should be provided by the system
Rationale	The input of the sensing function needs to be aligned with the data recorded by the system.
Fit Criterion (Measurable)	The data needed by the sensing functions need to be provided 100% by the vehicle
Conflicts	-
Author	PASEU
Revision	V1.3.6, 5th of April, 2021

3.1.2.3.4 Reliability Requirements

Table 24: R-Req-01

ID	R-Req-01 (UR 66)
Name	The system will be robust to deterioration of LIDAR quality
Requirement Type	Non-functional – Reliability Requirement

Description	The sensing functions need to be robust along a diverse set of signal quality deformations in order to address efficiently cyber security attacks or other sensor problems
Rationale	Robustness of the system along a set of image deformations is critical for automotive safety
Fit Criterion (Measurable)	A test benchmark will be used in order to measure the accuracy of the sensing functions when specific deformations are applied
Conflicts	-
Author	PASEU
Revision	V1.3.6, 5th of April, 2021

Table 25: R-Req-02

ID	R-Req-02 (UR 70)
Name	The system will preserve adequate levels of system availability/continuity of operations
Requirement Type	Non-functional – Reliability Requirements
Description	The system needs to be available along a variety of different occasions (weathering conditions, lighting conditions, cybersecurity attacks etc)
Rationale	In order the system to be usable on real driving scenarios it need to be available along a wide range of conditions.
Fit Criterion (Measurable)	The accuracy of the system on corner cases (weathering conditions/ cybersecurity attacks) will be tracked during the Software in the Loop and Hardware in the Loop testing, The functions need to score more than 80% in terms of the accuracy in the difficult scenarios.
Conflicts	-
Author	PASEU
Revision	V1.3.6, 5th of April, 2021

3.1.2.3.5 *Sustainability Requirements*

Table 26: S-Req-01

ID	S-Req-01 (UR 71)
Name	The system will preserve adequate levels of accountability
Requirement Type	Non-functional – Sustainability Requirements
Description	The output of the system when presented to similar use-cases needs to be deterministic and provide similar levels of accuracy.
Rationale	The deterministic behavior of the system is a property that is enforced by the national legislations.
Fit Criterion (Measurable)	The repeatability/ accountability of the system behavior will be monitored by the software and hardware in the loop tests. The behavior and accuracy of the system needs to be similar when tested on similar use-cases
Conflicts	-
Author	PASEU
Revision	V1.3.6, 5th of April, 2021

Table 27: S-Req-02

ID	S-Req-02 (UR 65)
Name	The system will be robust to deteriorated image quality in a way that can be either inspected or not by HVS
Requirement Type	Non-functional – Sustainability Requirements
Description	The sensing functions need to be robust along a diverse set of image quality deformations in order to address efficiently cyber security attacks or other sensor problems
Rationale	Robustness of the system along a set of image deformations is critical for automotive safety

Fit Criterion (Measurable)	A test benchmark will be used in order to measure the accuracy of the sensing functions when specific deformations are applied
Conflicts	-
Author	PASEU
Revision	V1.3.6, 5th of April, 2021

3.1.2.3.6 Programming Requirements

Table 28: P-Req-01

ID	P-Req-01 (UR 57)
Name	The SW architecture shall be designed with an appropriate management of shared resources
Requirement Type	Non-functional - Programming
Description	The software architecture principle that will be used involves parallelizing and pipelining the software in order the usability of shared resources to be maximized.
Rationale	The solution needs to be ported on embedded platform, so the maximization of shared resources usage is critical.
Fit Criterion (Measurable)	The embedded architect will supervise the process by using some specific tools e.g.: OpenVX in order to assess whether this requirement is satisfied.
Conflicts	-
Author	PASEU
Revision	V1.3.6, 5th of April, 2021

Table 29: P-Req-02

ID	P-Req-02 (UR 56)
Name	The SW architecture shall be designed so as to restricts size and complexity of software components
Requirement Type	Non-functional - Programming
Description	It consists a software design approach in order to guarantee that the software component is algorithmically optimized and easily ported on embedded platforms.
Rationale	The software components should go through an optimization phase that eliminate redundancies and optimize the complexity in order to achieve the solution that achieves the desired accuracy with lowest possible complexity.
Fit Criterion (Measurable)	The runtime profile and num of operations should be reviewed jointly by the Embedded Architect and the hardware architect to judge the maturity of the module
Conflicts	-
Author	PASEU
Revision	V1.3.6, 5th of April, 2021

Table 30: P-Req-03

ID	P-Req-03 (UR 55)
Name	The SW architecture shall be designed with an appropriate hierarchical structure of the software components
Requirement Type	Non-functional - Programming
Description	The hierarchical design of the software components facilitates the reusability of already tested modules, which in turn brings benefit in (a) the reduction of development time and (b) the easier alignment with the V-model.
Rationale	Hierarchical software design helps the development and testing process.
Fit Criterion (Measurable)	The reusability of software components and the number of redundant software modules Is the criteria.
Conflicts	-
Author	PASEU
Revision	V1.3.6, 5th of April, 2021

3.1.2.3.7 Documentation Requirements

Table 31: D-Req-01

ID	D-Req-01 (UR 47)
Name	The vehicle controller shall report its failures to the Auto Parking Module
Requirement Type	Non-functional - Documentation
Description	The vehicle controller outputs data to the log file concerning the time, duration, coordinates of the parking slot as well as the reasons for failure.
Rationale	The collection of statistical data and temporal data are subsequently analyzed to draw conclusions on the stability and safety level of the function.
Fit Criterion (Measurable)	There is an upper limit of failures (3) that the system is allowed to make. If this is exceeded, the maturity of the application is tagged as low.
Conflicts	-
Author	PASEU
Revision	V1.3.6, 5th of April, 2021

3.2 Requirements from the Manufacturing Use Case and Scenarios

In this same document (Paragraph 2.2) the manufacturing Use Case has been outlined. Its definition and identification starts from plant requirements with a particular attention to the ergonomics (the spaghetti chart reduction). Other requirements come directly and intrinsically from the characteristics of the HRC and are strongly related to the identified functionalities in the use-case.

Further requirements are extracted from initial considerations on the description of the application to be realized, the robotic workcell and its operational scenarios.

Interviews with internal CRF experts have been contacted in relation to the use-case in order to highlight different points of view on the workcell and extract all necessary user-requirements.

3.2.1 Methodology and tools used

3.2.1.1 *User requirements*

In order to have a comprehensive analysis of the Use Cases, a mixed methodology, a combination of qualitative and quantitative methods, is applied [65]. The qualitative perspective offers an understanding of the users' perceptions by considering non numerical data such as text, pictures or videos [66], while the quantitative approach uses numerical values, used here to quantify the data and validate choices [67].

In order to gather the data an internal analysis of the CRF Use Case was made by the researchers involved in the project. In support to the identification of the user requirements a set of questions was prepared to discuss with the experts about the application: the points of major interest were so extracted and analysed from the description of the application, the robotic workcell and its operational scenarios.

A group of experts from CRF have been interviewed in relation to the specific use case that will be implemented within the project context. The original procedure used to extract the requirements started from the following set of questions.

1. In what environments must the robot operate?
2. Are there any dangers, which the robot must react to?
3. Are there any danger that the robot can generate?
4. What functions must the robot perform?
5. What functions must the operator perform?
6. What are the mission requirements?
7. How accurate must the operations be performed?
8. Which are the optimization criteria?
9. What kind of interaction is required between the user and robot?
10. What other kind of interaction is required with the environment?
11. What kind of feedback the user requires from the environment?
12. Is it necessary to modify the environment?
13. Which negative aspects are in the reference use-case in relation to the operators (in terms of physical impacts, expectation, uncomfortable use…)
14. Which solutions could be possible?
15. Is training available/possible?
16. Would training support/help the operator?

The questions, referred to the analysed use-case and scenarios, define a minimum set of information; other areas of interest are identified from international standards, laws and regulation, and from internal standard operating procedures in automotive manufacturing related to human-machine interaction, safety and ergonomics.

After the first analysis of the basic functional requirements, each requirement has been deeply analysed in term of sub-functions and features which are themselves requirements for the use-case.

This analysis brought to a list of 78 URs for the manufacturing Use-case.

After the definition of the 78 user requirements, an activity of classification, ranking and scoring has been performed in order to highlight the most relevant for the development inside the project activities.

3.2.1.2 *Ranking of the User-Requirements*

The user-requirements have been collected in an excel sheet for the ranking and scoring phases. The Excel sheet is intended to collect, classify and score the User-Requirements in the CPSoSaware use-cases. The Excel file contains two sheets for each use-case (manufacturing and automotive) with slightly different contents. As for the manufacturing use case we have:

Sheet ***User Requirements - CRF***: requirements' collection and initial classification. The fields in the description of the User Requirements are:

1. **ID:** sequential Identification code.
2. **Originated from:** System that is responsible for the achievement of the specific requirement.
3. **User Requirement** Explicative title of the User Requirement.
4. **Category** Categorization of the UR according to the functional and non-functional categories adopted in the Volere representation (e.g Function, Configuration / Adaptability, Safety / Security).
5. **Implementation in Reference use-case** Level of Expectation in relation to the implementation in the reference use-case. Related to the Business case, but not to the specific Project's development.
6. **Implementation in CPSoSaware** Similar to the above in respect to the CPSoSaware Project's Pilot (expectation might be different considering that the pilot's HW setup and layout differs).
7. **Complexity in CPSoSaware**: Preliminary complexity estimation for the implementation in CPSoSaware.

Some of the above fields are used in the scoring of the UR, others are only descriptive for clarity.

				Implementation		
ID	**Originated from**	**User Requirement**	**Category**	**Implementation in Reference use-case**	**Implementation in CPSoSaware**	**Complexity in CPSoSaware**
UR_01	Robot+ End effector	The system shall be able to handle heavy payload	0-Functions	Expected	Expected	Automatic
UR_02	Robot+ End effector	The system shall be able to withstand strong reaction forces from the operator	0-Functions	Expected	Expected	Feasible
UR_03	Robot+ End effector	The solution shall be able to change the position of the handled object by HG (Hand Guiding function - ISO 10218:2)	0-Functions	Expected	Desired	Feasible
UR_04	System	The System shall learn from the user's feedback in order to be proactive to the next steps	0-Functions	Desired	Desired	Complex
UR_05	System	The robot shall be able to adapt to each operator that uses the workcell (adaptation to anthropometrics)	0-Functions	Expected	Expected	Feasible

Figure 36: User-Requirements table extract

Figure 36 is a screenshot of the user requirements table. The full table is inserted in Annex 2.

Sheet ***Ranking and scoring - CRF Case:*** Scoring and ranking of the requirements. This sheet collects scoring from the end-user (both as operator and as "end-user" intended as the company investing on the Use-Case technology) and scoring from the technology and research developers.

The aim in the scoring is the selection of the most important user-requirements to be implemented in the use-case. In this table the scoring is made both from the user point of view (CRF) and from the partnership.

RANKING AND SCORING																			
			Ease of			Operator Perspective					End-User Perspective						Development		
	Requirement / Criteria	Total score	Ref.	CPS.	Final Impl	High Usability	Intuitivity	Satisfaction	Dissatisfaction	Average	Economics	Productivity/ Flexibility	Quality	Ergonomics	Safety	Average	TRL Equally averaged partners scoring	Feasibility Equally averaged partners scoring	Integrability Equally averaged partners scoring
			10%			25%					20%						15%	15%	15%
UR	Weighting		20%	80%		40%	20%	20%	20%		16,7%	16,7%	16,7%	25%	25%				
	Compiler		CRF			CRF					CRF						Partners	Partners	Partners
UR_01	The system shall be able to handle heavy payload	2,70	3	3	3	5	1	5	5	4,2	2	4	5	5	5	4,333	2	1,6	1,6
UR_02	The system shall be able to withstand strong reaction forces from the operator	2,70	3	3	3	5	3	5	3	4,2	3	3	5	5	5	4,333	2,2	1,6	1,6
UR_03	The solution shall be able to change the position of the handled object by HG (Hand Guiding function - ISO 10218:2)	2,20	3	2	2,2	4	3	5	2	3,6	2	3	2	4	4	3,167	1,6	1,6	1,4
UR_04	The System shall learn from the user's feedback in order to be proac	1,67	2	2	2	3	2	5	2	3	1	2	1	3	1	1,667	1,6	1	1,6

Figure 37: User-Requirements scoring from the user and development point of view - table extract

Figure 37 is a screenshot of the user requirements scoring table. The full table is inserted in Annex 2. The scoring provided by the user was defined by the CRF team in a joint meeting analyzing each and every UR highlighted in the first phase. Score was given according to the following fields:

Ease of implementation

a) **Ref.**: A numerical Value related to "**Implementation in Reference use-case"**
b) **CPS.**: A numerical Value related to " **Implementation in CPSoSaware"**

For both the above fields a numerical value is assigned as: Accepted=0 / Desired=2 / Expected=3 / Indifferent=1 / Undesired=-3

Final Impl: Weighted average of the above: ref*20%+CPS*80%

The Use-Requirements definition has been made considering the possible point of view of the main stakeholders in the plant. In the following paragraphs the role in the plant organization for the main stakeholders is described with more detail; in the table we made a difference between the operator perspective (that weight the system behaviour mainly upon criteria of satisfaction, usability, ease of use and so on, and the End-User which is mainly represented from the management level of the plant and is weighting the system behaviour upon criteria of cost, performance, productivity and so on.

All the following parameters are scored in a scale from 1=very low impact, to 5=high positive impact. 0 corresponds to a negative expected impact.

Operator perspective:

- **"High Usability"** defines if the implementation of a requirement would have a negative or positive impact on usability by the operator.
- **"Intuitivity"** Tells how the implementation of a requirement affects the intuitivity of using the system.
- **"Satisfaction"** Defines the satisfaction a requirement will bring to the operator if it will be implemented.
- **"Dissatisfaction"** Defines the dissatisfaction a requirement will bring to the operator if it will NOT be implemented.

End-User perspective:

- **"Economics"** defines in which degree the implementation of a feature would give a positive impact on the economics factors (considered as a single parameter related to costs, both direct and indirect). 5=most appreciated=lower costs.
- **"Productivity/Flexibility"** defines in which degree the implementation of a feature would give a positive impact on the factory productivity or capability to perform a flexible production (increased Job per Hour, reduction of NVAA…).

- **“Quality”** defines in which degree the implementation of a feature would give a positive impact on the product quality (both in term of “final result” and in term of reduction of efforts necessary to reach the quality level required).
- **“Ergonomics”** defines in which degree the implementation of a feature would give a positive impact on the Operator’s ergonomics.
- **“Safety”** defines in which degree the implementation of a feature would give a positive impact on the Operator’s safety.

Both the operator perspective parameters and the end-user perspective ones are weight averaged according the respective weight indicated in the table. The choice of the weights is such to give higher impact to:

1. URs whose implementation is feasible within the framework of the CPSoSaware project
2. Operator’s perspective
3. Aspects affecting positively the operators (ergonomics, safety)
4. All other aspects

After the User’s perspective further scoring have been assigned by the partners according to three main scales:

Development:

- " **TRL** " The scale expresses if the technology is advanced enough for a requirement to be implemented.
- " **Feasibility** " Shows in which degree the implementation of a requirement is feasible within the project framework.
- " **Integrability** " Defines how easy is for every requirement to be integrated into the robotic system .

The scores from the partners have been averaged equally. The resulting averages of the above scores are weight averaged in a single Total score parameter.

3.2.1.3 *Stakeholders*

The Use-Requirements definition has been made considering the possible point of view of the main stakeholders in the plant.

As described in the paragraph 2.3.1.2 there are find 5 different organizational levels.

The highest level is represented by the Plant Manager, who is the responsible for all activities that occur in the plant and as such the one who organizes and distributes the work inside. Each Area Manager (one for Operating Units) will collect the specific production needs of each individual area from the Plant Manager and then involve the Supervisor, who will communicate the workloads to the Team Leader and then distribute them to the individual workers of each station.

In the Figure 38, we present the relationship between the different levels of the production plant and in particular which are the specific skills to achieve all objectives.

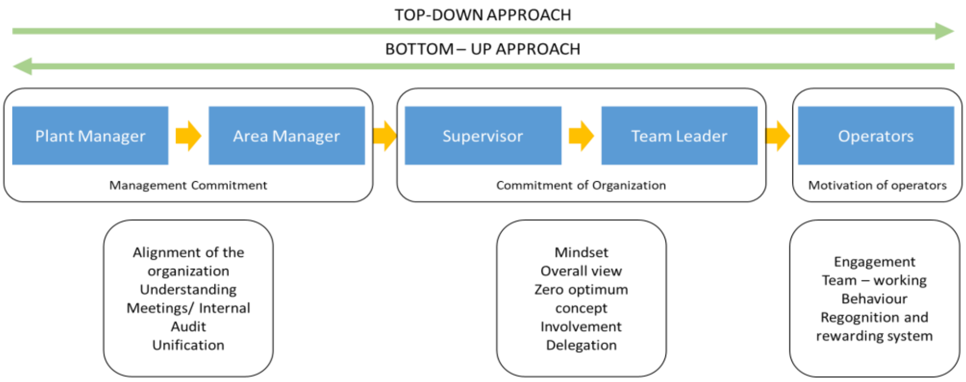

Figure 38: Relationship between 5 levels of the organization

The information flow of communications follows a double track: coming both from top to bottom and vice versa. The involvement of operators and their active participation in the activities is a very important aspect for each organizational reality. It will be the task of the Plant Manager and its first levels (Area Manager and Supervisor) to transmit the right commitment to their collaborators, so that the correct mind-set is guaranteed. Another important aspect is the ability to delegate, without which Team Leaders and operators would not reach full awareness of their work.

Like any team that works and wins, the internal organization of the plant must also be based on those principles that work and that allow the achievement of increasingly challenging objectives.

For major level of detail about the stakeholders' landscape, it is possible to identify two different levels: internal production stakeholders and external production stakeholders:

Internal stakeholders include the specific Operating Units: Press Shop, Body in White (BiW), Paint Shop and Final Assembly and all people involved in these units in each level.

External stakeholders include: HR (Human Resources) department, Finance, Procurement, HSE (Health Safety and Environment) department, Logistic and Supply Chain department, Maintenance and WCM (World Class Manufacturing) coordinator.

Each level of stakeholders have different approaches and expectations in relation to the requirements of the Human Robot Collaboration. The following table tries to summarize these aspects.

Table 32: Expectations related to HRC by internal stakeholder categories

Operators	They are the end users of the technology; they are mainly interested by usability, improvements, ergonomics, safety, relief from heavy work activities and so on. They can as well oppose or dislike the introduction of the new technology because of the fear to lose their job.
Team Leaders	They are end-users with an organizational approach; they consider mainly time execution, quality target achievements, ease of maintenance, amount of stops; team personnel wellness. Their job is heavily affected by operators' wellbeing, and as such they can consider this aspect as a priority.
Supervisors	They coordinate parts of the line directly from the field; they consider all the aspects considered by the Team-Leaders, but also coordinate the logistics and the Maintenance in their lines. Maintenance, simplification of logistics activities, amount of stops and generically the line functionality will be to be
Area manager	Considers the same parameters of the supervisors at Area level; they are proxies for the safety of the operators
Plant manager	Considers econometric aspects related to the productivity and profitability of the plant. HRC can affect these parameters where applied

Transversal to all these function there are the responsible of Logistics and maintenance for which:

Table 33: Expectations related to HRC by internal, transversal stakeholder categories

Logistics	Considers the ease of interface at the line side. Logistics can be one of the main end-users as well since HRC can support and simplify many manual operations that are made in incoming logistics (unloading of trucks, components preparation, kitting, sequencing, distribution and so on). Logistic operators are among those mainly affected by ergonomics issues.
Maintenance	Being responsible of the maintenance of any equipment, they are heavily involved in the functional verification and programming of the robots (and COBOTs) in use. The complexity of use generates multiple fake support requests. They are strongly affected by Safety having the necessity to interface with the equipment in non-standard situation.

The CRF department "Factory Innovation" participating in the CPSoSaware project is usually approaching its developments facing with all categories of stakeholders and has the habit and capability to empathize with the role of the various organizational levels. The CRF team studied the application taking into account all the main aspects and requirements that can be generated by the various stakeholders to the investigated process. The results, the technical features implemented in the application and the following user requirements comes from this consideration.
The application itself was investigated with the colleagues from the Advanced Manufacturing Engineering processes department and reference plant Assembly Manager (Area manager of the final assembly shop floor) as a confirmation to the approach used.
As for the requirements that may come from the end-user category (the line operators), It is important to note that the usual feedback provided by line operators can be strongly biased by the direct interest in the consequences of the results of these innovative studies. Considering the difficulties to perform any interviews with line operators, CRF used the approach to consider the standard procedures used in human centred application design that already transformed into design procedures the necessities and the expectations of the operators.
For the following description of the requirements, CRF have used the approach formulated by the Volere Methodology.

3.2.1.4 *Volere methodology*

After the definition of Scores to the User-Requirements a ranking have been made and the highest ranked User-requirements are analysed and described using the Volere methodology.
Several requirement specification methodologies have been proposed over the past, with each one introducing different approaches for the categorization of requirements and focusing on a specific type of applications. Although some of these methods have been compared in recent bibliography [55], no wide consensus is reached on, regarding the selection of the optimum methodology based on the needs and the application area of a project.
The first version of the Volere Requirements Specifications template was released in 1995 and focused on a highly detailed structure that tries to integrate the widest possible spectrum of requirement categories. As presented in Figure 39, the Volere template covers the drivers, constraints and the dynamically arising issues of a project, in addition to its functional and non-functional requirements.
Since its first introduction the Volere method has been continuously updated based on the feedback from users and affiliated organizations. The most recent updates are characterized by the increased specificity of requirements as proposed by these organizations.

In detail, the Volere template of Requirement Specification begins with the description of the Project Drivers. The Project Drivers aim to outline market and research related forces that support and justify the project. The following chapter summarizes the Project Constraints which include any type of restriction that affects the design of the project including for example technical issues, and financial limits. The last chapter of Project Issues includes the conditions of the project's development. The intended purpose of this chapter is to present the full spectrum of reasons which would facilitate the success of the project and also indicate the ones that could lead to significant difficulties and failures.

Based on the Volere template the requirements are separated into two fundamental categories namely functional and non-functional. The Functional Requirements describe the desired functionalities that the project should have and how they should be connected in a complete useful final product. The Non-Functional Requirements on the other hand describe the desired properties of all the components of the system such as their performance, efficiency, and usability.

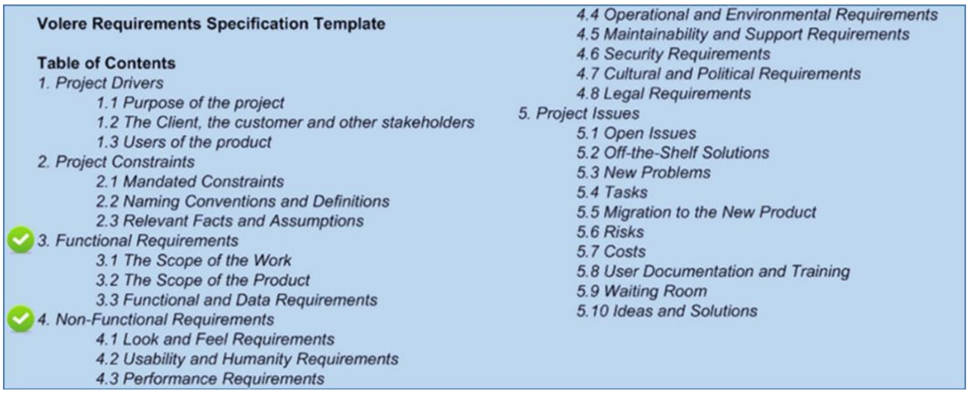
Volere Requirements Specification Template

Table of Contents

1. Project Drivers
   - 1.1 Purpose of the project
   - 1.2 The Client, the customer and other stakeholders
   - 1.3 Users of the product
2. Project Constraints
   - 2.1 Mandated Constraints
   - 2.2 Naming Conventions and Definitions
   - 2.3 Relevant Facts and Assumptions
3. Functional Requirements
   - 3.1 The Scope of the Work
   - 3.2 The Scope of the Product
   - 3.3 Functional and Data Requirements
4. Non-Functional Requirements
   - 4.1 Look and Feel Requirements
   - 4.2 Usability and Humanity Requirements
   - 4.3 Performance Requirements
   - 4.4 Operational and Environmental Requirements
   - 4.5 Maintainability and Support Requirements
   - 4.6 Security Requirements
   - 4.7 Cultural and Political Requirements
   - 4.8 Legal Requirements
5. Project Issues
   - 5.1 Open Issues
   - 5.2 Off-the-Shelf Solutions
   - 5.3 New Problems
   - 5.4 Tasks
   - 5.5 Migration to the New Product
   - 5.6 Risks
   - 5.7 Costs
   - 5.8 User Documentation and Training
   - 5.9 Waiting Room
   - 5.10 Ideas and Solutions

Figure 39: The Volere requirements specification template

As already mentioned the main advantage and quality that separates the Volere methodology over its alternatives is the detail in which the functional and non-functional requirements are identified. In this way, the Volere template facilitates the organisation of the requirements thorough understanding with regards to the project. In addition, Volere offers a formal template for the collection of the requirements in tabular format through its "requirements shell" (also called a "snow card"). The suggested template is illustrated in Figure 40.

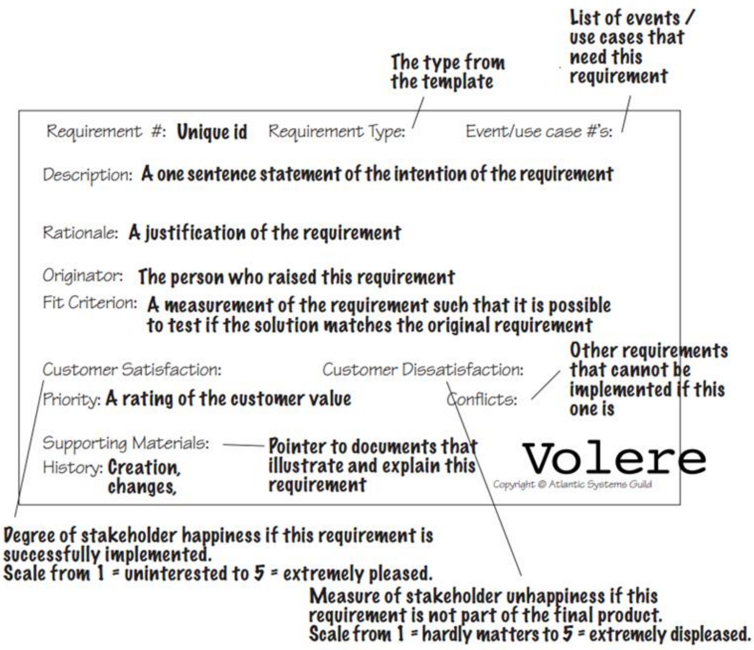

Figure 40: Volere Requirements "snow card" as a guide to writing each atomic requirement

For the description of each specific requirement that belongs to each one of the categories listed in Figure 39, a tabular template was created based mainly on the Volere requirements shell, after applying desired modifications. The final template followed is presented in Table 34.

ID	A unique identifier.
Name	Title of the requirement.
Requirement Type	Functional / Non-functional
Description	A requirement must be described with as much detail as possible. If necessary, an example has to be added.
Rationale	A justification of the requirement.
Fit Criterion (Measurable)	The term measurable refers to the ability to identify if the requirement has been met at the final stages of the project, and after the system has been constructed. In other words this means the tests which must be performed in order to verify whether the requirement has been addressed.
Conflicts	Description of any relation of the current requirement with previously described ones. Special attention to conflict with other requirements whose implementation is blocked by this one.
Constraints (Attainable)	An attainable requirement will usually answer the question: "How can the requirement be accomplished?" Hence, here we explain any constraints / conditions for the requirement to be executed.
Actors	An actor is someone or something outside the system that interacts with it or with one of its components (primary actor). If the actor is interacted by the system or one of its components is a secondary actor.
Author	The owner of each requirement that was recorded.
Revision	This section lists when a version of the requirement was created.
User satisfaction	*Degree of stakeholder satisfaction depending on the successful implementation of the current requirement (Scale from 1=uninterested to 5=extremely pleased). Definition for every category of involved stakeholders (worker, production manager, system technician, researcher).*
User dissatisfaction	*Degree of stakeholder dissatisfaction if this requirement is not implemented (Scale from 1=hardly matters to 5=extremely displeased). Definition for every category of involved stakeholders (worker, production manager, system technician, researcher)*
Priority	*The requirement is ranked according to the value that distinct categories of users attach to it (worker, production manager, system technician, and researcher). (Scale from 1=low priority to 5=highest priority).*
Difficulty	*Level of difficulty for requirement implementation (estimation). (Scale from 1=low difficulty to 5=extreme difficulty).*

Table 34: Template for defining a system requirement

With respect the basic table suggested Volere Template, some fields have been added or removed in order to provide the best descriptions for the CPSoSaware project purposes:

- Constraints, which describes potential constraints / conditions for the requirement to be executed.
- Difficulty, which indicates the level of difficulty for the implementation of this requirement (estimated from a technical point of view). Difficulty ranges on a scale from 1 (=low difficulty) to 5 (=extreme difficulty).
- Actors, indicates either those persons or things that interact externally with the system or one of its components.

Removal/replacement of fields:

- Supporting materials: This field has been also removed because the majority of the documents that are related to requirements will be subjected to IPR.
- Originator (the person who provided this requirement), this field has been replaced by the Author field (the owner of each recorded requirement).
- History this field has been replaced by Revision (indicates versioning).

The last four fields in the table above (in Italic in the texts) will not be detailed in the tables for each UR but only in the overall table listing and ranking all the Selected User Requirements.

In order to adapt the Volere methodology to the needs of the CPSoSaware system, a list of functional and non-functional requirements was selected. This selection was based on their relation and applicability to the current project. The CPSoSaware system requirements are organized as follows:

- *Functional requirements*, i.e. system requirements which are needed for running the Use Cases and the application scenarios.
- *Non-functional requirements*, which include the system requirements which are not mandatory for running the CPSoSaware platform components, but concern the proper usability, performance and expandability of the system.

The non-functional system requirements are split in the following categories:

- *Usability and human requirements, Look and Feel Requirements:* as the CPSoSaware platform aims to offer an integrated set of tools and interfaces, which is user-friendly and user-intuitive, to allow workers, supervisors, system technicians and researchers to interact with the system.
- *Performance Requirements:* requirements which ensure the overall high performance of the system in order to support the conduction of the system training and assembly performance in a short and reasonable amount of time.
- *Reliability Requirements:* the ability to perform RAMIS procedures with low probability of application failure of the CPSoSaware components.
- *Maintainability & Interoperability Requirements:* requirements ensuring the maintainability and interoperability of the CPSoSaware platform.
- *Safety:* requirements ensuring the human safety.

The list of Functional and Non – Functional requirements for CPSoSaware system is adapted to the specific needs related to the use-case and pilot of CPSoSaware manufacturing use-Case and will be explained in the following paragraphs.

3.2.2 Main KPIs for HRC description

Besides of the identified user-requirements, this paragraph poses the attention to some of the KPIs used for the description and evaluation of the collaborative User-requirements. This description is made since many of the KPIs here described represent intrinsic User-Requirements. Not all of the KPIs are listed and reported as user-requirements, but their description supports and integrates the main user-requirements previously identified.

Many of the requirements intrinsically made in any plant have already been analysed and considered in the definition of the main KPIs (Key Performance Parameters). Generic KPIs don't usually fit at the best to Collaborative applications for each use-case and situation. This fact is related to the different nature of the two original fields of applications: the Human and the Robot.

Among manufacturing standard KPIs, those that better fit to HRC should be [66] [69]:

- Non-financial: while it is certainly important to calculate the Return on Investment (ROI) of the collaborative robot, this metric won't tell how to improve its operation.
- Measured continuously: COBOTs make it easy to gather data, since they are able to log it directly within their programs. KPIs should be logged continuously in order to compare both long-term and short-term data and quantify the effect of small changes on the robot's performance.
- Linked with other Operational KPIs: the robot operation affects other KPIs within the business (e.g. time from order to shipment, manufacturing cost per unit, plant downtime). The metrics used for the COBOT should have clear links to broader effects on the business.
- Focused on one or more of the common losses: many of the performance gains in collaborative robotics can be achieved by tackling some common losses. KPIs that reflect these losses will likely point to ways of improving performance.
- Easy to measure: KPIs that are hard to measure won't be measured at all. When picking a KPI, it is important to ask how much time it will take to gather the data.

- Clear and simple: the best KPIs can be understood without any extra training. The simpler they are, the more useful they'll be for everyone when it comes to optimizing the process.

In standard automation the robot, as any machine is usually characterized by the OEE (Overall equipment effectiveness) KPI. This parameter is defined as:

$$OEE = Availability \times Performance \times Quality\ Rate$$

with

$$\textbf{Availability} = \frac{\textbf{Actual Run Time}}{\textbf{Planned Production Time}}$$

$$\textbf{Performance} = \frac{\textbf{Ideal Cycle Time x Total Counts}}{\textbf{Run Time}}$$

$$\textbf{Quality} = \frac{\textbf{Number Good Counts}}{\textbf{Total Counts}}$$

Its definition contains three main KPIs: the availability, the Performance (in productivity terms) and the Quality.

OEE can be used to indicate the overall effectiveness of the robot inside a manufacturing line, both at single operation level and entire production line level. OEE measurement is therefore useful in identifying which aspects of a process can be improved and how this improvement will impact on the overall process performances. The main common losses that apply to COBOTS application are the following.

1. *Planned downtime*: Due to changeovers, planned maintenance, end-of-arm tooling changeover, etc.
2. *Breakdowns and unplanned downtime*: Due to equipment failure, unplanned maintenance, etc.
3. *Minor stops*: Due to misalignment, blockages, safety stops (e.g. due to people entering the workspace), etc.
4. *Speed loss*: Due to untrained operators, inefficient waypoint programming, misalignment, etc. This category is a major loss for some collaborative robots, which automatically enter a "reduced speed" mode when people enter the workspace or touch the robot. Monitoring and minimizing such events (e.g. by teaching people to only enter the workspace when necessary) is an easy way to improve performance.
5. *Production rejects*: Due to damaged products, scrap, etc.
6. *Rejects on ramp up*: Due to scrap caused by changeover, damage, etc.
7. *Integration faults* (or communication faults, for COBOTs): The COBOT suffers from brief stoppages due to faults such as errors in machine-to-machine communication or synchronization, misaligned parts, connectivity failure, etc.
8. *Lack of use*: The COBOT is not being used to its full potential due to lack of training, process optimization issues, poor resource allocation, etc.
9. *Inefficiency* (poor trajectory planning, for COBOTs): an un-optimized cell layout leads to inefficient movement of the robot. The robot's paths should be measured and optimized to eliminate this waste.
10. *Wait time*: The COBOT is unable to achieve its full potential because it is waiting for other processes. This can be due to limited understanding of the COBOT's full potential, bottlenecks or un-optimized steps elsewhere in the process, etc.

Considering that the Wait time and stops are among the major losses, it is important to define the STOP modes of collaborative robots:

- Emergency Stop: This state stops the program and cuts power to the robot. It's usually triggered by an external signal like an emergency stop button. The robot must be manually reset to clear this state.
- Safeguard Stop: Like the Emergency Stop, this state means that the robot has stopped following an external signal. However, it only pauses the program and there is power to the robot. The program will continue either automatically or following a manual reset, depending on the robot's configuration.
- Protective Stop: This stop state is triggered by the internal safety limits of the robot control system. It can only be reset manually.
- Idle: the robot is powered up but no program is running. See the later section on Utilization (KPI 3).
- Disconnected: the robot is powered down or otherwise disconnected from the network. See the later section on Disconnect Time.

While this KPIs is usually applied considering only the machine in its application, it can be applied also to HRC with some adaptation and extension: considering the Team = Human + Robot, as a single entity, its availability contains the combined availability of both the operator and of the robot. If the team is stopped, due to any reason originated by the team, the availability is reduced. In the evaluation of the Actual Run Time, also parameters like the usability or similar will have an impact (if the usability is poor, unplanned stops are likely to occur).

Same reasoning can be applied also to the performance, where any stop, (Planned/unplanned downtime speed loss, breakdown and so on) will reduce the overall system performance. In this parameter, for example, also slowdowns occurring in SSM mode due to a non-optimized sequence of operator's action that cause an excessive number of "slow down" events, or idle wait time of the operator or the robot waiting for the partner, will be considered.

As for the quality the team's collaboration becomes immediately relevant since the overall achieved quality in the workstation will describe the results of the team and won't separate or isolate each player's contribution.

Similar considerations can be adopted almost for any KPI in the manufacturing environment, with the attention to consider the full Team characterization and/or measurement.

It is important to note that these KPIs are referred to the optimal planned action i.e., for example, if the COBOT supports the operator acting as a continuously adjustable support for the parts, then a high Wait Time can be not meaningful.

All these KPIs are important to be considered in design phase as indicators, nevertheless their application has to be performed only after the effective deployment in the productive environment of the application.

The standard KPIs (declined according to previous considerations) intrinsically contain some requirements on the system performances: for example the improvement of saturation, the decrease of downtime, the improvements of quality and so on. This kind of requirements will not be listed in the requirements in these documents unless they have a direct impact on the CPSoSaware developments, but have been considered in the design phases of the application.

3.2.3 Resulting Requirements

3.2.3.1 *Definition of common taxonomy and categories of requirements*

As declared in D1.1 Supportive, Motivating and Persuasive Approaches, Tools and Metrics – Task 1.1 "SoA analysis, technological selection and benchmarking of best practices" in the paragraph 3.3 "Customization to world CPSoSaware Use Cases", for each specific requirement was created a tabular template based mainly on the Volere requirements shell.

In CPSoSaware, the notation used for the requirement ID field is as it is as follows:

Table 35: ID naming for the functional and non-functional requirements.

Type	Subtype	ID (*x = 01, 02, …, n*)
Functional	All	F-Req-*x*
Non-Functional	User Interface	I-Req-*x*
	Availability/Accessibility	A-Req-x
	Configuration/Adaptability	C-Req-x
	Training	T-Req-x
	Safety/Security	S-Req-x

3.2.3.2 *Manufacturing Use-Case User-Requirements analysis*

This subsection contains the description and analysis of the user requirements of the CPSoSaware platform in the manufacturing use-case. An overview list of the user requirements is contained in Annex 2, Figure 48. From an overview analysis of the outcomes the distribution of URs according to their functionality is presented in the following graph.

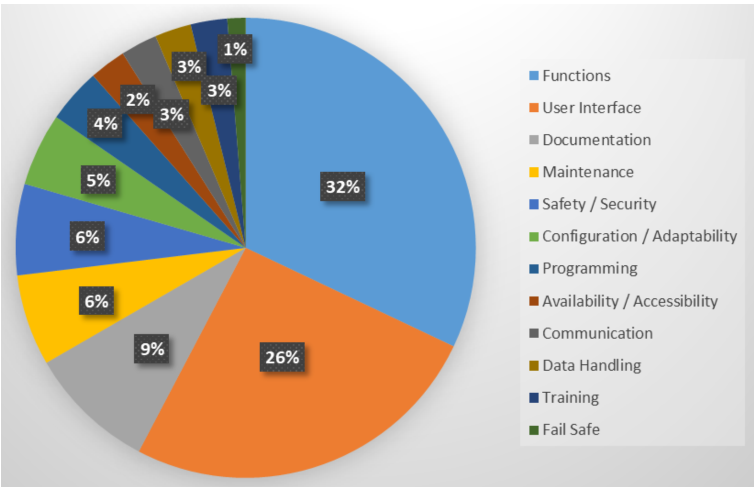

Figure 41: Percentage distribution of functionalities of all the User Requirements

From Figure 41 it is evident that, besides the functional requirements, the higher attention in the use-case is toward the user interfaces (under any aspect related to them). The detailed analysis of the functional requirements will be made in the following text.

Another clustering of the user requirements has been made according to the field "**Complexity in CPSoSaware**" in the table ***User Requirements – CRF*** described before. This field describes the preliminary complexity estimation for the implementation in CPSoSaware. It is a preliminary analysis considering if the specific UR will be implementable, complex to implement (to the level to require additional dedicated efforts) or “automatic”. Automatic means that the UR is important, but it is already achieved by the purchased hardware/software that will be implemented on the pilot. For example the UR “the robot shall be safe” is automatically achieved since the model of robot implemented is a safe one by specification. These URs are anyway listed since they require specific SW solutions for compatibility, and involve specific behaviors of the system. The unfeasible UR refers to user-requirements that are requested in the use-case, but that are unfeasible in the CPSoSaware Pilot because of pilot’s constraints.

The Figure 42 represents the frequency distribution of this field in the 78 URs.

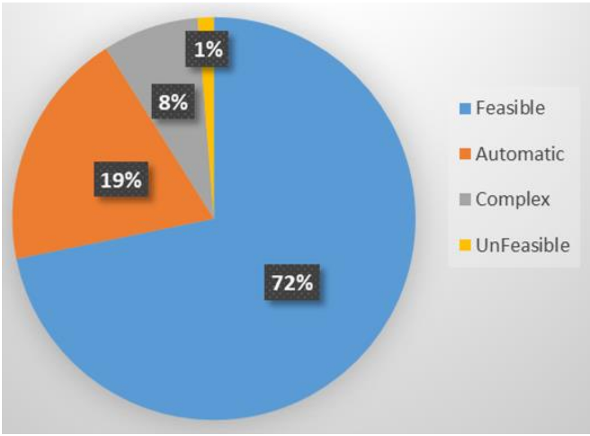

Figure 42: Percentage distribution of the *complexity in CPSoSaware* field

In the following analysis, that details each relevant UR, the “*Automatic*” user requirements will not be analyzed in further detail.

After this introductory description and details, a high level analysis of the 78 UR was made; the most relevant 25 have been selected identifying the top ranked ones.

Figure 51 shows the list of the top 25 selected URs.

Based on the same analysis made before, the Figure 43 represents the distribution of the top 25 selected URs according to their functionality and complexity in this project.

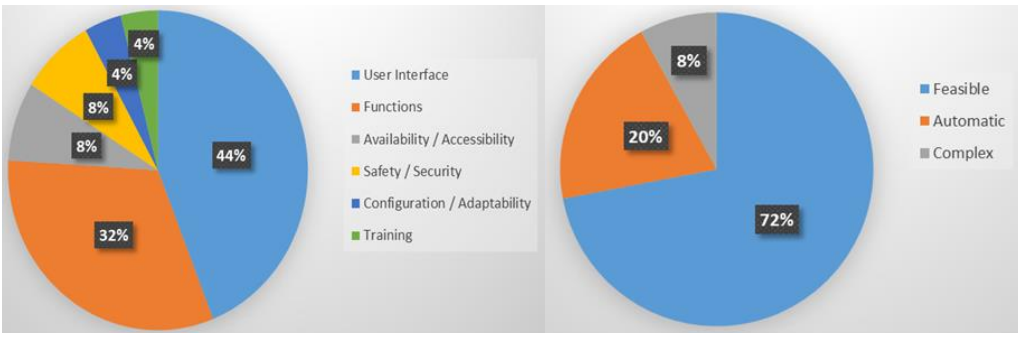

Figure 43: Representation of the distribution of URs in the top ranked 25

From the list of requirements, a first level distinction of Functional and non- Functional requirements have been done. In the functional distribution, the percentage of functional URs is now lower than the percentage of “user interface” non-functional requirements. This fact is coherent with the higher expectation in the CPSoSaware project in relation to aspects concerning the HMI (AR/VR/XR/MR) and the training aspects. Besides of this difference, it is of interest to highlight that the field non-functional requirements class "documentation" – previously third- is not relevant in the top 25 URs. This can be easily justified by the fact that in such a complex use-case the documentation is fundamental, but obviously less important that the mere implementation aspects. A similar comment can be made for the UR class "maintenance". From the overall analysis some classes of URs have been excluded in the top ranked 25.

As expected the non-feasible UR is not listed in the top ranked 25.

3.2.3.3 *Functional Requirements (CRF)*

This subsection contains the functional requirements of the CPSoSaware platform for the manufacturing use-case. An overview list of the requirements is contained in Table 36. For clarity the URs have been renamed according to the "F-Req-nn" form with the numbering in order of ranking. The F-Req-01UR is thus the more relevant Functional UR of the list.

Besides the top most relevant 25 URs, it was decided to analyse in higher detail also another requirements that ranked at position 33. This requirement ("The robotic system shall detect attention and fatigue state of the operator") is specifically of interest for the partnership since a similar development is performed in the automotive use case. In the project execution this development will be tested also on the manufacturing use-case, and as such the relative User-Requirement will be here described in further details.

As stated the "*automatic*" type of URs are listed in details since no further development is expected on them.

Table 36: Overview list of the functional requirements.

ID	Original ID*	Requirement name
F-Req-01	UR 05	The system shall be able to adapt to operator's anthropometrics
F-Req-02	UR 02	The system shall be able to withstand strong reaction forces from the operator
F-Req-03	UR 18	The system shall be able to analyze and understand the scene in the workplace
F-Req-04	UR 19	The system shall be provide warnings and manage situations related to intrusions by external operators or other factors
F-Req-05	UR 14	The system shall Self-reconfigure when products/process variations are requested
F-Req-06	UR 16	The robotic system shall detect attention and fatigue state of the operator

*New ID are assigned in descending ranking order

In the following tables each requirement is described in a separate table.

Table 37: F-Req-01

ID	F-Req-01 (UR 05)
Name	The system shall be able to adapt to operator's anthropometrics
Requirement Type	Functional
Description	The skeleton of the human workers that operate inside the collaborative space should be continuously tracked by the system and safety constraints should be constructed and enforced to the collaborative robot.
Rationale	Since the human workers and the collaborative robots will work on close proximity to each other, the human skeleton tracking will provide the necessary information, in order to predict unintended contacts between them and prevent them by adjusting the robots' trajectories.
Fit Criterion (Measurable)	At least a tracking rate of 10Hz should be achieved, depending always on the working velocity of the robotic manipulators.

Conflicts	-
Constraints (Attainable)	The human workers should be within the field of view of the system's RGBD sensors
Actors	Assembly line worker/Instructor
Author	CRF
Revision	V1.3.5, 29th of March, 2021

Table 38: F-Req-02

ID	F-Req-02 (UR 02)
Name	The system shall be able to withstand strong reaction forces from the operator
Requirement Type	Functional
Description	The system must be able to withstand strong reaction forces, voluntary and involuntary, arriving from the operator during the entire work cycle.
Rationale	Since human workers and collaborative robots will work in close proximity to each other, the robotic system will need to be able to continue its tasks even when there is a high reaction force from the operator.
Fit Criterion (Measurable)	The robotic system must be able to continue its tasks even beyond 2 cases in which there was a high reaction force from the operator.
Conflicts	-
Constraints (Attainable)	N/A
Actors	Assembly line worker/Instructor, Robot technician
Author	CRF
Revision	V1.3.5, 29th of March, 2021

Table 39: F-Req-03

ID	F-Req-03 (UR 18)
Name	The system shall be able to analyze and understand the scene in the workplace
Requirement Type	Functional
Description	The CPSoSaware HRI component should provide feedback to the user in real-time by providing information of its status and percentage of the current task completion.
Rationale	Users should be informed about the current state of the system in order to interact more efficiently with it.
Fit Criterion (Measurable)	The HRI component's GUI should include loading, processing percentage bars, along with the necessary information boxes informing the current action/status of the system.
Conflicts	-
Constraints (Attainable)	N/A
Actors	Assembly line worker/Instructor, Production supervisor, Robot technician, Researcher
Author	CRF
Revision	V1.3.5, 29th of March, 2021

Table 40: F-Req-04

ID	F-Req-04 (UR 19)
Name	The system shall be able to warn and manage situations related to intrusions by external operators or other factors
Requirement Type	Functional
Description	The system must be able to identify all subjects outside the scene and immediately report it to the operator using the appropriate screen.
Rationale	The operator must be informed immediately of the presence of elements external to the work activity and in the event that he is in a dangerous situation, immediately stop carrying out the activities.
Fit Criterion (Measurable)	The system must be able to detect more than 5 intrusions that occurred during the same work shift.
Conflicts	-
Constraints (Attainable)	N/A
Actors	Assembly line worker/Instructor, Production supervisor, Robot technician

Author	CRF
Revision	V1.3.5, 29th of March, 2021

Table 41: F-Req-05

ID	F-Req-05 (UR 14)
Name	The system shall Self-reconfigure when products/process variations are requested
Requirement Type	Functional
Description	The system is able to recognize the product / process in progress and if necessary, it is able to reconfigure itself automatically.
Rationale	The system must be able to reconfigure itself automatically without the need for intervention by the Team Leader of the line.
Fit Criterion (Measurable)	The system must be able to automatically reconfigure itself even more than 5 times during the same work shift.
Conflicts	-
Constraints (Attainable)	N/A
Actors	Assembly line worker/Instructor, Production supervisor, Robot technician
Author	CRF
Revision	V1.3.5, 29th of March, 2021

Table 42: F-Req-06

ID	F-Req-06 (UR 16)
Name	The robotic system shall detect attention and fatigue state of the operator
Requirement Type	Functional
Description	Using visual feedback the normal work activities of the human workers will be monitored in order to identify possible distraction, fatigue, harmful patterns and prevent future injuries by their repetition.
Rationale	Through the monitoring of the regular performance of the human workers, meaningful information related to human behaviour is extracted. Injury prevention in the workplace through quantitative and objective assessment of occupational exposure in normal work activities is achieved.
Fit Criterion (Measurable)	At least 20% reduction of the injury risk by normal work activities is achieved.
Conflicts	-
Constraints (Attainable)	N/A
Actors	Assembly line worker/Instructor, Production supervisor
Author	CRF
Revision	V1.3.5, 29th of March, 2021

3.2.3.4 *Non-Functional Requirements*

This subsection contains the non-functional requirements of the CPSoSaware platform. A cumulative list of the non-functional requirements is contained in Table 43. The requirements related to safety have been inserted in the list of detailed URs given the critical importance even is classified as "automatic".

Table 43: Overview list of the non-functional requirements.

ID	Original ID	Type	Requirement name
I-Req-01	UR 75	User Interface	Always understandable way of communication
I-Req-02	UR 71	User Interface	Timely notification to the operator of the safety aspects
I-Req-03	UR 35	User Interface	Prompt notification to the operator
I-Req-04	UR 33	User Interface	Ability to send feedback to the operator in a collaborative situation
I-Req-05	UR 73	User Interface	Graphical configuration of the HMI
I-Req-06	UR 34	User Interface	Possibility of continuous communication between humans and robots
I-Req-07	UR 74	User Interface	Human-machine interface (HMI) on the robot
I-Req-08	UR 72	User Interface	Intuitiveness of Use
I-Req-09	UR 68	User Interface	Specific training in relation to how to collaborate with the robot
I-Req-10	UR 25	User Interface	Wearable HMI in AR or XR for the operator
I-Req-11	UR 31	User Interface	User-friendly HMI interface for the communication of the worker with the system
A-Req-01	UR 38	Availability / Accessibility	Ease of Use
A-Req-02	UR 39	Availability / Accessibility	Respect of the speed of the current cycle time
C-Req-01	UR 78	Configuration / Adaptability	Anonymous anthropometric recognition
T-Req-01	UR 32	Training	Anthropometrics and ergonomics adaptation of the operator.
S-Req-01	UR 65	Safety / Security	Compliance with existing safety standards for collaborative robots
S-Req-02	UR 64	Safety / Security	Intrinsic safety (PLd-CAT3)

3.2.3.4.1 User Interface Requirements

Table 44: I-Req-01

ID	I-Req-01 (UR 75)
Name	Always understandable way of communication
Requirement Type	Non-functional - User Interface
Description	The worker will interact with the system through a user-friendly interface.
Rationale	The worker will use the interface for making any initial configuration of the system, but also to send commands during operations.
Fit Criterion (Measurable)	The interface achieves high usability score during testing by the workers.
Conflicts	-
Constraints (Attainable)	N/A
Actors	Assembly line worker, Researcher
Author	CRF
Revision	V1.3.5, 29th of March, 2021

Table 45: I-Req-02

ID	I-Req-02 (UR 71)
Name	Timely notification to the operator of the safety aspects
Requirement Type	Non-functional - User Interface
Description	Using visual feedback the normal work activities of the human workers will be monitored in order to identify possible distraction, fatigue, harmful patterns and prevent future injuries by their repetition.
Rationale	Through the monitoring of the regular performance of the human workers, meaningful information related to human behaviour is extracted. Injury prevention in the workplace through quantitative and objective assessment of occupational exposure in normal work activities is achieved.
Fit Criterion (Measurable)	At least 20% reduction of the injury risk by normal work activities is achieved.
Conflicts	-
Constraints (Attainable)	During training of the monitoring algorithms wearable EMG sensors might be employed
Actors	Assembly line worker/Instructor
Author	CRF
Revision	V1.3.5, 29th of March, 2021

Table 46: I-Req-03

ID	I-Req-03 (UR 35)
Name	Prompt notification to the operator
Requirement Type	Non-functional - User Interface
Description	The communication between the robot and the operator must be continuously guaranteed, so that the latter can immediately realize what is happening. In particular, in the case that a problem may happen.
Rationale	Through continuous monitoring within the collaborative cell, the robotic system must ensure clear and efficient communication to the user, so that the operator can receive the appropriate signal when it is strictly necessary.
Fit Criterion (Measurable)	The robotic system must be able to promptly send all the necessary signals to the operator according to the processed product and the conditions that are occurring in the collaborative cell.
Conflicts	-
Constraints (Attainable)	N/A
Actors	Assembly line worker, Researcher
Author	CRF
Revision	V1.3.5, 29th of March, 2021

Table 47: I-Req-04

ID	I-Req-04 (UR 33)
Name	Ability to send feedback to the operator in a collaborative situation
Requirement Type	Non-functional - User Interface
Description	The robotic solution must be able to communicate with the operator during the activities in which both are involved, without any production downtime.
Rationale	The communication must be clear and not allow the operator to bypass the activities in charge of the robotic system.
Fit Criterion (Measurable)	The system must be able to communicate to the operator what he is doing, at what speed during the entire collaborative work phase.
Conflicts	-
Constraints (Attainable)	N/A
Actors	Assembly line worker
Author	CRF
Revision	V1.3.5, 29th of March, 2021

Table 48: I-Req-05

ID	I-Req-05 (UR 73)
Name	Graphical configuration of the HMI
Requirement Type	Non-functional - User Interface
Description	The interface between the operator and the system must be clear and focus mainly on graphic elements, containing as few words as possible.
Rationale	The presentation of the functionalities and the messages to the operator must be clear and prefer the streamlined and graphic mode.
Fit Criterion (Measurable)	The interface must contain at least 90% of the functionality in graphic form and not in words.
Conflicts	-
Constraints (Attainable)	N/A
Actors	Assembly line worker/Instructor
Author	CRF
Revision	V1.3.5, 29th of March, 2021

Table 49: I-Req-06

ID	I-Req-06 (UR 34)
Name	Possibility of continuous communication between humans and robots
Requirement Type	Non-functional - User Interface
Description	The operator must be able to proactively collaborate with the robot, like a human colleague.
Rationale	The operator must be able to involve the robotic system during the activities to be carried out together, without impeding their performance.
Fit Criterion (Measurable)	The operator must be able to receive feedback from the robotic system as confirmation of the requested command.
Conflicts	-
Constraints (Attainable)	N/A
Actors	Assembly line worker/Instructor, Researcher, Maintenance Operator
Author	CRF
Revision	V1.3.5, 29th of March, 2021

Table 50: I-Req-07

ID	I-Req-07 (UR 74)
Name	Human-machine interface (HMI) on the robot
Requirement Type	Non-functional - User Interface
Description	The robotic system must be equipped with a communication system capable of being understood and used by each line operator, without particular complexity.
Rationale	The man-machine interface must be designed and configured according to real production needs and contain all the functions necessary for carrying out the activities required for the collaborative cell.
Fit Criterion (Measurable)	The human-machine interface must be understandable to anyone who uses it.
Conflicts	-
Constraints (Attainable)	N/A
Actors	Assembly line worker, Researcher
Author	CRF
Revision	V1.3.5, 29th of March, 2021

Table 51: I-Req-08

ID	I-Req-08 (UR 72)
Name	Intuitiveness of Use
Requirement Type	Non-functional - User Interface
Description	The robotic solution must be intuitive to use and allow the operator a practical use after an initial training phase.
Rationale	The robotic system must be designed and configured without complexity, so that anyone can use it after an adequate *training phase on the job*.
Fit Criterion (Measurable)	The robotic system must contain 90% of the simple functionalities and with a user friendly appearance for the operator.
Conflicts	-
Constraints (Attainable)	N/A
Actors	Assembly line worker, Maintenance technicians
Author	CRF
Revision	V1.3.5, 29th of March, 2021

Table 52: I-Req-09

ID	I-Req-09 (UR 68)
Name	Specific training in relation to how to collaborate with the robot
Requirement Type	Non-functional - User Interface
Description	The operator training must be in line with the actions required for use in cooperation with the robot.
Rationale	Operator training must be guaranteed and monitored so that there are no deficits that could compromise its use during production.
Fit Criterion (Measurable)	Operator training must be carried out both with lectures and during on-the-job training.
Conflicts	-
Constraints (Attainable)	N/A
Actors	Assembly line worker, Trainer
Author	CRF
Revision	V1.3.5, 29th of March, 2021

Table 53: I-Req-10

ID	I-Req-10 (UR 25)
Name	Wearable HMI in AR or XR for the operator
Requirement Type	Non-functional - User Interface
Description	The system must enable a wearable HMI for the operator, so that he can identify the areas of greatest difficulty in advance, especially during the on-the-job training phases.
Rationale	The possibility of having an AR or XR environment for the operator must be seen as an important opportunity for the users of the cell, so that the experience gained in this context can also be extended to other similar situations.
Fit Criterion (Measurable)	At least 50% of the training must be guaranteed with this technology.
Conflicts	-
Constraints (Attainable)	N/A
Actors	Assembly line worker, Researcher
Author	CRF
Revision	V1.3.5, 29th of March, 2021

Table 54: I-Req-11

ID	I-Req-11 (UR 31)
Name	User-friendly HMI interface for the communication of the worker with the system
Requirement Type	Non-functional - User Interface
Description	Communication between the human being and the robot must always be guaranteed and respected through an HMI as a communication system.
Rationale	The possibility of guaranteeing an effective communication system between the human being and the robot avoids that there may be moments of alienation on the part of the operator.
Fit Criterion (Measurable)	An adequate communication system must be guaranteed between the operator and the robot, as in a working situation in which there are only human users.
Conflicts	-
Constraints (Attainable)	N/A
Actors	Assembly line worker, Researcher
Author	CRF
Revision	V1.3.5, 29th of March, 2021

3.2.3.4.2 Availability / Accessibility Requirements

Table 55: A-Req-01

ID	A-Req-01 (UR 38)
Name	Ease of Use
Requirement Type	Non-functional - Availability/Accessibility
Description	The system should be easy to use for all the target user categories. Each of the input parameters either for the demonstration, design and assembly phase should be given an explanation which is understandable by the non-expert users.
Rationale	The user shall be able to setup the system easily in order to not result into frustration.
Fit Criterion (Measurable)	The user adjusts the system and uses it without any frustration and learns to master it in a relative short time.
Conflicts	-
Constraints (Attainable)	N/A.
Actors	Assembly line worker/Instructor, Production supervisor, Robot technician, Researcher.
Author	CRF
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Table 56: A-Req-02

ID	A-Req-02 (UR 39)
Name	Respect of the speed of the current cycle time
Requirement Type	Non-functional - Availability/Accessibility
Description	The robotic system must be designed to operate at least at the speed of the current cycle time, to ensure the correct distribution of activities between the robot and the operator.
Rationale	The robotic system must be configured in such a way as not to create a desaturation for the line operator.
Fit Criterion (Measurable)	The robotic system must be accessible by the line operator at any time and can allow him to make the necessary corrections, if authorized by the Production supervisor.
Conflicts	-
Constraints (Attainable)	N/A
Actors	Assembly line worker/Instructor, Production supervisor, Robot technician
Author	CRF
Revision	V1.3.5, 29th of March, 2021

3.2.3.4.3 Configuration / Adaptability Requirements

Table 57: C-Req-01

ID	C-Req-01 (UR 78)
Name	Anonymous anthropometric recognition
Requirement Type	Non-functional –Configuration/Adaptability
Description	The recognition of the anthropometry of the operator who is working inside the cell must not for any reason be attributable to the identity of a specific person, but will have to preserve anonymity.
Rationale	The anthropometry detection system will only be active when it physically detects an operator inside the cell.
Fit Criterion (Measurable)	The detection system achieves a high effectiveness score when tested by workers.
Conflicts	-
Constraints (Attainable)	N/A
Actors	Assembly line worker/Instructor, Production supervisor
Author	CRF
Revision	V1.3.5, 29th of March, 2021

3.2.3.4.4 Training Requirement

Table 58: T-Req-01

ID	T-Req-01 (UR 32)
Name	Anthropometrics and ergonomics adaptation of the operator
Requirement Type	Non-functional - Training
Description	Fast reconfiguration and adaptation of the existing work-cell to perform different operation within a feasible set of tasks and adapting to the human co-worker personalized ergonomic conditions.
Rationale	Passive reconfigurable elements such as adjustable fixtures, linear guides (which will extend the robot workspace) and reconfigurable robot tools in a collaborative robotic cell will be employed.
Fit Criterion (Measurable)	At least 10% decrease in the deployment time of a new assembly task with respect to manual reconfiguration.
Conflicts	-
Constraints (Attainable)	N/A
Actors	Assembly line worker/Instructor, Production supervisor, Robot technician, Researcher
Author	CRF
Revision	V1.3.5, 29th of March, 2021

3.2.3.4.5 Safety/Security Requirements

Table 59: S-Req-01

ID	S-Req-01 (UR 65)
Name	Compliance with existing safety standards for collaborative robots
Requirement Type	Non-functional – Safety/Security
Description	The system shall be safe to use by all the target user categories.
Rationale	The robot should be capable to co-operate safely with human workers in a real industrial environment.
Fit Criterion (Measurable)	The prototype system should meet safety criteria so as to be acceptable by human-use committees for experiments on collaborative robots. The final system should comply with the EU safety standards for collaborative robots.
Conflicts	-
Constraints (Attainable)	N/A
Actors	Assembly line worker/Instructor, Production supervisor, Robot technician, Researcher
Author	CRF
Revision	V1.3.5, 29th of March, 2021

Table 60: S-Req-02

ID	S-Req-02 (UR 64)
Name	Intrinsic safety (PLd-CAT3)
Requirement Type	Non-functional – Safety/Security
Description	The choice of the robot must be such that it meets the required standard and be PLd-CAT3.
Rationale	The robot must be designed to comply with the required safety standards, especially suitable for being introduced into a production environment.
Fit Criterion (Measurable)	The robot must have the necessary certificate and guarantee during the performance of the activities all the safety standards required for our production plants.
Conflicts	-
Constraints (Attainable)	N/A
Actors	Assembly line worker/Instructor, Production supervisor, Robot technician, Researcher
Author	CRF
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4 Conclusions

This deliverable has described the main content of the use-cases that will be implemented in the CPSoSaware project. The main purpose in the use-case herein made is the extraction the user requirements of interest for the project.

In order to represent properly the two use-cases, the Deliverable provided the methodology used for the description of the Use Cases, where applicable, and the methodology to extract and describe the User Requirements.

Given the different nature of the use cases different methodological aspects were used and introduced. For the Autonomous Driving Use-Case we include the development process proposed in the ISO 26262 standard, based upon multiple V-models, moving to Operational Design Domain (ODD) to get to the Autonomous Vehicle Acceptance Model (AVAM).

Instead, as regards the Manufacturing Use-Case the main features that enhance the performance of the work cell where the operator will work inside, are: the task analysis with relative timings (e.g. MTM Task analysis); the type of operation to be performed (e.g. NVAA/VAA respective sections); the ergonomics; the distance traveled by the operator in the workstation (through the spaghetti chart).

For Human Robot Collaboration applications it is possible to highlight 4 minimum levels of requirements: SMS systems require the presence of a safety sensor (environmental sensing) in order to stop the motion; SSM systems need to know the position and speed of the persons in the workzone to regulate its own speed in real time; in HG the robot needs to have a specific handle capable to detect the action request and to understand whether it is voluntary or not; in PFL the robot needs to have an advanced and safe force feedback in any time.

The current document described the functional and operational features of the Use Cases and the desired functionalities from which the CPSoSaware project will extract and detail the architectural features to be implemented in the CPSoSaware system.

The definition of the User requirements is made upon considerations coming from the main stakeholders of the applications in the use cases. This document presents the process methodology for the quantification and description of the use-case and for the definition of the User Requirements. It also provides the list of the main User-Requirements of the CPSoSaware project.

The identified and here represented User Requirements represent a set of URs valid at the moment of description of the Use-Cases. During the implementation of the Pilots, slight modifications of the pilot themselves could involve new or updated user-requirements. Because of this reason, the list of URs can be modified, if necessary, during the execution of the project. Eventually updated versions of the URs will be added to this deliverable in future as annexes.

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Annex 1: **Tool for the representation of Human-Robot Collaboration applications.**

MTM is the abbreviation of Methods-Time Measurement. Methods-Time Measurement means that the time required to perform a specific task depends on the method chosen for the activity. The MTM method was developed 1940s as a system of predetermined motion time used in industrial settings to analyze the methods used to perform any manual operation or task and, as a product of that analysis, set the standard time in which a worker should complete that task. Since then, MTM has been used both as an analytical tool for directly analyzing manual work processes, as well as, a tool for developing standardized building blocks from the MTM basic system (MTM-1). These building blocks are being used to economically describe, quantify and design a wide range of work processes.

In addition to the base MTM, building block systems were developed based on MTM-1 for application in different process types (mass production, batch production and one-of-a-kind and small variable batch production). MTM offers a worldwide uniform standard for businesses to use in describing and quantifying manual work processes. As early as the 1990s, MTM began the gradual transformation from a system of predetermined times to a productivity management system.

Today, the MTM method includes a framework of MTM building block systems used to model the full range of work processes. In addition to the standard MTM, in recent times, ERGO-MTM have been developed in the light of the most recent ISO/CEN standards dealing with biomechanical load; as a consequence the traditional models do not meet the requirements anymore and it becomes mandatory to consider the load generated by the overall assignment of working tasks to a workstation to be compliant with the new ergonomics standards.

ERGO-MTM determines a fatigue allowance (named Ergonomic Allowance), which is applied on the total workstation basic MTM time to allow the necessary recovery periods, enough to keep the biomechanical load within safety limits. The final result is a standard time based on a norm level of performance and a work sequence with a controlled biomechanical load.

From the basis of MTM, many methods can be derived. The basic concept is to have a task analysis tool that associates, to each specific task, other parameters that are useful for the description and representation of the process.

Zanella et al. [57] used, for the task analysis, a modified MTM-UAS [58] analysis, defined by considering the motion of the robot in parallel with the operator together with its interaction. This kind of representation allows the designer to identify the core tasks (equivalent to task building blocks in the MTM, or eventually grouping even larger time description) according to its characteristics. The description is based on a MTM analysis and a NVAA analysis.

The tasks are grouped in order to allow the description of single work phases with a unique characteristic in terms of:

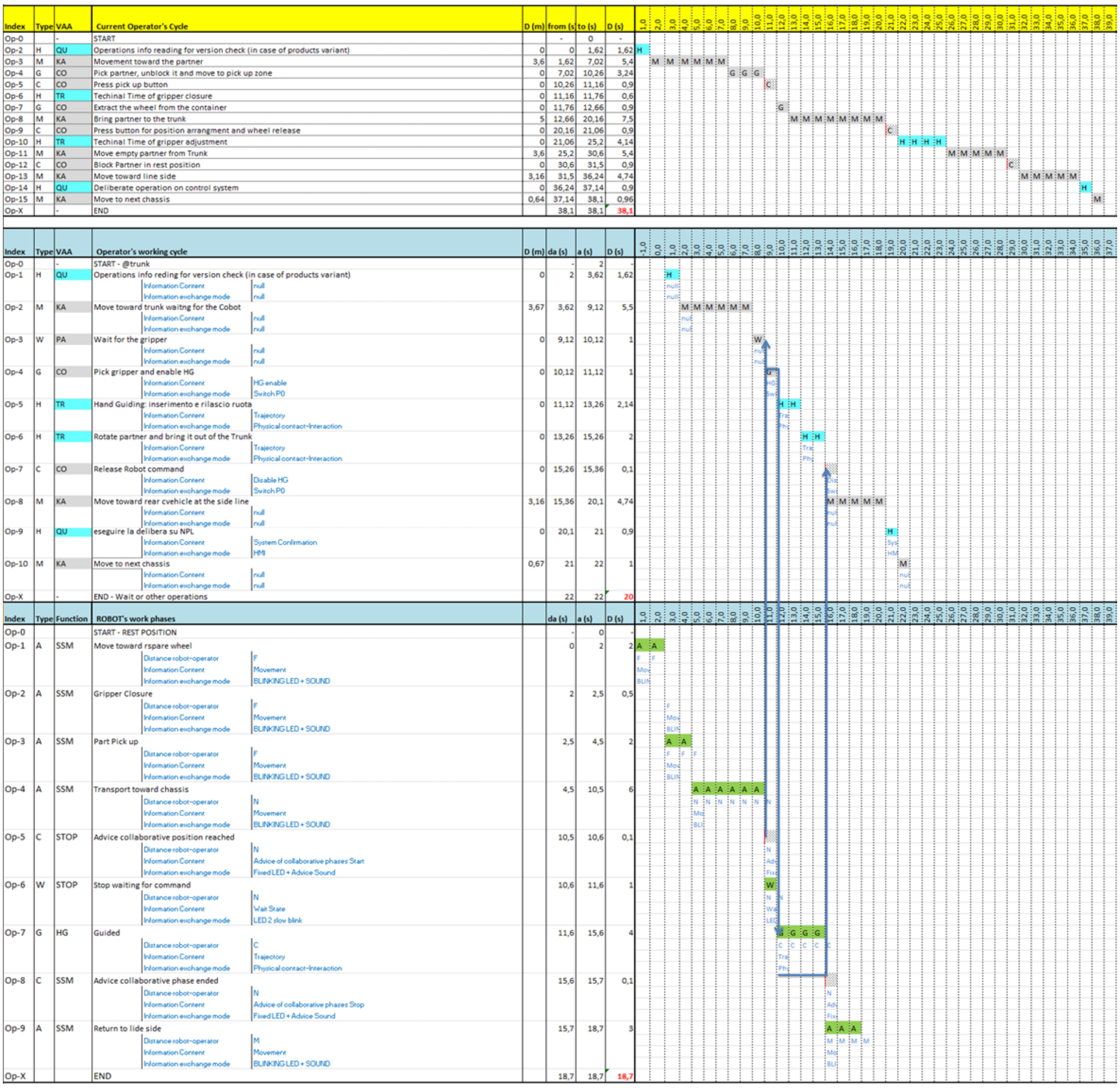
- Same type of NVAA/VAA operation
- Single walking phases are grouped
- Phases of interaction with system (commands, HMI reading…) are defined as single tasks

Figure 44 represents a modified MTM analysis. It is mainly composed by three parts:

a) representing the analysis of the operations as performed by the operator alone;
b) with the analysis of the operations performed by the human operator in collaboration with the robot
c) description of the operations performed by the COBOT.

On the left side of the analysis each operation is classified and quantified, for the operator, according to the MTM analysis (VAA, NVAA and subclasses such as walk – KA, Transform – TR, passivity – PA, and so on); while for the Robot the classification is in term of interaction, wait, hand guiding, handling, automatic and so on, and in terms of cooperative phases according to ISO/TS 15066 [54] (SSM, SMS, HG, PFL) plus the stop condition.

A lot of information is detailed in the three sections of the representation above. The following figures represent the most important elements. Figure 45 represents section (a). It is defined in order to represent manual tasks of the operator in an AS IS mode. In case the operation is at a Green Field, the only part (b) contains all the information contained in part (a).



Index	Type	VAA	Current Operator's Cycle	D (m)	from (s)	to (s)	D (s)
Op-0		-	START		-	0	-
Op-2	H	QU	Operations info reading for version check (in case of products variant)	0	0	1,62	1,62
Op-3	M	KA	Movement toward the partner	3,6	1,62	7,02	5,4
Op-4	G	CO	Pick partner, unblock it and move to pick up zone	0	7,02	10,26	3,24
Op-5	C	CO	Press pick up button	0	10,26	11,16	0,9
Op-6	H	TR	Techinal Time of gripper closure	0	11,16	11,76	0,6
Op-7	G	CO	Extract the wheel from the container	0	11,76	12,66	0,9
Op-8	M	KA	Bring partner to the trunk	5	12,66	20,16	7,5
Op-9	C	CO	Press button for position arrangment and wheel release	0	20,16	21,06	0,9
Op-10	H	TR	Techinal Time of gripper adjustment	0	21,06	25,2	4,14
Op-11	M	KA	Move empty partner from Trunk	3,6	25,2	30,6	5,4
Op-12	C	CO	Block Partner in rest position	0	30,6	31,5	0,9
Op-13	M	KA	Move toward line side	3,16	31,5	36,24	4,74
Op-14	H	QU	Deliberate operation on control system	0	36,24	37,14	0,9
Op-15	M	KA	Move to next chassis	0,64	37,14	38,1	0,96
Op-X		-	END		38,1	38,1	38,1

Index	Type	VAA	Operator's working cycle		D (m)	da (s)	a (s)	D (s)
Op-0		-	START - @trunk			-	2	-
Op-1	H	QU	Operations info reding for version check (in case of products variant)		0	2	3,62	1,62
			Information Content	null				
			Information exchange mode	null				
Op-2	M	KA	Move toward trunk waitng for the Cobot		3,67	3,62	9,12	5,5
			Information Content	null				
			Information exchange mode	null				
Op-3	W	PA	Wait for the gripper		0	9,12	10,12	1
			Information Content	null				
			Information exchange mode	null				
Op-4	G	CO	Pick gripper and enable HG		0	10,12	11,12	1
			Information Content	HG enable				
			Information exchange mode	Switch P0				
Op-5	H	TR	Hand Guiding: inserimento e rilascio ruota		0	11,12	13,26	2,14
			Information Content	Trajectory				
			Information exchange mode	Physical contact-Interaction				
Op-6	H	TR	Rotate partner and bring it out of the Trunk		0	13,26	15,26	2
			Information Content	Trajectory				
			Information exchange mode	Physical contact-Interaction				
Op-7	C	CO	Release Robot command		0	15,26	15,36	0,1
			Information Content	Disable HG				
			Information exchange mode	Switch P0				
Op-8	M	KA	Move toward rear cvehicle at the side line		3,16	15,36	20,1	4,74
			Information Content	null				
			Information exchange mode	null				
Op-9	H	QU	eseguire la delibera su NPL		0	20,1	21	0,9
			Information Content	System Confirmation				
			Information exchange mode	HMI				
Op-10	M	KA	Move to next chassis		0,67	21	22	1
			Information Content	null				
			Information exchange mode	null				
Op-X		-	END - Wait or other operations			22	22	20

Index	Type	Function	ROBOT's work phases		da (s)	a (s)	D (s)
Op-0			START - REST POSITION		-	0	-
Op-1	A	SSM	Move toward rspare wheel		0	2	2
			Distance robot-operator	F			
			Information Content	Movement			
			Information exchange mode	BLINKING LED + SOUND			
Op-2	A	SSM	Gripper Closure		2	2,5	0,5
			Distance robot-operator	F			
			Information Content	Movement			
			Information exchange mode	BLINKING LED + SOUND			
Op-3	A	SSM	Part Pick up		2,5	4,5	2
			Distance robot-operator	F			
			Information Content	Movement			
			Information exchange mode	BLINKING LED + SOUND			
Op-4	A	SSM	Transport toward chassis		4,5	10,5	6
			Distance robot-operator	N			
			Information Content	Movement			
			Information exchange mode	BLINKING LED + SOUND			
Op-5	C	STOP	Advice collaborative position reached		10,5	10,6	0,1
			Distance robot-operator	N			
			Information Content	Advice of collaborative phases Start			
			Information exchange mode	Fixed LED + Advice Sound			
Op-6	W	STOP	Stop waiting for command		10,6	11,6	1
			Distance robot-operator	N			
			Information Content	Wait State			
			Information exchange mode	LED 2 slow blink			
Op-7	G	HG	Guided		11,6	15,6	4
			Distance robot-operator	C			
			Information Content	Trajectory			
			Information exchange mode	Physical contact-Interaction			
Op-8	C	SSM	Advice collaborative phase ended		15,6	15,7	0,1
			Distance robot-operator	N			
			Information Content	Advice of collaborative phases Stop			
			Information exchange mode	Fixed LED + Advice Sound			
Op-9	A	SSM	Return to lide side		15,7	18,7	3
			Distance robot-operator	M			
			Information Content	Movement			
			Information exchange mode	BLINKING LED + SOUND			
Op-X			END		18,7	18,7	18,7

Figure 44: Modified MTM-UAS analysis. Sections a), b) and c) are explained in the text

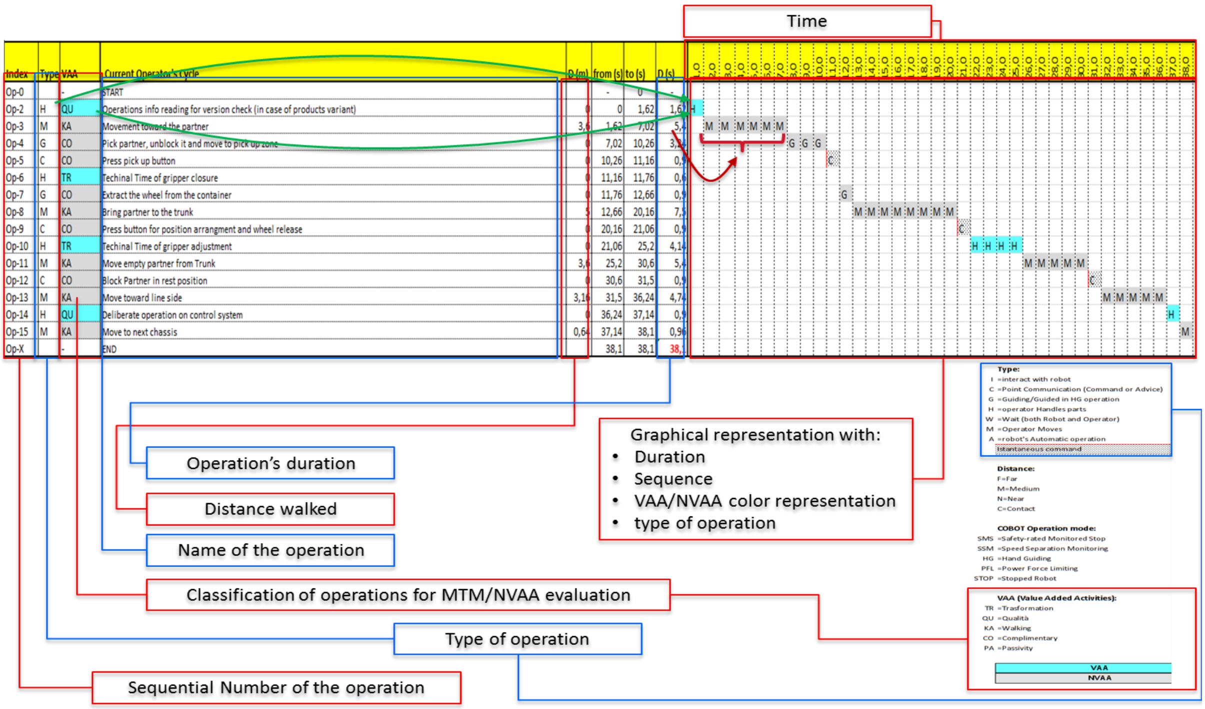


Figure 45: Modified MTM-UAS analysis. Details of Section (a)

Figure 46 represents section (b). It contains all the information contained in part (a) with the specific addition of the information exchange. In HRC the human operator continuously interact with the system through the robot or through other devices. From the functional point of view, the operator needs to have information related to the activities he is performing, or to activities the robot is performing. In section (b) the information is that coming from the operator toward the system; in section (c) that from the system to the operator.

The definition of the HMI in cooperative systems is fundamental both to achieve enhanced functionality and to evaluate cognitive ergonomics overload. Indeed the operator's environment is filled with stimuli, ranging from:

- Functional interfaces;
- Robot movement information
- Safety rules
- Voluntary information exchange (confirmations, buttons…) and so on.

During every work activity the operator has to face the stimuli coming from the robot that can potentially represent a risk. In this situation the understanding of the Interfaces (both voluntary and involuntary) is fundamental. Furthermore the architectural description of the Use Case can be simplified from the analysis of the interfaces that are needed to fulfil the functional requirements of the workplace.

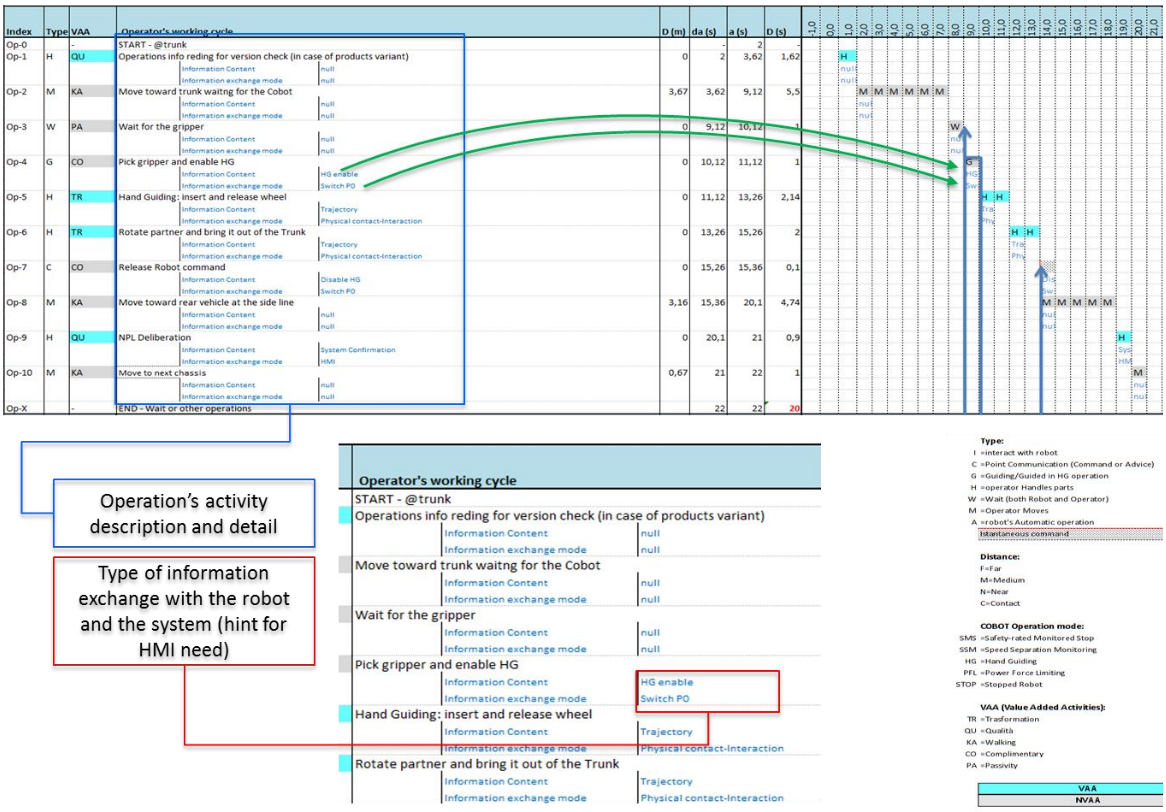


Figure 46: Modified MTM-UAS analysis. Details of the operator's Section

In Figure 47 there is the representation of section (c) that is describing the ROBOT's phases. In addition to previous information there are other information:

- The robot operative modes according to ISO 102018:2 [53];
- The relative distance
  - F= FAR: robot and operator cannot touch each other;
  - M= MEDIUM: Operator can enter Robot zone easily;
  - N= NEAR: Operator is in the Robot zone;
  - C= CONTACT: Operator and Robot are in contact, e.g. Hand Guiding or enhanced PFL as HMI
- The information from the robot to the operator

Finally section (b) and (c) are connected by arrows that indicate processes starting from the robot or the operator that needs interaction with the cooperator and go back as soon as the operation is closed.

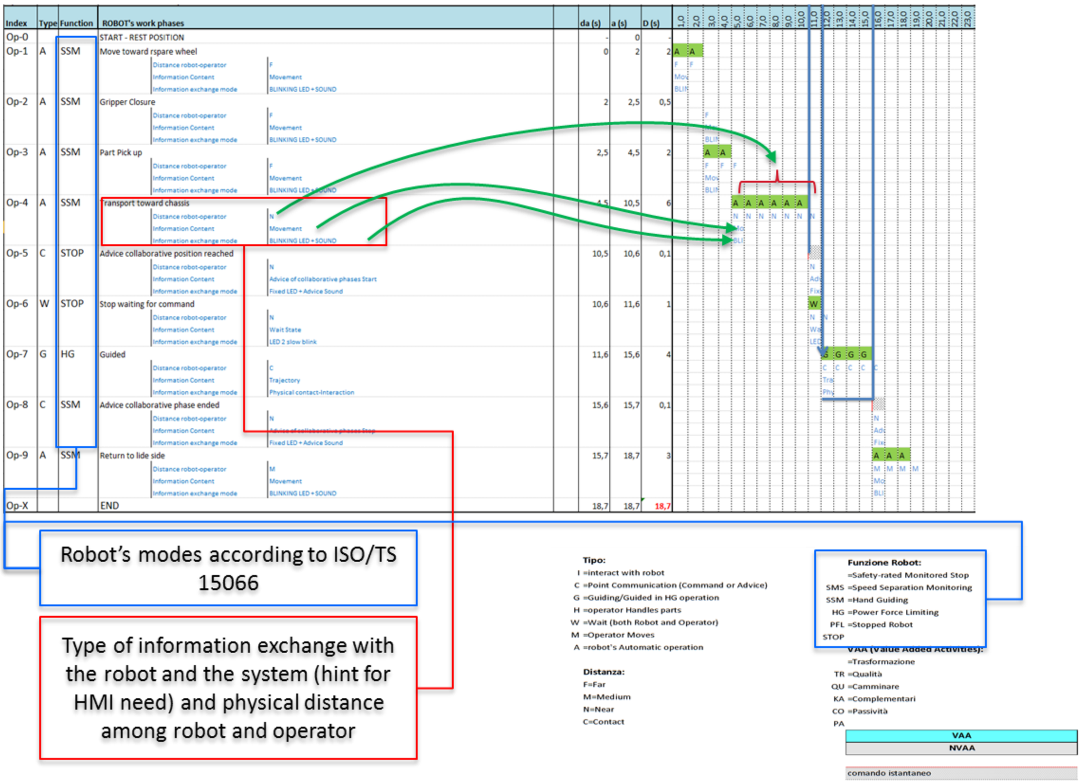


Figure 47: Modified MTM-UAS analysis. Details of Robot Section

The ISO standard ISO10218:2 [53] introduces and details the concepts of the four Collaborative Operating Methods.

Any application defined according to the ISO standards have to be defined according one or more of these methods, introduced shortly in paragraph 2.3.2. Their functionalities are defined to cover all the needed applications in a collaborative environment. As described in the paragraph 2.3.3.1.4, the used task representation contains, for every task, a reference to the collaborative method used in the specific task; this is because the ISO itself details hardware and functional requisites for each collaborative method. In this paragraph the collaborative methods will be detailed further.

The four methods (described in details in the paragraph 2.3.2) are:

a) Safety-rated Monitored Stop (SMS);

b) Hand Guiding (HG);

c) Speed and Separation Monitoring (SSM);

d) Power and Force Limiting (PFL).

Annex 2: **Manufacturing Use-Case User requirements**

				Implementation		
ID	Originated from	User Requirement	Category	Implementation in Reference UC	Implementation in CPSoSaware	Complexity in CPSoSaware
UR_01	Robot+ End effector	The system shall be able to handle heavy payload	0-Functions	Expected	Expected	Aut.
UR_02	Robot+ End effector	The system shall be able to withstand strong reaction forces from the operator	0-Functions	Expected	Expected	Feas.
UR_03	Robot+ End effector	The solution shall be able to change the position of the handled object by HG (Hand Guiding function - ISO 10218:2)	0-Functions	Expected	Desired	Feas.
UR_04	System	The System shall learn from the user's feedback in order to be proactive to the next steps	0-Functions	Desired	Desired	Comp.
UR_05	System	The robot shall be able to adapt to each operator that uses the workcell (adaptation to anthropometrics)	0-Functions	Expected	Expected	Feas.
UR_06	System	The robot shall be able to monitor the quality of the performed activity	0-Functions	Desired	Desired	Feas.
UR_07	Robot+ End effector	The System (Robot+Gripper) shall perform pick-move-place operations	0-Functions	Expected	Expected	Aut.
UR_08	Robot+ End effector	The Robot shall be able to detect and understand the applied force	0-Functions	Expected	Desired	Aut.
UR_09	System	The robot shall be able to perform specific tasks without the human operator	0-Functions	Expected	Expected	Aut.
UR_10	System	Human-Robot Collaboration phases are not on continous moving (they are parallel to the line)	0-Functions	Expected	Expected	Aut.
UR_11	Robot+ End effector	The operator shall perform collaborative operations in front of the end-effector of the robot	0-Functions	Expected	Expected	Feas.
UR_12	System	The execution time is superior limited by the TAKT TIME	0-Functions	Expected	Expected	Feas.
UR_13	Robot+ End effector	The robotic system shall be able to pick windshields from the tray	0-Functions	Expected	Expected	Aut.
UR_14	System	The System shall Self-reconfigure when products/process variations are requested	0-Functions	Desired	Expected	Comp.
UR_15	Robot+ End effector	The robotic system shall assemble the windshield on the chassis	0-Functions	Expected	Undesired	UnFeas.
UR_16	System	The robotic system shall detect attention and fatigue state of the operator	0-Functions	Desired	Desired	Feas.
UR_17	System	The robotic system shall use wearable devices to monitor the state of the operator	0-Functions	Desired	Desired	Feas.
UR_18	System	The sytem shall be able to analyze and understand the scene in the workplace	0-Functions	Desired	Expected	Comp.
UR_19	System	The sytem shall be able to warn and manage situations related to intrusions by external operators or other factors	0-Functions	Expected	Expected	Feas.
UR_20	Robot+ End effector	The Robot System shall be able to prevent and avoid singularities during operator's direct manipulation	0-Functions	Expected	Expected	Feas.
UR_21	System	The System should monitor logistics state to manage refill requirements	0-Functions	Expected	Expected	Aut.
UR_22	System	The system should implement a SMS (Safety rated Monitored Stop Function - ISO 10218:2)	0-Functions	Expected	Expected	Aut.
UR_23	System	The system should implement a SSM (Speed Separation Monitoring - ISO 10218:2)	0-Functions	Expected	Expected	Aut.
UR_24	Robot+ End effector	The Robot shall adjust its feedback stiffness according to the human interaction ongoing	0-Functions	Desired	Desired	Comp.
UR_25	System	The System shall enable a wearable HMI in AR or XR for the operator	User Interface	Expected	Expected	Feas.
UR_26	System	The system shall be simulated and represented in a digital twin and in a dynamic SoS representation	Programming	Expected	Expected	Feas.
UR_27	System	The system shall be able to detect known gestures from the operator as HMI	User Interface	Expected	Expected	Feas.
UR_28	System	The system shall be able to detect and interpret natural movements as gestures from the operator as HMI	User Interface	Expected	Expected	Feas.
UR_29	System	The system could dialogue with the operator using voice recognition and Natural Language Processing	User Interface	Expected	Expected	Comp.
UR_30	Additional functions	The system shall warn if the estimated operation duration is above TAKT time	User Interface	Expected	Expected	Feas.
UR_31	System	The Human and the robot shall have a HMI as communication System	User Interface	Expected	Expected	Feas.
UR_32	System	The users shall have a solution which will help improving their ergonomics.	Training	Expected	Expected	Feas.
UR_33	System	The robotic solution shall be able to send feedback to the operator in a collaborative situation	User Interface	Expected	Expected	Feas.
UR_34	System	The human shall always be able to interact with the robot during collaboration phases	User Interface	Expected	Expected	Feas.
UR_35	System	The robotics system shall communicate properly and timely to the users, so the user gets the proper signal at the proper moment (if something happens)	User Interface	Expected	Expected	Feas.
UR_36	System	The robot shall notify the human operator of lack of quality or non compliance to the quality expectation	0-Functions	Desired	Desired	Feas.
UR_37	System	The user will have seamless communication with the robot within the collaborative tasks	User Interface	Desired	Accepted	Feas.
UR_38	System	The robotic solution should be easy to use for any level of experience among the operators	Availability / Access	Desired	Desired	Feas.
UR_39	System	The robotic system shall perform at least as fast as the current cycle time	Availability / Access	Expected	Expected	Feas.
UR_40	Additional functions	The users shall be able to access documentation from their smartphone or the operating tablet	Communication	Accepted	Accepted	Feas.
UR_41	System	The robotic system shall be performing for at least 2 shifts (16H)	Communication	Expected	Indifferent	Feas.
UR_42	System	The Robotic system shall communicate sequences, performances, validation data with above data layers	Configuration / Ada	Expected	Expected	Feas.
UR_43	System	The system should handle change of tools/parts autonomously updating information on the handled part	Configuration / Ada	Desired	Accepted	Feas.
UR_44	System	The developers shall be able to add additional programs to the robot, so new configurations for new objects can be added	Configuration / Ada	Accepted	Desired	Feas.
UR_45	System	The robot should be in phase with the continous moving system of the production line	Data Handling	Expected	Undesired	Comp.
UR_46	System	The robotics system shall reconfigure to manipulate different variations of the same product with small dimensional changes	Data Handling	Indifferent	Expected	Feas.
UR_47	System	The system shall not manage nor collect personal/sensitive data from the operators, unless it is safety related	Documentation	Expected	Expected	Feas.
UR_48	Additional functions	The robotic system shall be able to show performance data	Documentation	Expected	Indifferent	Feas.
UR_49	Additional functions	The system shall support the user in the risk assessment report	Documentation	Desired	Desired	Feas.
UR_50	Additional functions	The user will have all the essential information about using the robot to be available on site	Documentation	Expected	Indifferent	Feas.
UR_51	Additional functions	The user will have all the essential information about using the robot to be visible at any moment during their work	Documentation	Accepted	Accepted	Feas.
UR_52	Additional functions	The user will have visual documentation of how to use the robot	Documentation	Indifferent	Indifferent	Feas.
UR_53	Additional functions	The users shall have easy access to the documentation	Documentation	Desired	Desired	Feas.
UR_54	End effector	The users needs documentation which is easy to read, and is most preferred graphical	Fail Safe	Indifferent	Indifferent	Aut.
UR_55	Robot+ End effector	The maintenance team shall have a detailed documentation so they can repair the general problems in the robotic system	Maintenance	Expected	Expected	Aut.
UR_56	Additional functions	The windshield manipulation shall be fail safe	Maintenance	Expected	Expected	Aut.
UR_57	Additional functions	The user needs perform the usual service and maintenance procedures in house, for the crucial parts of the robotic system	Maintenance	Expected	Expected	Feas.
UR_58	Additional functions	The user needs external support and maintenance always available for more serious problems related to the robotic solution	Maintenance	Expected	Indifferent	Feas.
UR_59	Additional functions	The user needs easy and quick maintenance for the robotic solution	Maintenance	Desired	Desired	Feas.
UR_60	System	The user needs affordable maintenance of the robot (costs, time, etc.)	Programming	Desired	Desired	Feas.
UR_61	System	The required maintenance operations on the robotic systems shall be minimum during its expected life	Programming	Desired	Desired	Feas.
UR_62	System	The robotic and workcell programming shall be accessible for the Maintenance (Partly)	Safety / Security	Expected	Expected	Feas.
UR_63	System	The robotic and workcell programming shall be accessible for the operators (Partly)	Safety / Security	Undesired	Expected	Feas.
UR_64	Robot+ End effector	The Robot shall be Safe (PLd-CAT3)	Safety / Security	Expected	Expected	Aut.
UR_65	System	The robotic system shall comply with the existing safety standards for collaborative robots.	Safety / Security	Expected	Desired	Aut.
UR_66	System	The robotic solution should be certified	Safety / Security	Expected	Desired	Aut.
UR_67	System	The system shall be able to identify the operator	Training	Desired	Expected	Feas.
UR_68	System	The user needs specific training in relation to how to collaborate with the robot	User Interface	Expected	Expected	Feas.
UR_69	System	The user needs a light training for technicians for how to communicate with and understand the robot	User Interface	Expected	Expected	Feas.
UR_70	System	The main language of communication between the robotic system and the human operator(s) shall be English	User Interface	Accepted	Accepted	Feas.
UR_71	System	The system shall communicate any Safety related information to the user in a timely, immediate, perception level way	User Interface	Expected	Expected	Feas.
UR_72	System	The robotic solution shall be intuitive to use	User Interface	Expected	Expected	Feas.
UR_73	System	The user needs an HMI which uses as less words as possible, preferably graphical	User Interface	Desired	Desired	Feas.
UR_74	System	The robot shall be equipped with a human machine interface	User Interface	Expected	Expected	Feas.
UR_75	System	The system should communicate in a always understandable way	User Interface	Expected	Expected	Feas.
UR_76	System	The system should communicate without verbal language (I.e. physical interaction or sign)	User Interface	Desired	Desired	Feas.
UR_77	System	The system could support an HMI which communicates in operator's local language	User Interface	Expected	Indifferent	Feas.
UR_78	Sensory system	Anthropometrics recognition should be anonymous	Configuration / Ada	Expected	Desired	Feas.

Figure 48: Full list of the manufacturing use-case user-requirements

UR	RANKING AND SCORING Requirement / Criteria	Total score	Ease of Implementation			Operator Perspective					End-User Perspective						Development		
			Ref.	CPS.	Final Impl	High Usability	Intuitivity	Satisfaction	Dissatisfaction	Average	Economics	Productivity/ Flexibility	Quality	Ergonomics	Safety	Average	TRL Equally averaged partners scoring	Feasibility Equally averaged partners scoring	Integrability Equally averaged partners scoring
			10%			25%					20%						15%	15%	15%
	Weighting		20%	80%		40%	20%	20%	20%		17%	17%	17%	25%	25%				
	Compiler		CRF			CRF					CRF						Partners	Partners	Partners
UR_01	The system shall be able to handle heavy payload	3,00	3	3	3	5	1	5	5	4,2	2	4	5	5	5	4,3	2	1,6	1,6
UR_02	The system shall be able to withstand strong reaction forces from the operator	3,03	3	3	3	5	3	5	3	4,2	3	3	5	5	5	4,3	2,2	1,6	1,6
UR_03	The solution shall be able to change the position of the handled object by HG (Hand Guiding function - ISO 10218:2)	2,44	3	2	2,2	4	3	5	2	3,6	2	3	2	4	4	3,2	1,6	1,6	1,4
UR_04	The System shall learn from the user's feedback in order to be proactive to the next steps	1,91	2	2	2	3	2	5	2	3	1	2	1	3	1	1,7	1,6	1	1,6
UR_05	The robot shall be able to adapt to each operator that uses the workcell (adaptation to anthropometrics)	3,61	3	3	3	5	4	5	4	4,6	3	4	3	5	4	3,9	3	3	3,2
UR_06	The robot shall be able to monitor the quality of the performed activity	2,31	2	2	2	3	3	3	1	2,6	5	4	5	1	5	3,8	1,6	1,6	1,4
UR_07	The System (Robot+Gripper) shall perform pick-move-place operations	2,80	3	3	3	4	5	5	5	4,6	3	3	4	5	1	3,2	2	1,4	1,4
UR_08	The Robot shall be able to detect and understand the applied force	2,07	3	2	2,2	1	1	1	1	1	4	3	5	4	5	4,3	1,8	1,6	1,6
UR_09	The robot shall be able to perform specific tasks without the human operator	3,26	3	3	3	5	5	5	5	5	5	5	5	4	4	4,5	2,2	1,6	1,6
UR_10	Human-Robot Collaboration phases are not on continous moving (they are parallel to the line)	2,60	3	3	3	4	3	3	5	3,8	3	3	3	3	3	3,0	2	1,6	1,4
UR_11	The operator shall perform collaborative operations in front of the end-effector of the robot	2,78	3	3	3	4	5	3	4	4	3	4	3	4	4	3,7	2	1,6	1,4
UR_12	The execution time is superior limited by the TAKT TIME	2,44	3	3	3	3	4	1	3	2,8	5	4	2	2	5	3,6	2	1,4	1,4
UR_13	The robotic system shall be able to pick windshields from the tray	3,06	3	3	3	5	3	5	5	4,6	4	4	4	4	4	4,0	2,2	1,6	1,6
UR_14	The System shall Self-reconfigure when products/process variations are requested	2,81	2	3	2,8	4	3	4	5	4	4	5	5	2	3	3,6	2,2	1,6	1,6
UR_15	The robotic system shall assemble the windshield on the chassis	2,05	3	-3	-1,8	1	2	4	5	2,6	3	5	5	3	5	4,2	2	1,6	1,4
UR_16	The robotic system shall detect attention and fatigue state of the operator	2,68	2	2	2	2	2	4	2	2,4	3	4	4	4	4	3,8	2,4	2,6	2,4
UR_17	The robotic system shall use wearable devices to monitor the state of the operator	2,62	2	2	2	2	2	4	2	2,4	3	4	4	4	4	3,8	2	2,6	2,4
UR_18	The sytem shall be able to analyze and understand the scene in the workplace	3,02	2	3	2,8	2	3	3	3	2,6	4	4	3	4	4	3,8	2,8	2,8	3,2
UR_19	The sytem shall be able to warn and manage situations related to intrusions by external operators or other factors	2,93	3	3	3	3	3	5	5	3,8	3	3	2	1	5	2,8	2,2	2,8	2,4
UR_20	The Robot System shall be able to prevent and avoid singularities during operator's direct manipulation	2,58	3	3	3	3	3	4	4	3,4	3	3	3	2	5	3,3	2	1,8	1,4
UR_21	The System should monitor logistics state to manage refill requirements	2,77	3	3	3	4	3	3	3	3,4	3	4	3	2	4	3,2	2,2	2,4	2
UR_22	The system should implement a SMS (Safety rated Monitored Stop Function - ISO 10218:2)	2,79	3	3	3	3	4	5	5	4	3	4	3	2	5	3,4	2	1,8	1,6
UR_23	The system should implement a SSM (Speed Separation Monitoring - ISO 10218:2)	2,76	3	3	3	3	4	5	5	4	3	3	3	2	5	3,3	2	1,8	1,6
UR_24	The Robot shall adjust its feedback stiffness according to the human interaction ongoing	2,42	2	2	2	3	4	5	5	4	3	2	2	2	4	2,7	2	1	1,6
UR_25	The System shall enable a wearable HMI in AR or XR for the operator	2,87	3	3	3	4	3	3	2	3,2	4	3	3	3	3	3,2	2,4	2,6	2,6
UR_26	The system shall be simulated and represented in a digital twin and in a dynamic SoS representation	2,41	3	3	3	3	2	2	2	2,4	1	3	3	2	2	2,2	2,4	2,6	2,2
UR_27	The system shall be able to detect known gestures from the operator as HMI	2,71	3	3	3	4	3	5	5	4,2	4	3	3	2	3	2,9	2,2	1,6	1,4
UR_28	The system shall be able to detect and interpret natural movements as gestures from the operator as HMI	2,66	3	3	3	4	3	5	4	4	3	4	3	2	3	2,9	2,2	1,6	1,4
UR_29	The system could dialogue with the operator using voice recognition and Natural Language Processing	2,51	3	3	3	5	3	5	2	4	4	3	2	2	3	2,8	2	1	1,4
UR_30	The system shall warn if the estimated operation duration is above TAKT time	2,55	3	3	3	4	2	4	3	3,4	4	5	3	2	3	3,3	2	1,6	1,4
UR_31	The Human and the robot shall have a HMI as communication System	2,84	3	3	3	5	5	5	5	5	3	3	3	3	3	3,0	2,2	1	1,4
UR_32	The users shall have a solution which will help improving their ergonomics.	3,21	3	3	3	5	2	5	5	4,4	3	3	2	5	3	3,3	2,4	2,6	2,6
UR_33	The robotic solution shall be able to send feedback to the operator in a collaborative situation	2,99	3	3	3	4	4	5	5	4,4	5	4	3	3	4	3,8	2,2	1,8	1,6
UR_34	The human shall always be able to interact with the robot during collaboration phases	2,96	3	3	3	4	4	5	5	4,4	5	3	3	3	4	3,6	2,2	1,8	1,6
UR_35	The robotics system shall communicate properly and timely to the users, so the user gets the proper signal at the proper moment (if something happens)	3,04	3	3	3	5	5	5	5	5	4	3	3	3	4	3,4	2	1,8	1,6
UR_36	The robot shall notify the human operator of lack of quality or non compliance to the quality expectation	2,08	2	2	2	3	3	3	2	2,8	3	3	4	1	1	2,2	2	1,8	1,2
UR_37	The user will have seamless communication with the robot within the collaborative tasks	2,60	2	0	0,4	5	4	4	4	4,4	4	3	3	3	4	3,4	2	1,6	1,6
UR_38	The robotic solution should be easy to use for any level of experience among the operators	2,91	2	2	2	5	5	5	5	5	5	4	3	2	3	3,3	2,2	1,6	1,6
UR_39	The robotic system shall perform at least as fast as the current cycle time	2,81	3	3	3	3	3	4	4	3,4	4	4	4	2	4	3,5	2,4	2,4	1,6

Figure 49: Full list of the manufacturing use-case user-requirements part 1/2

UR	RANKING AND SCORING Requirement / Criteria	Total score	Ease of Implementation			Operator Perspective					End-User Perspective						Development		
			Ref.	CPS.	Final Impl	High Usability	Intuitivity	Satisfaction	Dissatisfaction	Average	Economics	Productivity/ Flexibility	Quality	Ergonomics	Safety	Average	TRL Equally averaged partners scoring	Feasibility Equally averaged partners scoring	Integrability Equally averaged partners scoring
			10%			25%					20%						15%	15%	15%
	Weighting		20%	80%		40%	20%	20%	20%		17%	17%	17%	25%	25%				
	Compiler		CRF			CRF					CRF						Partners	Partners	Partners
UR_40	The users shall be able to access documentation from their smartphone or the operating tablet	1,69	0	0	0	2	2	4	2	2,4	5	2	2	1	1	2,0	1,8	1,6	1,2
UR_41	The robotic system shall be performing for at least 2 shifts (16H)	1,66	3	1	1,4	1	1	2	1	1,2	3	5	2	2	2	2,7	1,8	1,6	1,2
UR_42	The Robotic system shall communicate sequences, performances, validation data with above data layers	2,06	3	3	3	2	2	2	2	2	3	5	3	2	2	2,8	1,8	1,6	1,2
UR_43	The system should handle change of tools/parts autonomously updating information on the handled part	1,70	2	0	0,4	1	2	2	1	1,4	3	5	3	2	3	3,1	1,8	1,6	1,2
UR_44	The developers shall be able to add additional programs to the robot, so new configurations for new objects can be added	1,67	0	2	1,6	1	2	2	1	1,4	4	5	3	1	1	2,5	1,6	1,6	1,2
UR_45	The robot should be in phase with the continous moving system of the production line	1,54	3	-3	-1,8	1	1	3	3	1,8	3	5	3	3	3	3,3	1,6	1	1,4
UR_46	The robotics system shall reconfigure to manipulate different variations of the same product with small dimensional changes	2,25	1	3	2,6	1	3	3	1	1,8	3	5	3	3	3	3,3	1,8	2,2	1,8
UR_47	The system shall not manage nor collect personal/sensitive data from the operators, unless it is safety related	1,99	3	3	3	1	1	4	4	2,2	4	1	1	1	4	2,3	2	1,4	1,2
UR_48	The robotic system shall be able to show performance data	2,41	3	1	1,4	3	3	4	4	3,4	5	5	4	2	2	3,3	2	1,6	1,4
UR_49	The system shall support the user in the risk assessment report	1,56	2	2	2	1	1	1	1	1	4	1	1	1	4	2,3	1,8	1,6	1
UR_50	The user will have all the essential information about using the robot to be available on site	2,56	3	1	1,4	3	3	4	4	3,4	5	3	2	2	3	2,9	2	2,4	2,2
UR_51	The user will have all the essential information about using the robot to be visible at any moment during their work	2,20	0	0	0	3	4	4	4	3,6	4	3	2	2	3	2,8	2	1,6	1,4
UR_52	The user will have visual documentation of how to use the robot	2,28	1	1	1	4	4	4	4	4	4	2	2	2	3	2,6	1,4	1,6	1,4
UR_53	The users shall have easy access to the documentation	2,61	2	2	2	3	3	5	5	3,8	4	2	2	2	2	2,3	2	2,4	2,2
UR_54	The users needs documentation which is easy to read, and is most preferred graphical	2,43	1	1	1	4	3	5	5	4,2	5	3	2	2	2	2,7	1,8	1,8	1,4
UR_55	The maintenance team shall have a detailed documentation so they can repair the general problems in the robotic system	2,58	3	3	3	3	3	5	5	3,8	5	2	2	2	3	2,8	2	1,8	1,4
UR_56	The windshield manipulation shall be fail safe	2,64	3	3	3	3	2	5	5	3,6	3	2	2	3	5	3,2	2,2	1,8	1,4
UR_57	The user needs perform the usual service and maintenance procedures in house, for the crucial parts of the robotic system	2,17	3	3	3	2	2	3	3	2,4	4	3	2	2	3	2,8	2	1,6	1,2
UR_58	The user needs external support and maintenance always available for more serious problems related to the robotic solution	2,06	3	1	1,4	2	2	4	3	2,6	4	3	2	2	3	2,8	2	1,6	1,2
UR_59	The user needs easy and quick maintenance for the robotic solution	1,89	2	2	2	2	2	2	2	2	4	3	2	2	2	2,5	1,8	1,6	1,2
UR_60	The user needs affordable maintenance of the robot (costs, time, etc.)	1,99	2	2	2	2	2	2	2	2	5	2	2	2	4	3,0	1,8	1,6	1,2
UR_61	The required maintenance operations on the robotic systems shall be minimum during its expected life	2,13	2	2	2	2	2	3	3	2,4	4	5	4	2	1	2,9	2	1,6	1,4
UR_62	The robotic and workcell programming shall be accessible for the Maintenance (Partly)	2,45	3	3	3	5	2	3	3	3,6	4	3	2	2	2	2,5	2	1,6	1,4
UR_63	The robotic and workcell programming shall be accessible for the operators (Partly)	2,29	-3	3	1,8	5	3	3	3	3,8	4	2	2	2	2	2,3	1,6	1,6	1,4
UR_64	The Robot shall be Safe (PLd-CAT3)	2,96	3	3	3	5	4	5	5	4,8	3	4	2	2	5	3,3	2,2	1,6	1,6
UR_65	The robotic system shall comply with the existing safety standards for collaborative robots.	3,04	3	2	2,2	5	3	4	4	4,2	3	3	3	4	5	3,8	2,2	2,2	2,4
UR_66	The robotic solution should be certified	2,43	3	2	2,2	3	3	3	3	3	3	2	4	3	4	3,3	2,2	1,8	1,4
UR_67	The system shall be able to identify the operator	2,80	2	3	2,8	4	4	4	2	3,6	3	2	2	3	2	2,4	2,2	3,4	2
UR_68	The user needs specific training in relation to how to collaborate with the robot	2,89	3	3	3	4	4	4	2	3,6	4	3	2	3	2	2,8	2,4	2,8	2,4
UR_69	The user needs a light training for technicians for how to communicate with and understand the robot	2,66	3	3	3	3	3	3	2	2,8	4	3	2	3	2	2,8	2,4	2,6	2,4
UR_70	The main language of communication between the robotic system and the human operator(s) shall be English	1,86	0	0	0	3	3	3	2	2,8	5	3	2	2	2	2,7	1,2	1,6	1,4
UR_71	The system shall communicate any Safety related information to the user in a timely, immediate, perception level way	3,16	3	3	3	5	3	4	5	4,4	5	2	2	2	5	3,3	2,4	2,6	2,4
UR_72	The robotic solution shall be intuitive to use	2,93	3	3	3	5	5	5	5	5	5	3	3	2	2	2,8	2	1,8	1,6
UR_73	The user needs an HMI which uses as less words as possible, preferably graphical	2,99	2	2	2	5	5	5	4	4,8	5	3	3	2	2	2,8	2	2,4	2,4
UR_74	The robot shall be equipped with a human machine interface	2,93	3	3	3	5	5	5	4	4,8	5	3	3	2	3	3,1	2,2	1,6	1,6
UR_75	The system should communicate in a always understandable way	3,19	3	3	3	5	4	4	4	4,4	5	3	3	2	3	3,1	2,4	2,8	2,6
UR_76	The system should communicate without verbal language (I.e. physical interaction or sign)	2,42	2	2	2	5	4	3	3	4	4	3	3	2	2	2,7	1,6	1,6	1,4
UR_77	The system could support an HMI which communicates in operator's local language	2,44	3	1	1,4	5	5	3	3	4,2	3	3	3	2	2	2,5	1,8	1,6	1,6
UR_78	Anthropometrics recognition should be anonymous	2,99	3	2	2,2	1	1	5	3	2,2	4	3	3	3	3	3,2	3,4	3,6	3,6

Figure 50: Full list of the manufacturing use-case user-requirements part 2/2

	RANKING AND SCORING		Ease of			Operator					End-User Perspective						Development			
	Requirement / Criteria	Total score	Ref.	CPS.	Final Implementation	High Usability	Intuitivity	Satisfaction	Dissatisfaction	Average	Economics	Productivity/ Flexibility	Quality	Ergonomics	Safety	Average	TRL Equally averaged partners scoring	Feasibility Equally averaged partners scoring	Integrability Equally averaged partners scoring	Complexity in CPSoSaware
			10%			25%					20%						15%	15%	15%	
UR	*Weighting*		*20%*	*80%*		*40%*	*20%*	*20%*	*20%*		*17%*	*17%*	*17%*	*25%*	*25%*					
	Compiler		*CRF*			*CRF*					*CRF*						*Partners*	*Partners*	*Partners*	
UR_05	The robot shall be able to adapt to each operator that uses the workcell (adaptation to anthropometrics)	3,61	3	3	3	5	4	5	4	4,6	3	4	3	5	4	3,9	3	3	3,2	Feas.
UR_09	The robot shall be able to perform specific tasks without the human operator	3,26	3	3	3	5	5	5	5	5	5	5	5	4	4	4,5	2,2	1,6	1,6	Aut.
UR_32	The users shall have a solution which will help improving their ergonomics.	3,21	3	3	3	5	2	5	5	4,4	3	3	2	5	3	3,3	2,4	2,6	2,6	Feas.
UR_75	The system should communicate in a always understandable way	3,19	3	3	3	5	4	4	4	4,4	5	3	3	2	3	3,1	2,4	2,8	2,6	Aut.
UR_71	The system shall communicate any Safety related information to the user in a timely, immediate, perception level way	3,16	3	3	3	5	3	4	5	4,4	5	2	2	2	5	3,3	2,4	2,6	2,4	Aut.
UR_13	The robotic system shall be able to pick windshields from the tray	3,06	3	3	3	5	3	5	5	4,6	4	4	4	4	4	4,0	2,2	1,6	1,6	Aut.
UR_35	The robotics system shall communicate properly and timely to the users, so the user gets the proper signal at the proper moment (if something happens)	3,04	3	3	3	5	5	5	5	5	4	3	3	3	4	3,4	2	1,8	1,6	Aut.
UR_65	The robotic system shall comply with the existing safety standards for collaborative robots.	3,04	3	2	2,2	5	3	4	4	4,2	3	3	3	4	5	3,8	2,2	2,2	2,4	Aut.
UR_02	The system shall be able to withstand strong reaction forces from the operator	3,03	3	3	3	5	3	5	3	4,2	3	3	5	5	5	4,3	2,2	1,6	1,6	Feas.
UR_18	The sytem shall be able to analyze and understand the scene in the workplace	3,02	2	3	2,8	2	3	3	3	2,6	4	4	3	4	4	3,8	2,8	2,8	3,2	Comp.
UR_01	The system shall be able to handle heavy payload	3,00	3	3	3	5	1	5	5	4,2	2	4	5	5	5	4,3	2	1,6	1,6	Aut.
UR_78	Anthropometrics recognition should be anonymous	2,99	3	2	2,2	1	1	5	3	2,2	4	3	3	3	3	3,2	3,4	3,6	3,6	Feas.
UR_33	The robotic solution shall be able to send feedback to the operator in a collaborative situation	2,99	3	3	3	4	4	5	5	4,4	5	4	3	3	4	3,8	2,2	1,8	1,6	Aut.
UR_73	The user needs an HMI which uses as less words as possible, preferably graphical	2,99	2	2	2	5	5	5	4	4,8	5	3	3	2	2	2,8	2	2,4	2,4	Feas.
UR_64	The Robot shall be Safe (PLd-CAT3)	2,96	3	3	3	5	4	5	5	4,8	3	4	2	2	5	3,3	2,2	1,6	1,6	Aut.
UR_34	The human shall always be able to interact with the robot during collaboration phases	2,96	3	3	3	4	4	5	5	4,4	5	3	3	3	4	3,6	2,2	1,8	1,6	Aut.
UR_74	The robot shall be equipped with a human machine interface	2,93	3	3	3	5	5	5	4	4,8	5	3	3	2	3	3,1	2,2	1,6	1,6	Feas.
UR_19	The sytem shall be able to warn and manage situations related to intrusions by external operators or other factors	2,93	3	3	3	3	3	5	5	3,8	3	3	2	1	5	2,8	2,2	2,8	2,4	Aut.
UR_72	The robotic solution shall be intuitive to use	2,93	3	3	3	5	5	5	5	5	5	3	3	2	2	2,8	2	1,8	1,6	Aut.
UR_38	The robotic solution should be easy to use for any level of experience among the operators	2,91	2	2	2	5	5	5	5	5	5	4	3	2	3	3,3	2,2	1,6	1,6	Feas.
UR_68	The user needs specific training in relation to how to collaborate with the robot	2,89	3	3	3	4	4	4	2	3,6	4	3	2	3	2	2,8	2,4	2,8	2,4	Feas.
UR_25	The System shall enable a wearable HMI in AR or XR for the operator	2,87	3	3	3	4	3	3	2	3,2	4	3	3	3	3	3,2	2,4	2,6	2,6	Feas.
UR_31	The Human and the robot shall have a HMI as communication System	2,84	3	3	3	5	5	5	5	5	3	3	3	3	3	3,0	2,2	1	1,4	Feas.
UR_39	The robotic system shall perform at least as fast as the current cycle time	2,81	3	3	3	3	3	4	4	3,4	4	4	4	2	4	3,5	2,4	2,4	1,6	Feas.
UR_14	The System shall Self-reconfigure when products/process variations are requested	2,81	2	3	2,8	4	3	4	5	4	4	5	5	2	3	3,6	2,2	1,6	1,6	Comp.

Figure 51: 25 Top ranked user requirements for the manufacturing use-case

Annex 3: **Automotive Use-Case User requirements**

				Implementation		
ID	From	User Requirement	Category	Implementation in Reference use-case	Implementation in CPSoSaware	Complexity in CPSoSaware
UR_01	Sensory system	The system shall detect a moving pedestrain (normal adults size with normal walking speed) who has 6m of lateral offset vertically to driving tube of Ego vehilce and corssing the driving tube of Ego vehilce (with moving speed of maximum 20 kph) in daytime and at sufficient lighting conditions at night.	Safety/ Security	Expected	Expected	Feasible
UR_02	Sensory system	The system shall detect a moving pedestrain (normal adults size with normal walking speed) who has 4m of lateral offset vertically to driving tube of ego vehilce and corssing the driving tube of Ego vehilce (with moving speed of MAX 20 kph) and is behind the park vehilces with 1m of offset in daylight.	Safety/ Security	Expected	Expected	Feasible
UR_03	Sensory system	The system shall detect a moving pedestrain (normal adults size with normal walking speed) who is 10m away from the vehicle and is moving towards the vehicle (middle) while the vehicle is stationary.	Safety/ Security	Expected	Expected	Feasible
UR_04	Sensory system	The system shall detect a moving pedestrain (normal adults size with normal walking speed) who is 10m away from the vehicle and is moving towards the vehicle (middle) while the vehicle is moving with a speed of maximum 20 kph.	Safety/ Security	Expected	Expected	Feasible
UR_05	Sensory system	The system shall detect a moving pedestrain (normal adults size with normal walking speed) who is 10m from the vehicle and is moving towards the vehicle (has 25% of carwidth offset to the middle of ego vehicle) while the vehicle is moving (with moving speed of maximum 20 kph).	Safety/ Security	Expected	Expected	Complex
UR_06	Sensory system	The system shall detect a moving cyclist (normal adults size) who has 17m of lateral offset vertically to driving tube of ego vehilce and corssing the driving tube of Ego vehilce (with moving speed of maximum 20 kph).	Safety/ Security	Expected	Expected	Feasible
UR_07	Sensory system	The system shall detect a moving cyclist (normal adults size with normal walking speed) who is behind the parked vehicle (which have 3.5 m offset to the driving tube of ego vehicle) and will collide to the middle of front bumper of the vehicle while both are moving with constant speed.	Safety/ Security	Expected	Expected	Complex
UR_08	Sensory system	The system shall detect a moving cyclist (normal adults size) who is moving in font of the vehicle (in middle) with a speed less than ego vehicle in day light.	Safety/ Security	Expected	Expected	Feasible
UR_09	System	The system shall detect a moving cyclist (normal adults size with normal walking speed) who is moving if font of the vehicle (has 25% of car width offset to the middle of ego vehicle) and with a speed less than ego vehicle.	Safety/ Security	Expected	Expected	Complex
UR_10	System	The system shall detect a moving pedestrain (normal adults size) who has 6m of lateral offset vertically to driving tube of ego vehilce and corssing the driving tube of Ego vehilce and collide to the middle of front bumper,then warn and activate AEB (Auto Emergency Brake) system before collision.	Safety/ Security	Expected	Expected	Feasible
UR_11	System	The system shall detect a moving child (normal walking speed) who has 4m of lateral offset vertically to driving tube of ego vehilce and corssing the driving tube of Ego vehilce (with moving speed of maximum 20 kph) and is behind the park vehilces with 1m of offset and collide to the middle of front bumper,then warn and activate AEB (Auto Emergency Brake) system before collision.	Safety/ Security	Expected	Expected	Feasible
UR_12	System	The system shall detect a moving pedestrain (normal adults size with normal walking speed) who is 10m from the vehicle (with moving speed of MAX 20 kph) and is moving towards the vehicle (middle), warn and and activate AEB (Auto Emergency Brake) system before collision.	Safety/ Security	Expected	Expected	Feasible
UR_13	System	The system shall detect a moving pedestrain (normal adults size with normal walking speed) who is 10m from the vehicle and is moving towards the vehicle (has 25% of carwidth offset to the middle of ego vehicle), then warn and activeate the AEB system before any collision while the vehicle is moving with speed of maximum 20 kph.	Safety/ Security	Expected	Expected	Complex
UR_14	System	The system shall detect a moving cyclist (normal adults size with normal walking speed) who has 17m of lateral offset vertically to driving tube of ego vehilce and corssing the driving tube of Ego vehilce. The system should be able to warn and activate AEB system before any collision while the vehicle is moving with speed of maximum 20 kph.	Safety/ Security	Expected	Expected	Feasible
UR_15	System	The system shall detect a moving cyclist (normal adults size with normal cycling speed) who is behind the parked vehicle (which has 3.5 m offset the driving tube of ego vehicle) and will collide to the middle of front bumper of the vehicle while both moving with constant speed. The system shall first warn and then activate AEB system to avoid collision while the vehicle is moving with speed of maximum 20 kph.	Safety/ Security	Expected	Expected	Feasible
UR_16	System	The system shall detect a moving cyclist (normal adults size with normal cycling speed) who is moving if font of the vehicle (in middle) and with a speed less than ego vehicle (vehicle speed is less than 20 kph). The system shall first warn then activate AEB system	0-Functions	Expected	Expected	Feasible
UR_17	System	The system shall detect a moving cyclist (normal adults size with normal cycling speed) who is moving if font of the vehicle (has 25% of car width offset to the middle of ego vehicle) and with a speed less than ego vehicle (with moving speed of maximum 20 kph), then warn the driver and activate AEB to avoid any collision.	0-Functions	Expected	Expected	Feasible
UR_18	System	The moving accelerations (lateral and longitudinal) of the vehicle shall be in an acceptable range based on ISO 2631-1 standard to ensure the driving comfort for passengers	0-Functions	Expected	Expected	Feasible
UR_19	Operator/Driver	The system shall detect a moving child (normal walking speed) who has 6m of lateral offset vertically to driving tube of ego vehilce and corssing the driving tube of Ego vehilce (with moving speed of maximum 20 kph) at sufficient lighting conditions at night time.	Safety/ Security	Expected	Expected	Feasible
UR_20	Operator/Driver	While the vehicle is in AutoPark mode and approaching the parking space in reverse gear (with pseed of maximum 6 kph) shall detect a stationary child in middle of the parking slot in day and night light.	Comfort	Expected	Expected	Feasible
UR_21	System	While the system is detecting the free space to park, if a standing child occupied the parking place the parking slot shall be detected as a non-free parking slot (daylight)	Safety/ Security	Expected	Expected	Feasible
UR_22	Sensory system	Camera Sensing Module interfaceperiodic shall be updated assigned with a timestamp.	0-Functions	Expected	Expected	Feasible
UR_23	System	The frames of each camera shall be updated assigned with a timestamp	0-Functions	Expected	Expected	Feasible
UR_24	System	Each planned path shall be defined with an ID.	0-Functions	Expected	Expected	Feasible
UR_25	Operator/Driver	While the vehicle is in AutoPark mode and approaching the parking space (with pseed of maximum 6 kph) shall detect a stationary child in middle of the parking slot in daylight and foggy weather.	0-Functions	Expected	Expected	Feasible
UR_26	Operator/Driver	While the system is detecting the free space to park, if a standing child occupied the parking place the parking slot shall be detected as a non-free parking slot in daylight and rainny weather conditions.	Reliability/ Performance	Expected	Expected	Feasible
UR_27	System	The localization Module shall have a timestamp to be sure that the odometry of ego vehicle is up	0-Functions	Expected	Expected	Feasible
UR_28	System	CAN signal shall be tracked to be sure that they are updating each 20 ms.	0-Functions	Expected	Expected	Automatic
UR_29	Sensory system	The Sonar ping counter shall be updated.	0-Functions	Expected	Expected	Automatic
UR_30	Operator/Driver	While the vehicle is in AutoPark mode and approaching the parking space in reverse gear (with pseed of maximum 6 kph) shall detect a stationary sitting child in middle of the parking slot in daylight.	Reliability	Expected	Expected	Automatic

Figure 52: Automotive Use Case full list of user requirements part 1/2

				Implementation		
ID	From	User Requirement	Category	Implementation in Reference use-case	Implementation in CPSoSaware	Complexity in CPSoSaware
UR_31	System	The status of the vehicle controller shall be tracked by a WatchDog (WD) to ensure its availability.	0-Functions	Expected	Expected	Automatic
UR_32	System	The localization module shall ensure that it is working on update CAN signal. (timestamps)	0-Functions	Expected	Expected	Automatic
UR_33	Sensory system	The CameraSensingModule shall Inform the WD that the calculation of the module is done and a new interface is valid.	0-Functions	Expected	Expected	Automatic
UR_34	System	It's recommended to use SPICE code guidlines to ensure the high quality of the code.	0-Functions	Expected	Expected	Automatic
UR_35	System	In Auto Parking Module shall ensure that the runtime of the planner is less than the periodic update rate of the localization module (100 ms)	0-Functions	Expected	Expected	Feasible
UR_36	Operator/Driver	The Auto Parking Module shall always has priority to provide the high-level control signals for the vehicle	Reliability/ Performance	Expected	Expected	Feasible
UR_37	System	The Auto Parking Module shall check the timestamp of the provided information from the CameraSensingModule to ensure that the unused itterations of the planning process.	0-Functions	Expected	Expected	Feasible
UR_38	System	The Auto Parking Module shall apply ist own safety margines to the detected obstacles to be sure that safety distance to the objects will be applied	Safety/ Security	Expected	Expected	Complex
UR_39	Operator/Driver	The AutoParkingModule (APM) shall give the full control of the vehicle to the driver whenever it	0-Functions	Expected	Expected	Feasible
UR_40	System	The APM should not requesthigher speed than for safety limit defined in ist "config" file.	Configuration	Expected	Expected	Feasible
UR_41	System	The Auto Parking Module shall provide the requested motions of the vehicle as a single package assigned with an ID. To ensure the expected behaviour of the vehicle.	User Interface	Expected	Expected	Feasible
UR_42	System	The Auto Parking Module shall ensure that the vehicle controller recieved the correct motion package before starting the low level controller	0-Functions	Expected	Expected	Complex
UR_43	System	The vehicle controller shall ensure that it reads on CAN bus autoparking relevant updated messa	0-Functions	Expected	Expected	Feasible
UR_44	System	The vehicle controller shall ensure that it is able to detect malfunctions in the case of missing CAN signals.	0-Functions	Expected	Expected	Feasible
UR_45	System	The vehicle controller shall give the driver always the highest priority	Reliability/ Performance	Expected	Expected	Feasible
UR_46	Vehicle	The vehicle controller shall provide its status to the Auto Parking Module while the car is in auto drive mode in CAN update rate	0-Functions	Expected	Expected	Complex
UR_47	System	The vehicle controller shall report its failures to the Auto Parking Module	Documentation	Expected	Expected	Feasible
UR_48	System	If steering controls (CAN Signal : ..) are blocked or manipulated by the driver the vehicle control module shall give back the control to the driver, stopping the manevourings and braking the car. This action finalizes the control operation without need of confirmation.	0-Functions	Expected	Expected	Feasible
UR_49	Vehicle	If gear is changed or manipulated by the driver the vehicle control module shall give back the control to the driver, stopping the manevourings and braking the car. This action finalizes the control operation without need of confirmation.	0-Functions	Expected	Expected	Feasible
UR_50	System	A WatchDog (WD) functions shall be implemented inside the framwork to track the required signals between the diffrent hardward of the Auto Parking System	0-Functions	Expected	Expected	Feasible
UR_51	Vehicle	When the vehicle is in Auto Parking mode, it shall not listen to the driver's request for acceleration.	0-Functions	Expected	Expected	Automatic
UR_52	Vehicle	The driver of the vehicel shall be able to cancel the parking menuvers of Auto parking system at any time.	User Interface	Expected	Expected	Feasible
UR_53	System	The SW architecht shall be desinged based on: comprehensibility,maintainability,simplicity and verifiability;	0-Functions	Expected	Expected	Feasible
UR_54	System	The SW architecht shall be desinged with Natural language notation	0-Functions	Expected	Expected	Feasible
UR_55	System	The SW architecht shall be desinged with an Appropriate hierarchical structure of the software co	Programming	Expected	Expected	Feasible
UR_56	System	The SW architecht shall be desinged while Restricts size and complexity of software components	Programming	Expected	Expected	Feasible
UR_57	System	The SW architecht shall be desinged with an Appropriate management of shared resources	Programming	Expected	Expected	Complex
UR_58	System	The system shall detect the presence of a driver	0-Functions	Expected	Expected	Feasible
UR_59	System	The system shall detect through a Driver State Monitoring (DSM) functionality the drowsiness lev	0-Functions	Expected	Expected	Feasible
UR_60	System	The system should detect visual distraction of the driver based on his/her head position and/or gaze vector	0-Functions	Expected	Expected	Complex
UR_61	Sensory system	An Android device with an API higher than 28 and a front camera available shall be present withi	User Interface	Expected	Expected	Complex
UR_62	Sensory system	An Android application shall be implemented to provide the DSM functionality	User Interface	Expected	Expected	Feasible
UR_63	Sensory system	The Android DSM application shall notify through proper alerts the driver if the DSM detects high level of drowsiness or inattention	User Interface	Expected	Expected	Feasible
UR_64	Security	The system will be robust to timestamp alteration attacks	Reliability/ Performance	Expected	Expected	Feasible
UR_65	Security	The system will be robust to deteriotated image quality in a way that can be either inspected or r	Sustainability	Expected	Expected	Complex
UR_66	Security	The system will be robust to deteriotion of LIDAR quality	Reliability/ Performance	Expected	Expected	Complex
UR_67	Security	The system will preserve adequate levels of data confidentiality	Reliability	Expected	Expected	Complex
UR_68	Security	The system will preserve adequate levels of data integrity	Data Handling	Expected	Expected	Feasible
UR_69	Security	The system will preserve adequate levels of data availability	Data Handling	Expected	Expected	Feasible
UR_70	Security	The system will preserve adequate levels of system availability/continuity of operations	Reliability/ Performance	Expected	Expected	Extremely complex
UR_71	Security	The system will preserve adequate levels of accountability	Sustainability	Expected	Expected	Feasible
UR_72	Security	The system will provide means that contribute to cybersecurity awareness	0-Functions	Expected	Expected	Complex
UR_73	Security	The system will provide means that contribute to cybersecurity protection	0-Functions	Expected	Expected	Complex
UR_74	Security	The system will be protected against physical/implementation security attacks	0-Functions	Expected	Expected	Extremely complex

Figure 53: Automotive Use Case full list of user requirements part 2/2

RANKING AND SCORING

UR	Requirement / Criteria	Total score	Implementation			Operator Perspective Total: 50%					End-User Perspective Total: 50%						Development		
			Ref.	CPS.	Final Impl	High Usability	Intuitivity	Satisfaction	Dissatisfaction	Average	Economics	Maintenance	Quality	Comfort	Safety	Average	TRL Equally averaged partners scoring	Feasibility Equally averaged partners scoring	Integrability Equally averaged partners scoring
			20%			30%					30%						3%	7%	10%
	Weighting		25%	75%	20%	30%	20%	20%	30%		20%	20%	20%	20%	20%				
	Compiler		PASEU			PASEU					PASEU						Partners	Partners	Partners
UR_01	The system shall detect a moving pedestrain (normal adults size with normal walking speed) who has 6m of lateral offset vertically to driving tube of Ego vehicle and crossing the driving tube of Ego vehicle (with moving speed of maximum 20 kph) in day and night lights.	3,96	3	3	3	4	5	4	4	4,2	4	5	5	5	5	4,8	3,7	3,3	3,2
UR_02	The system shall detect a moving pedestrain (normal adults size with normal walking speed) who has 4m of lateral offset vertically to driving tube of ego vehicle and crossing the driving tube of Ego vehicle (with moving speed of MAX 20 kph) and is behind the park vehicles with 1m of offset in daylight.	3,36	3	3	3	4	5	4	4	4,2	4	5	5	5	5	4,8	3,7	3,3	3,2
UR_03	The system shall detect a moving pedestrain (normal adults size with normal walking speed) who is 10m away from the vehicle and is moving towards the vehicle (middle) while the vehicle is stationary.	3,24	3	3	3	4	3	5	4	4	4	5	4	5	5	4,6	3,7	3,3	3,2
UR_04	The system shall detect a moving pedestrain (normal adults size with normal walking speed) who is 10m away from the vehicle and is moving towards the vehicle (middle) while the vehicle is moving with a speed of maximum 20 kph.	3,30	3	3	3	4	5	4	4	4,2	4	4	5	5	5	4,6	3,7	3,3	3,2
UR_05	The system shall detect a moving pedestrain (normal adults size with normal walking speed) who is 10m from the vehicle and is moving towards the vehicle (has 25% of carwidth offset to the middle of ego vehicle) while the vehicle is moving (with moving speed of maximum 20 kph).	3,06	3	3	3	4	4	4	4	4	3	4	3	5	5	4	3,5	3,3	3,2
UR_06	The system shall detect a moving cyclist (normal adults size) who has 17m of lateral offset vertically to driving tube of ego vehicle and crossing the driving tube of Ego vehicle (with moving speed of maximum 20 kph).	3,27	3	3	3	5	4	4	4	4,3	4	4	5	4	5	4,4	3,7	3,3	3,2
UR_07	The system shall detect a moving cyclist (normal adults size with normal walking speed) who is behind the parked vehicle (which have 3.5 m offset to the driving tube of ego vehicle) and will collide to the middle of front bumper of the vehicle while both are moving with constant speed.	3,45	3	3	3	4	5	5	5	4,7	4	5	4	5	5	4,6	3,5	3,3	3,2
UR_08	The system shall detect a moving cyclist (normal adults size) who is moving in font of the vehicle (in middle) with a speed less than ego vehicle in day light.	3,27	3	3	3	4	4	4	5	4,3	4	4	5	4	5	4,4	3,7	3,3	3,2
UR_09	The system shall detect a moving cyclist (normal adults size with normal walking speed) who is moving if font of the vehicle (has 25% of car width offset to the middle of ego vehicle) and with a speed less than ego vehicle.	3,51	3	3	3	5	5	5	5	5	5	5	5	4	5	4,8	3,8	2,7	2,7
UR_10	The system shall detect a moving pedestrain (normal adults size) who has 6m of lateral offset vertically to driving tube of ego vehicle and crossing the driving tube of Ego vehicle and collide to the middle of front bumper,then warn and activate AEB (Auto Emergency Brake) system before collision.	3,36	3	3	3	4	5	5	5	4,7	5	5	4	4	5	4,6	3,8	2,7	2,7
UR_11	The system shall detect a moving child (normal walking speed) who has 4m of lateral offset vertically to driving tube of ego vehicle and crossing the driving tube of Ego vehicle (with moving speed of maximum 20 kph) and is behind the park vehicle with 1m of offset and collide to the middle of front bumper,then warn and activate AEB (Auto Emergency Brake) system before collision.	3,18	3	3	3	4	5	4	5	4,5	4	4	4	4	5	4,2	3,7	2,7	2,7
UR_12	The system shall detect a moving pedestrain (normal adults size with normal walking speed) who is 10m from the vehicle (with moving speed of MAX 20 kph) and is moving towards the vehicle (middle), warn and and activate AEB (Auto Emergency Brake) system before collision.	3,03	3	3	3	4	3	4	4	3,8	5	4	4	4	5	4,4	3,7	2,7	2,7

Figure 54: Full list of the automotive use-case user-requirements part 1/4

RANKING AND SCORING

UR	Requirement / Criteria	Total score	Implementation: Ref.	Implementation: CPS.	Implementation: Final Impl	Operator Perspective Total: 50%: High Usability	Intuitivity	Satisfaction	Dissatisfaction	Average	End-User Perspective Total: 50%: Economics	Maintenance	Quality	Comfort	Safety	Average	Development: TRL Equally averaged partners scoring	Feasibility Equally averaged partners scoring	Integrability Equally averaged partners scoring
			20%			30%					30%						3%	7%	10%
	Weighting		25%	75%	20%	30%	20%	20%	30%		20%	20%	20%	20%	20%				
	Compiler		PASEU			PASEU					PASEU						Partners	Partners	Partners
UR_13	The system shall detect a moving pedestrain (normal adults size with normal walking speed) who is 10m from the vehicle and is moving towards the vehicle (has 25% of carwidth offset to the middle of ego vehicle), then warn and activeate the AEB system before any collision while the vehicle is moving with speed of maximum 20 kph.	3,11	3	3	3	4	3	5	5	4,3	4	4	4	4	5	4,2	3,5	2,7	2,7
UR_14	The system shall detect a moving cyclist (normal adults size with normal walking speed) who has 17m of lateral offset vertically to driving tube of ego vehicle and crossing the driving tube of Ego vehicle. The system should be able to warn and activate AEB system before any collision while the vehicle is moving with speed of maximum 20 kph.	3,12	3	3	3	4	3	4	5	4,1	4	5	5	3	5	4,4	3,7	2,7	2,7
UR_15	The system shall detect a moving cyclist (normal adults size with normal cycling speed) who is behind the parked vehicle (which has 3.5 m offset the driving tube of ego vehicle) and will collide to the middle of front bumper of the vehicle while both moving with constant speed. The system shall first warn and then activate AEB system to avoid collision while the vehicle is moving with speed of maximum 20 kph.	3,18	3	3	3	4	4	4	5	4,3	4	5	5	3	5	4,4	3,7	2,7	2,7
UR_16	The system shall detect a moving cyclist (normal adults size with normal cycling speed) who is moving if font of the vehicle (in middle) and with a speed less than ego vehicle (vehicle speed is less than 20 kph). The system shall first warn then activate AEB system.	2,94	3	3	3	3	4	4	4	3,7	4	4	4	4	5	4,2	3,7	2,7	2,7
UR_17	The system shall detect a moving cyclist (normal adults size with normal cycling speed) who is moving if font of the vehicle (has 25% of car width offset to the middle of ego vehicle) and with a speed less than ego vehicle (with moving speed of maximum 20 kph), then warn the driver and activate AEB to avoid any collision.	3,50	3	3	3	5	5	5	5	5	4	5	5	5	5	4,8	3,3	2,7	2,7
UR_18	The moving accelerations (lateral and longitudinal) of the vehicle shall be in an acceptable range based on ISO 2631-1 standard to ensure the driving comfort for passengers	2,54	2	2	3	3	3	3	3	3	4	4	3	4	3	3,6	3,3	2,7	2,7
UR_19	The system shall detect a moving child (normal walking speed) who has 6m of lateral offset vertically to driving tube of ego vehicle and crossing the driving tube of Ego vehicle (with moving speed of maximum 20 kph) at night light.	3,00	3	2	3	5	3	5	5	4,6	3	4	3	3	5	3,6	3,5	2,7	2,5
UR_20	While the vehicle is in AutoPark mode and approaching the parking space in reverse gear (with pseed of maximum 6 kph) shall detect a stationary child in middle of the parking slot in day and night light.	2,88	3	2	3	3	4	5	5	4,2	3	4	3	3	5	3,6	3,3	2,7	2,5
UR_21	While the system is detecting the free space to park, if a standing child occupied the parking place the parking slot shall be detected as a non-free parking slot (daylight)	2,76	3	3	3	3	3	4	5	3,8	3	4	3	3	5	3,6	3,5	2,7	2,5
UR_22	Camera Sensing Module interfaceperiodic shall be updated assigned with a timestamp.	1,86	3	1	1,5	2	2	1	2	1,8	2	2	2	2	5	2,6	3,5	2,7	2,5
UR_23	The frames of each camera shall be updated assigned with a timestamp	2,47	3	2	2,25	3	4	2	2	2,7	3	3	3	2	4	3	4,3	4,2	3,3
UR_24	Each planned path shall be defined with an ID.	2,64	3	3	3	3	4	5	5	4,2	3	2	2	2	5	2,8	3,3	2,7	2,5
UR_25	While the vehicle is in AutoPark mode and approaching the parking space (with pseed of maximum 6 kph) shall detect a stationary child in middle of the parking slot in daylight and foggy weather.	1,97	3	2	2,25	2	2	2	2	2	1	3	3	2	5	2,8	3,2	2,8	2,3
UR_26	While the system is detecting the free space to park, if a standing child occupied the parking place the parking slot shall be detected as a non-free parking slot in daylight and rainny weather conditions.	2,15	3	2	2,25	3	2	3	2	2,5	2	3	3	2	5	3	3,0	2,5	2,3
UR_27	The localization Module shall have a timestamp to be sure that the odometry of ego vehicle is updating all the time.	2,41	3	3	3	3	3	4	3	3,2	3	3	4	2	4	3,2	3,5	2,3	2,2
UR_28	CAN signal shall be tracked to be sure that they are updating each 20 ms.	2,43	3	3	3	3	2	3	3	2,8	3	4	3	3	5	3,6	3,0	2,7	2,3
UR_29	The Sonar ping counter shall be updated.	2,09	3	3	3	3	2	2	2	2,3	3	3	2	2	5	3	3,2	2,7	2,2
UR_30	While the vehicle is in AutoPark mode and approaching the parking space in reverse gear (with pseed of maximum 6 kph) shall detect a stationary sitting child in middle of the parking slot in daylight.	1,95	3	2	2,25	2	2	2	2	2	3	3	3	1	4	2,8	3,0	2,7	2,3

Figure 55: Full list of the automotive use-case user-requirements part 2/4

RANKING AND SCORING

UR	Requirement / Criteria	Total score	Implementation			Operator Perspective Total: 50%					End-User Perspective Total: 50%						Development		
			Ref.	CPS.	Final Impl	High Usability	Intuitivity	Satisfaction	Dissatisfaction	Average	Economics	Maintenance	Quality	Comfort	Safety	Average	TRL Equally averaged partners scoring	Feasibility Equally averaged partners scoring	Integrability Equally averaged partners scoring
			20%			30%					30%						3%	7%	10%
	Weighting		25%	75%	20%	30%	20%	20%	30%		20%	20%	20%	20%	20%				
	Compiler		PASEU			PASEU					PASEU						Partners	Partners	Partners
UR_31	The status of the vehicle controller shall be tracked by a WatchDog (WD) to ensure its availability.	2,83	3	2	2,25	4	4	3	4	3,8	3	5	3	4	5	4	3,3	2,5	2,2
UR_32	The localization module shall ensure that it is working on update CAN signal. (timestamps)	3,32	3	3	3	5	5	4	5	4,8	4	5	5	4	5	4,6	3,3	2,3	2,3
UR_33	The CameraSensingModule shall Inform the WD that the calculation of the module is done and a new interface is valid.	2,05	3	2	2,25	1	1	3	3	2	3	4	3	3	3	3,2	3,2	2,5	2,2
UR_34	It's recommended to use SPICE code guidlines to ensure the high quality of the code.	1,75	3	2	2,25	1	2	3	1	1,6	3	2	2	3	3	2,6	2,7	2,5	2,3
UR_35	In Auto Parking Module shall ensure that the runtime of the planner is less than the periodic update rate of the localization module (100 ms).	2,44	3	3	3	3	3	4	4	3,5	4	2	2	2	5	3	3,3	2,5	2,2
UR_36	The Auto Parking Module shall always has priority to provide the high-level control signals for the vehicle.	1,89	3	3	3	2	1	2	2	1,8	3	2	4	2	3	2,8	3,3	2,5	2,3
UR_37	The Auto Parking Module shall check the timestamp of the provided information from the CameraSensingModule to ensure that the unused itterations of the planning process.	1,86	3	3	3	2	1	1	1	1,3	4	2	3	3	4	3,2	3,3	2,5	2,3
UR_38	The Auto Parking Module shall apply ist own safety margines to the detected obstacles to be sure that safety distance to the objects will be applied.	3,54	3	3	3	5	5	5	5	5	5	5	5	5	5	5	3,7	2,5	2,5
UR_39	The AutoParkingModule (APM) shall give the full control of the vehicle to the driver whenever it is requested.	2,23	3	3	3	2	2	2	3	2,3	4	3	3	3	4	3,4	3,5	2,5	2,3
UR_40	The APM should not requesthigher speed than for safety limit defined in ist "config" file.	2,17	3	2	2,25	2	3	2	3	2,5	4	2	2	2	5	3	3,7	2,5	2,3
UR_41	The Auto Parking Module shall provide the requested motions of the vehicle as a single package assigned with an ID. To ensure the expected behaviour of the vehicle.	3,14	3	2	2,25	5	4	5	4	4,5	4	3	5	4	5	4,2	3,5	2,5	2,5
UR_42	The Auto Parking Module shall ensure that the vehicle controller recieved the correct motion package before starting the low level controller.	3,30	3	2	2,25	5	4	5	5	4,8	5	4	4	4	5	4,4	3,7	2,5	2,5
UR_43	The vehicle controller shall ensure that it reads on CAN bus autoparking relevant updated messages and signals.	2,44	3	2	2,25	3	2	3	2	2,5	4	5	4	2	5	4	3,2	2,5	2,2
UR_44	The vehicle controller shall ensure that it is able to detect malfunctions in the case of missing CAN signals.	3,17	3	3	3	5	5	4	4	4,5	4	3	5	4	5	4,2	3,3	3,2	2,3
UR_45	The vehicle controller shall give the driver always the highest priority.	2,81	3	3	3	3	2	4	4	3,3	4	5	5	3	5	4,4	3,5	2,5	2,2
UR_46	The vehicle controller shall provide its status to the Auto Parking Module while the car is in auto drive mode in CAN update rate.	2,10	3	3	3	2	2	3	3	2,5	3	4	2	2	3	2,8	3,2	2,5	2,3
UR_47	The vehicle controller shall report its failures to the Auto Parking Module.	2,30	3	2	2,25	2	2	3	4	2,8	3	3	3	4	3	3,2	3,3	2,3	2,3
UR_48	If steering controls (CAN Signal : ..) are blocked or manipulated by the driver the vehicle control module shall give back the control to the driver, stopping the manevourings and braking the car. This action finalizes the control operation without need of confirmation.	2,13	3	2	2,25	2	2	3	3	2,5	3	2	4	3	3	3	3,3	2,3	2,2
UR_49	If gear is changed or manipulated by the driver the vehicle control module shall give back the control to the driver, stopping the manevourings and braking the car. This action finalizes the control operation without need of confirmation.	2,57	3	3	3	3	3	5	2	3,1	3	4	4	3	5	3,8	3,3	2,3	2,3
UR_50	A WatchDog (WD) functions shall be implemented inside the framwork to track the required signals between the diffrent hardward of the Auto Parking System.	1,67	3	3	3	2	2	2	2	2	3	2	2	3	3	2,6	1,0	1,2	1,8

Figure 56: Full list of the automotive use-case user-requirements part 3/4

RANKING AND SCORING

UR	Requirement / Criteria	Total score	Implementation			Operator Perspective Total: 50%					End-User Perspective Total: 50%						Development		
			Ref.	CPS.	Final Impl	High Usability	Intuitivity	Satisfaction	Dissatisfaction	Average	Economics	Maintenance	Quality	Comfort	Safety	Average	TRL Equally averaged partners scoring	Feasibility Equally averaged partners scoring	Integrability Equally averaged partners scoring
			20%			30%					30%						3%	7%	10%
	Weighting		25%	75%	20%	30%	20%	20%	30%		20%	20%	20%	20%	20%				
	Compiler		PASEU			PASEU					PASEU						Partners	Partners	Partners
UR_51	When the vehicle is in Auto Parking mode, it shall not listen to the driver's request for acceleration.	1,71	3	3	3	2	2	2	2	2	3	2	2	3	3	2,6	1,2	1,3	2,0
UR_52	The driver of the vehicel shall be able to cancel the parking menuvers of Auto parking system at any time.	2,86	3	3	3	4	4	5	5	4,5	4	3	4	4	5	4	1,2	1,3	1,8
UR_53	The SW architecht shall be desinged based on: comprehensibility,maintainability,simplicity and verifiability.	1,40	3	3	3	2	2	2	2	2	3	2	2	3	3	2,6	0,7	0,0	0,0
UR_54	The SW architecht shall be desinged with Natural language notation.	1,40	3	3	3	2	2	2	2	2	3	2	2	3	3	2,6	0,5	0,0	0,0
UR_55	The SW architecht shall be desinged with an Appropriate hierarchical structure of the software components.	1,40	3	3	3	2	2	2	2	2	3	2	2	3	3	2,6	0,5	0,0	0,0
UR_56	The SW architecht shall be desinged while Restricts size and complexity of software components.	1,39	3	3	3	2	2	2	2	2	3	2	2	3	3	2,6	0,3	0,0	0,0
UR_57	The SW architecht shall be desinged with an Appropriate management of shared resources.	1,39	3	3	3	2	2	2	2	2	3	2	2	3	3	2,6	0,3	0,0	0,0
UR_58	The system shall detect the presence of a driver.	1,57	3	3	3	2	2	2	2	2	3	2	2	3	3	2,6	1,5	0,8	0,8
UR_59	The system shall detect through a Driver State Monitoring (DSM) functionality the drowsiness level of the driver.	1,84	3	3	3	2	2	2	2	2	3	2	2	3	3	2,6	1,5	2,2	2,7
UR_60	The system should detect visual distraction of the driver based on his/her head position.	1,84	3	3	3	2	2	2	2	2	3	2	2	3	3	2,6	1,5	2,2	2,7
UR_61	An Android device with an API higher than 28 and a front camera available shall be present within the vehicle.	1,80	3	3	3	2	2	2	2	2	3	2	2	3	3	2,6	1,2	2,0	2,5
UR_62	An Android application shall be implemented to provide the DSM functionality.	1,81	3	3	3	2	2	2	2	2	3	2	2	3	3	2,6	1,3	2,0	2,5
UR_63	The Android DSM application shall notify through proper alerts the driver if the DSM detects high level of drowsiness or lack of attention.	1,81	3	3	3	2	2	2	2	2	3	2	2	3	3	2,6	1,5	2,0	2,5
UR_64	The system will be robust to timestamp alteration attacks.	1,73	3	3	3	2	2	2	2	2	3	2	2	3	3	2,6	1,5	1,5	2,0
UR_65	The system will be robust to deteriotated image quality in a way that can be either inspected or not by HVS.	1,64	3	3	3	2	2	2	2	2	3	2	2	3	3	2,6	1,3	1,0	1,5
UR_66	The system will be robust to deteriotion of LIDAR quality	1,64	3	3	3	2	2	2	2	2	3	2	2	3	3	2,6	1,3	1,0	1,5
UR_67	The system will preserve adequate levels of data confidentiality.	1,85	3	3	3	2	2	2	2	2	3	2	2	3	3	2,6	2,3	2,2	2,5
UR_68	The system will preserve adequate levels of data integrity.	1,87	3	3	3	2	2	2	2	2	3	2	2	3	3	2,6	2,3	2,2	2,7
UR_69	The system will preserve adequate levels of data availability.	1,75	3	3	3	2	2	2	2	2	3	2	2	3	3	2,6	1,7	1,5	2,2
UR_70	The system will preserve adequate levels of system availability/continuity of operations.	1,74	3	3	3	2	2	2	2	2	3	2	2	3	3	2,6	1,7	1,5	2,0
UR_71	The system will preserve adequate levels of accountability.	1,69	3	3	3	2	2	2	2	2	3	2	2	3	3	2,6	1,5	1,3	1,7
UR_72	The system will provide means that contribute to cybersecurity awareness.	1,77	3	3	3	2	2	2	2	2	3	2	2	3	3	2,6	2,0	1,8	2,0
UR_73	The system will provide means that contribute to cybersecurity protection.	1,79	3	3	3	2	2	2	2	2	3	2	2	3	3	2,6	2,0	1,8	2,2
UR_74	The system will be protected against physical/implementation security attacks.	1,84	3	3	3	2	2	2	2	2	3	2	2	3	3	2,6	2,2	2,0	2,5

Figure 57: Full list of the automotive use-case user-requirements part 4/4

RANKING AND SCORING

UR	Requirement / Criteria	Total score	Implementation			Operator Perspective Total: 50%					End-User Perspective Total: 50%						Development		
			Ref.	CPS.	Final Impl	High Usability	Intuitivity	Satisfaction	Dissatisfaction	Average	Economics	Maintenance	Quality	Comfort	Safety	Average	TRL Equally averaged partners scoring	Feasibility Equally averaged partners scoring	Integrability Equally averaged partners scoring
			20%			30%					30%						3%	7%	10%
	Weighting		25%	75%	20%	30%	20%	20%	30%		20%	20%	20%	20%	20%				
	Compiler		PASEU			PASEU					PASEU						Partners	Partners	Partners
UR_01	The system shall detect a moving pedestrain (normal adults size with normal walking speed) who has 6m of lateral offset vertically to driving tube of Ego vehicle and crossing the driving tube of Ego vehicle (with moving speed of maximum 20 kph) in day and night lights.	3,96	3	3	3	4	5	4	4	4,2	4	5	5	5	5	4,8	3,7	3,3	3,2
UR_38	The Auto Parking Module shall apply ist own safety margines to the detected obstacles to be sure that safety distance to the objects will be applied.	3,54	3	3	3	5	5	5	5	5	5	5	5	5	5	5	3,7	2,5	2,5
UR_09	The system shall detect a moving cyclist (normal adults size with normal walking speed) who is moving if font of the vehicle (has 25% of car width offset to the middle of ego vehicle) and with a speed less than ego vehicle.	3,51	3	3	3	5	5	5	5	5	5	5	5	4	5	4,8	3,8	2,7	2,7
UR_17	The system shall detect a moving cyclist (normal adults size with normal cycling speed) who is moving if font of the vehicle (has 25% of car width offset to the middle of ego vehicle) and with a speed less than ego vehicle (with moving speed of maximum 20 kph), then warn the driver and activate AEB to avoid any collision.	3,50	3	3	3	5	5	5	5	5	4	5	5	5	5	4,8	3,3	2,7	2,7
UR_07	The system shall detect a moving cyclist (normal adults size with normal walking speed) who is behind the parked vehicle (which have 3.5 m offset to the driving tube of ego vehicle) and will collide to the middle of front bumper of the vehicle while both are moving with constant speed.	3,45	3	3	3	4	5	5	5	4,7	4	5	4	5	5	4,6	3,5	3,3	3,2
UR_10	The system shall detect a moving pedestrain (normal adults size) who has 6m of lateral offset vertically to driving tube of ego vehicle and crossing the driving tube of Ego vehicle and collide to the middle of front bumper,then warn and activate AEB (Auto Emergency Brake) system before collision.	3,36	3	3	3	4	5	5	5	4,7	5	5	4	4	5	4,6	3,8	2,7	2,7
UR_02	The system shall detect a moving pedestrain (normal adults size with normal walking speed) who has 4m of lateral offset vertically to driving tube of ego vehicle and crossing the driving tube of Ego vehicle (with moving speed of MAX 20 kph) and is behind the park vehicles with 1m of offset in daylight.	3,36	3	3	3	4	5	4	4	4,2	4	5	5	5	5	4,8	3,7	3,3	3,2
UR_32	The localization module shall ensure that it is working on update CAN signal. (timestamps)	3,32	3	3	3	5	5	4	5	4,8	4	5	5	4	5	4,6	3,3	2,3	2,3
UR_04	The system shall detect a moving pedestrain (normal adults size with normal walking speed) who is 10m away from the vehicle and is moving towards the vehicle (middle) while the vehicle is moving with a speed of maximum 20 kph.	3,30	3	3	3	4	5	4	4	4,2	4	4	5	5	5	4,6	3,7	3,3	3,2
UR_42	The Auto Parking Module shall ensure that the vehicle controller recieved the correct motion package before starting the low level controller.	3,30	3	2	2,25	5	4	5	5	4,8	5	4	4	4	5	4,4	3,7	2,5	2,5
UR_06	The system shall detect a moving cyclist (normal adults size) who has 17m of lateral offset vertically to driving tube of ego vehicle and crossing the driving tube of Ego vehicle (with moving speed of maximum 20 kph).	3,27	3	3	3	5	4	4	4	4,3	4	4	5	4	5	4,4	3,7	3,3	3,2
UR_08	The system shall detect a moving cyclist (normal adults size) who is moving in font of the vehicle (in middle) with a speed less than ego vehicle in day light.	3,27	3	3	3	4	4	4	5	4,3	4	4	5	4	5	4,4	3,7	3,3	3,2
UR_03	The system shall detect a moving pedestrain (normal adults size with normal walking speed) who is 10m away from the vehicle and is moving towards the vehicle (middle) while the vehicle is stationary.	3,24	3	3	3	4	3	5	4	4	4	5	4	5	5	4,6	3,7	3,3	3,2
UR_11	The system shall detect a moving child (normal walking speed) who has 4m of lateral offset vertically to driving tube of ego vehicle and crossing the driving tube of Ego vehicle (with moving speed of maximum 20 kph) and is behind the park vehicle with 1m of offset and collide to the middle of front bumper,then warn and activate AEB (Auto Emergency Brake) system before collision.	3,18	3	3	3	4	5	4	5	4,5	4	4	4	4	5	4,2	3,7	2,7	2,7
UR_15	The system shall detect a moving cyclist (normal adults size with normal cycling speed) who is behind the parked vehicle (which has 3.5 m offset the driving tube of ego vehicle) and will collide to the middle of front bumper of the vehicle while both moving with constant speed. The system shall first warn and then activate AEB system to avoid collision while the vehicle is moving with speed of maximum 20 kph.	3,18	3	3	3	4	4	4	5	4,3	4	5	5	3	5	4,4	3,7	2,7	2,7
UR_44	The vehicle controller shall ensure that it is able to detect malfunctions in the case of missing CAN signals.	3,17	3	3	3	5	5	4	4	4,5	4	3	5	4	5	4,2	3,3	3,2	2,3

Figure 58: 25 Top ranked user requirements for the automotive use case 1/2

RANKING AND SCORING

UR	Requirement / Criteria	Total score	Implementation			Operator Perspective Total: 50%					End-User Perspective Total: 50%						Development		
			Ref.	CPS.	Final Impl	High Usability	Intuitivity	Satisfaction	Dissatisfaction	Average	Economics	Maintenance	Quality	Comfort	Safety	Average	TRL Equally averaged partners scoring	Feasibility Equally averaged partners scoring	Integrability Equally averaged partners scoring
			20%			30%					30%						3%	7%	10%
	Weighting		25%	75%	20%	30%	20%	20%	30%		20%	20%	20%	20%	20%				
	Compiler		PASEU			PASEU					PASEU						Partners	Partners	Partners
UR_41	The Auto Parking Module shall provide the requested motions of the vehicle as a single package assigned with an ID. To ensure the expected behaviour of the vehicle.	3,14	3	2	2,25	5	4	5	4	4,5	4	3	5	4	5	4,2	3,5	2,5	2,5
UR_14	The system shall detect a moving cyclist (normal adults size with normal walking speed) who has 17m of lateral offset vertically to driving tube of ego vehicle and crossing the driving tube of Ego vehicle. The system should be able to warn and activate AEB system before any collision while the vehicle is moving with speed of maximum 20 kph.	3,12	3	3	3	4	3	4	5	4,1	4	5	5	3	5	4,4	3,7	2,7	2,7
UR_13	The system shall detect a moving pedestrain (normal adults size with normal walking speed) who is 10m from the vehicle and is moving towards the vehicle (has 25% of carwidth offset to the middle of ego vehicle), then warn and activeate the AEB system before any collision while the vehicle is moving with speed of maximum 20 kph.	3,11	3	3	3	4	3	5	5	4,3	4	4	4	4	5	4,2	3,5	2,7	2,7
UR_05	The system shall detect a moving pedestrain (normal adults size with normal walking speed) who is 10m from the vehicle and is moving towards the vehicle (has 25% of carwidth offset to the middle of ego vehicle) while the vehicle is moving (with moving speed of maximum 20 kph).	3,06	3	3	3	4	4	4	4	4	3	4	3	5	5	4	3,5	3,3	3,2
UR_12	The system shall detect a moving pedestrain (normal adults size with normal walking speed) who is 10m from the vehicle (with moving speed of MAX 20 kph) and is moving towards the vehicle (middle), warn and and activate AEB (Auto Emergency Brake) system before collision.	3,03	3	3	3	4	3	4	4	3,8	5	4	4	4	5	4,4	3,7	2,7	2,7
UR_19	The system shall detect a moving child (normal walking speed) who has 6m of lateral offset vertically to driving tube of ego vehicle and crossing the driving tube of Ego vehicle (with moving speed of maximum 20 kph) at night light.	3,00	3	2	3	5	3	5	5	4,6	3	4	3	3	5	3,6	3,5	2,7	2,5
UR_16	The system shall detect a moving cyclist (normal adults size with normal cycling speed) who is moving if font of the vehicle (in middle) and with a speed less than ego vehicle (vehicle speed is less than 20 kph). The system shall first warn then activate AEB system.	2,94	3	3	3	3	4	4	4	3,7	4	4	4	4	5	4,2	3,7	2,7	2,7
UR_20	While the vehicle is in AutoPark mode and approaching the parking space in reverse gear (with pseed of maximum 6 kph) shall detect a stationary child in middle of the parking slot in day and night light.	2,88	3	2	3	3	4	5	5	4,2	3	4	3	3	5	3,6	3,3	2,7	2,5
UR_52	The driver of the vehicel shall be able to cancel the parking menuvers of Auto parking system at any time.	2,86	3	3	3	4	4	5	5	4,5	4	3	4	4	5	4	1,2	1,3	1,8

Figure 59: 25 Top ranked user requirements for the automotive use case 2/2