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Work Package 5
Demonstration in shipbuilding and retrofitting

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EXECUTIVE SUMMARY

The main scope of this deliverable is to setup the demonstrators at the small and medium-sized shipyards. This deliverable is a bridge between the technologies developed in Mari4_YARD and technology assessment based on sustainability and environmental impact. The setup will serve the following objectives:

1. Ability to demonstrate the technological specification at real industrial environments.
2. Provide the infrastructure and resources to perform assessments of the selected performance indicators with high fidelity.
3. Ability to assess the performance indicators selected within WP5 and WP6.

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INTRODUCTION

The main objective of this deliverable is to serve as the handbook for setting up of the demonstrator scenarios and the performance indicators. Each technology is elaborated with the business push and technology push. Then detailed scenario set-up is presented for each technology demonstrator. Finally, the demonstrator protocol is defined based on the main performance indicators and how to measure them. At the end, a mapping between the technology demonstrator level performance indicators and the WP6 and the proposal global performance indicators is presented.

TECHNOLOGIES DEMONSTRATION PREPARATIONS

1. ADVANCE MONITORING USING 3D SCANNING

M4Y Business Push (BIS)

Video of the scenario (Public)

WP1 Block under construction - BIS

WP1 Block under construction - NODOSA

Functional requirements (Public)

- Indoor and outdoor operation.
- Programable 3D scanning plan.
- Possibility of working in low light condition.
- 3D model available

Non-functional requirements (Public)

- Low noise levels
- Easily transferrable

End-user business impact (Public)

With 3D scanning monitoring it would be possible to have information's about tasks advance by checking 3D model versus 3D scan and detecting what it is already installed and what is missing. Those tasks could then be compared with ones planned in Shipyard ERP software. Summarised details of each assembly enable real time production monitoring which offers comparative advantage in comparison with companies that don't have such system. Also, will be monitored the differences between the 3D model and the reality, highlighting the differences that can be within or out of the tolerances.

M4Y Technology Push (GHENOVA, AIMEN)

Technology claims in nutshell

Table 1. Drone for confined spaces access Claims after Test Sprints

Claims	Description
C1.	Technology provides faster and evaluated information about finished assemblies
C2.	Technology could be used on daily basis
C3.	Technology is precise enough to record hull and equipment assembly process
C4.	Technology is precise enough to record outfitting differences

Technology specification definition and limitations

The scans should be processed to form point cloud or 3d model of designated area. Comparisons between daily point clouds should be visible and measurable. Main limitation is scanning time and point cloud register, that needs men hours. Insufficient detail of the 3D model could put limitations on useability of this technology

List of technology capabilities and suggested validation at sites

Technology can be applied for outdoor and indoor hull assembly stages. Comparison shots on daily basis, connect ability with plan or ERP software. Deviations of the real installation to the 3D model can be monitored and can be used to change installations with collisions due to the deviation.

Setting-up of scenarios at sites (BIS, GHENOVA, AIMEN)

Availability of the resources

Shipyard assembly of blocks under construction and 3D model of the same block. Necessary software in VERITY and NAVISWORKS SUMULATE. To register the point cloud may be used either SCENE or CLOUDCOMPARE (free software). Availability of blocks and 3D model is absolutely necessary, if there is no block o no 3D model the demo cannot be done.

Selected scenario infrastructure or alternative

The scenario will be a block under construction in any area of the shipyard.

Operators' and management

Some operators of 3D scanner can be useful if the shipyard wants to install this technology, in way the operators will learn the basis of the work.

Shipyard components and material

No material or components from the shipyard are necessaries.

Risk assessment

The 3D scanner does not represent any additional risk to the general risk of an industrial installation.

Logistics of transferring technologies to the sites

There are not logistics involved, scanner and auxiliary equipment is carried easily.

Pre-demo verification of the technologies at the sites

Design and implementation of the demonstrator protocol (BIS, GHENOVA, AIMEN)

Involved performance indicators.

- How much time is saved by having assembly information faster than shipyard usual system.
- How much accuracy on the work done is obtained versus the usual system of the shipyard.
- How many collision problems due to differences between reality and 3D model have been avoided.

Relating the WP5 – WP6 performance indicators

Table 2. Advance Monitoring Using 3D Scanning WP5-WP6 performance indicators.

KPI	Target
How much time is saved by having assembly information faster than shipyard usual system.	In case an issue (not existing component or location deviation from 3D model) was found in the scanned block, will be investigated the saved time in further repair operations (dismount elements from the assembly, cut new parts, transport new pieces to the ship in the slipway or dock, move weld machine to the ship, etc). This ***Reparation saved time*** will be compared with the time used in: a) scanning process + b) 3D Cloud analysis + c) Reporting.
How much accuracy on the work done is obtained versus the usual system of the shipyard.	The accuracy will be measured in the following way: • Element location differences: according following distribution ○ from 0 to 5 mm; -1 point ○ from 6 to 10 mm; -3 points ○ from 10 to 20 mm; -7 points ○ from 20 to 50 mm; -20 points ○ bigger than 50 mm; -80 points • Elements not installed: -50 points

	• Holes for pipes or ducts passing location differences: according following distribution
	  ○ from 0 to 5 mm; -1 point
	  ○ from 6 to 10 mm; -5 points
	  ○ from 10 to 20 mm; -12 points
	  ○ from 20 to 50 mm; -30 points
	  ○ bigger than 50 mm; -100 points
	• Holes not cut: - 25 points
	The objective is to find a Summatory of issues valued in -20 points.

How many collision problems due to differences between reality and 3D model have been avoided.	In case a location deviation from 3D model were found, will be investigated the possibility that the issue will cause a future collision with elements to be assembled in further stages. The objective is to find 1 case of deviations that could cause collision problems.

Involved measurement equipment.

3D scanner, targets, laptop.

Involved operators, demo supervisors.

An operator from BIS of the 3D Scanner will be in charge of the acquisition of the point cloud. A registering software expert to register the different point clouds recorded by the 3D scanner. An engineer from Ghenova, expert using analysis software for the comparation of the point cloud with the engineering 3D model a specialist will conduct the study and edit the report.

Pre-demo validation verification

A training course about the use of the tool will be provided by BIS to the shipyard personnel before doing the demonstration.

Before the point cloud acquisition, have to be confirmed the existence of a block in the shop of the shipyard and the corresponding 3D engineering model.

Data collection

The resulted report of this test will list of elements considered in the 3D engineering model not present in the real block and also the list of elements mounted in the real block in a deviated position from the stablished in the 3D engineering model, according an accuracy target defined.

Analysis

As a result, a report will be edited showing the elements considered in the 3D model not present in the actual block as well the installation deviations encountered between real block and 3D model.

The study of elements non installed or elements with deviations respect the expected position and according to the target maximum deviation

Demonstration Videos

The videos of the demonstration will be included in the following folder: BIS

2. Shipyard Production Planning Based On Aerial Surveillance

M4Y Business Push (NODOSA)

Video of the scenario (Public)

WP1 T2 Big drone for production planning

Functional requirements (Public)

- Graphic interface to represent the free and occupied areas of the shipyard, at a certain moment.
- Able to include elements in the shipyard facilities, to simulate status in a next period.
- Able to simulate different status of the shipyard arrangement.

Non-functional requirements (Public)

- Different sensors to be installed.

End-user business impact (Public)

The idea is to develop a tool that shows a 3D model of the shipyard facilities. The 3D model could be explored using the graphic interface (measurement of distances and areas, move and rotate the point of view, change the zoom factor). The point cloud of the shipyard facilities is obtained by means of the LIDAR mounted on a drone. This captured point cloud of the shipyard facilities will be registered in the tool as the 3D base model. The tool will allow importing new CAD models on the 3D base showing new blocks, equipment, etc that are expected to be present in the shipyard in the next days or weeks. The user of the tool will be able to locate new imported elements on the 3D base in the desired area of the facilities to show the status of the shipyard in a next period, also different alternatives of location of imported elements could be explored.

M4Y Technology Push (GHENOVA, AIMEN)

Technology claims in nutshell

Table 3. Drone Monitoring Technology Claims after three Test Sprints

Claims	Description
C1.	Possibility to communicate results using graphic interface.
C2.	Able to import new elements on the basis 3D environment.
C3.	Able to locate with precision new elements imported on the 3D basis environment (move and rotate elements).
C4.	Able to simulate different alternatives to arrange new elements on the 3D basis environment.

Technology specification definition and limitations

Technology should work in a collaborative environment to be ready to share information with relevant persons of the shipyard and also subcontractors. As the 3D base model (showing the shipyard facilities starting point) could be changed periodically, it is needed to find a way to get this model quickly avoiding dedicate modelling task on that. Therefore, it is important to consider legal requirements to fly drones in open areas as is the case of shipyards and also take into account the presence of seagulls or other birds that could attack to the AUV in some periods of the year.

The tool should allow importing at a same time different CAD elements and locating each of them with precision on the desired areas, then dedicated utilities have to be developed to allow these functions.

List of technology capabilities and suggested validation at sites

The proposed solution is able to:

- Import CAD models showing at the same time the point cloud of the shipyard and also previous imported elements.
- Locate imported elements (move and rotate).
- Measure distances and areas in the 3D model of the facilities and/or elements.
- Explore the global model on a 3D environment (move and rotate the point of view, change the zoom factor).

Setting-up of scenarios at sites (NODOSA, GHENOVA, AIMEN)

Availability of the resources

To perform the test, Ghenova will provide to the shipyard the tool which will run on a computer.

A person of the shipyard will operate the tool to demonstrate the capabilities.

Selected scenario infrastructure or alternative

The point cloud has to be taken in the shipyard. It is preferable to find the shipyard free of elements in the open areas to represent the shipyard in the most versatile condition, but this is not mandatory as the tool will permit change the 3D base model showing the shipyard facilities.

When all the system will be ready, to run the test only a computer will be needed and then the demonstration could be performed in a shipyard office an even shared with third parties transmitting the test online.

Operators' and management

Managers of NODOSA will operate the tool during the test.

Shipyard components and material

Shipyard has to put at disposition of Ghenova's personnel right of access, to their facilities to permit the fly of the drone with the LIDAR. In addition, the shipyard should share 3D CAD models of the blocks or main equipment, which will form part of the ship that is expected to be under construction in the next weeks/months.

Risk assessment

The flight of the drone to scan the shipyard facilities will be done after collect all the necessary permissions of the Authorities. Also, during the flight, presence of workers in the facilities will be avoided.

Logistics of transferring technologies to the sites

UAV and LIDAR will be provided by Ghenova. As the drone will be transported by road, no special transports will be required.

Pre-demo verification of the technologies at the sites

Will be investigated the best date to find the shipyard without ships in the slipways and/or blocks stored in open areas. If this is not possible, scanning will be done in a convenient date for NODOSA and Ghenova.

A training course about the use of the tool will be provided by Ghenova to the shipyard personnel before doing the demonstration.

Design and implementation of the demonstrator protocol (NODOSA, GHENOVA, AIMEN)

Involved performance indicators.

- Number of different point cloud formats able to be ready.
- Number of different CAD formats able to be imported.
- Time required to import point clouds.

- Time required to import 3D CAD elements.
- Time used to import a Ship Block and locate it in an open storage area.
- Time used to import a Ship Block and locate it in the slipway.
- Percentage deviation measuring the length of the dock with the 3D user interface Vs the real dock.
- Percentage deviation measuring the area of an open storage area with the 3D user interface Vs the real area.

Relating the WP5 – WP6 performance indicators

Table 4. . Shipyard Production Planning Based On Aerial Surveillance WP5-WP6 performance indicators.

KPI	Target
Number of different point cloud formats able to be ready.	At least 1 of the following: XYZ, OBJ, PTS, PTX, ASC, LAS/LAZ, E57, PLY, BIN, PNTS, PCD, S3MB (*)
Number of different CAD formats able to be imported.	At least one of the following: OBJ, STL, IGES (*)
Time required to import point clouds (including format conversion, if required).	< 10 minutes (direct import) < 15 minutes (format conversion required)
Time required to import 3D CAD elements (including format conversion, if required).	< 10 minutes < 15 minutes (format conversion required)
Time used to import a Ship Block and locate it in an open storage area (including format conversion).	< 15 minutes < 30 minutes (format conversion required)
Time used to import a Ship Block and locate it in the slipway. (including format conversion)	< 15 minutes < 30 minutes (format conversion required)
Percentage deviation measuring the length of the dock with the 3D user interface Vs the real dock.	≤ 0.5%
Percentage deviation measuring the area of an open storage area with the 3D user interface Vs the real area.	≤ 1%

(*) In the case LIDAR or CAD software does not supply a format compatible with the point cloud visualization system, an intermediate conversion software will be used.

Involved measurement equipment.

Involved operators, demo supervisors.

Operator of the drone is required to fly above shipyard facilities. No special skills are needed to run the informatic tool.

Pre-demo validation verification

Following components can be checked prior to carry on the final test:

- Shows the initial point the facilities of the shipyards free of ships in the dock.
- Shows the initial point the facilities of the shipyards free of ships in the slipway 1.
- Shows the initial point the facilities of the shipyards free of ships in the slipway 2.
- Shows the initial point the facilities of the shipyards free of blocks in the storage areas.
- Could be read by the tool the 3D models of the blocks in the CAD format which was shared by the shipyard.
- Could be read by the tool the 3D models of the main equipment in the CAD format which was shared by the shipyard.

Data collection

The tool will show, in a 3D visual environment, the status of the shipyard facilities in a specific future date after occurring the flow of works as were planned and simulated by the tool.

Analysis

The obtained results (data collection) will permit to managers of the shipyard to simulate the status of the shipyard in a next future and even different alternatives could be evaluated.

In addition, the tool will help to decide where and how to store row materials an even what to do in case something unexpected occurs in the workflow (e.g., where store a block in the case previous block is not received in time in the slipway).

Demonstration Videos

A session running the tool simulating the expected workflow and/or different alternatives can be recorded and the Video can be shared.

The videos of the demonstration will be included in the following folder: NODOSA

3. SMALL DRONE FOR CONFINED SPACES

M4Y Business Push (NODOSA)

Video of the scenario (Public)

WP1 T2 Small drone for confined spaces Video 1 and video 2

Functional requirements (Public)

- Distance Signal transmission by means of radio.
- Indoor and outdoor operation.
- Operation Control assisted by pilot.
- Access to tank by means of small holes.
- Possibility of working in low light condition inside tanks
    - Non-functional requirements (Public).
- Different sensors to be installed.
    - End-user business impact (Public).

Accessing tanks with drones equipped with sensors to measure air quality conditions, could allow shipyards to change the decision-making process to allow workers entering or not to confined spaces. This would allow them to make decisions based on air quality parameters far from the entrance of the tank without the need for workers to use protection equipment.

M4Y Technology Push (GHENOVA, AIMEN)

Technology claims in nutshell

Table 5. Drone Monitoring Technology Claims after three Test Sprints

Claims	Description
C1.	Flight stabilization and operation control
C2.	Signal transmission from sensors to drone operator
C3.	Register of signals transmitted (Parameters value, time, point location)

Technology specification definition and limitations

Technology should provide to drone operator enough control of the UAV when entering in confined spaces trough narrow openings to avoid collisions and/or drop of the drone due to the "ground effect" (similar case as helicopter flying between big buildings). Once the UAV is inside the tank, the control of the operation has to be kept allowing reaching areas of the tank far from the entry while the values measured by the sensors are transmitted to operator.

Narrow accesses, ground effect, low light condition and signal transmission are elements that cause difficulties that have to be solved to show the capacity of measuring the air quality remotely with drones instead of workers accessing confined spaces.

List of technology capabilities and suggested validation at sites

The proposed solution is able to:

- Entering in confined spaces through narrow openings and flying the UAV ensuring stabilized operation.
- Using sensors mounted in the UAV to measure parameters regarding air quality conditions.
- Transmitting signal taken from the sensors outside the space where the pilot of the drone is operating the UAV.
- Registering parameters values in relation to time operation and/or measurement location.
- The operation must be compatible with other normal works carried on the shipyard at same time.

Setting-up of scenarios at sites (NODOSA, GHENOVA, AIMEN)

Availability of the resources

To perform the tests, Ghenova will provide:

- UAV equipped with sensors to measure percentage of O2, temperature and humidity of the air.
- Pilot to flight and operate the drone.

On the other hand, NODOSA has to provide:

- Information regarding the space which will be explored (dimension, location and dimension of accesses, inner lighting condition, internal structure, presence of equipment or other obstacles). Selected scenario infrastructure or alternative

The test must be carried on a ship present in the shipyard. The exact location of the proposed test is a tank of the ship or double bottom space.

As an alternative, the test can be done in a block located in a workshop before it will be move to the slipway. This block must contain an area that has to be accessed through an opening in the structure.

Operators’ and management

Managers of NODOSA will command the accesses of personnel not involved in the test during the trial and the pilot of GHENOVA will operate the UAV.

Shipyard components and material

Tank of a ship located in the shipyard dock or block located in a workshop and drawings of the area to be inspected.

Risk assessment

As the test is going to be done with a prototype UAV built up by GHENOVA during a previous phase of M4Y project, the trials will be done in a previously degassed tank/local with a non-explosive environment.

Logistics of transferring technologies to the sites

UAV, sensors and radio equipment will be transported by GHENOVA personnel to shipyard. Since component involved in the test are relatively smalls, no special means are necessary to be provided by the shipyard.

Pre-demo verification of the technologies at the sites

The availability of a ship in the dock or a block in the workshop at the date proposed to perform the test, has to be ensured by the shipyard.

Design and implementation of the demonstrator protocol (NODOSA, GHENOVA, AIMEN)

Involved performance indicators.

- Time required to set-up the system.
- Time required to read the measured parameters.
- Distance, in X, Y and Z direction, from the access to the local where parameters can be measured.
- Impact over others works carried on at the same time in the ship or workshop.

Relating the WP5 – WP6 performance indicators

Table 6. Small drone for confined spaces WP5-WP6 performance indicators.

KPI	Target
Time required to set-up the system.	< 15 minutes
Time required to read the measured parameters.	< 30 minutes
Distance, in X, Y and Z direction, from the access to the local where parameters can be measured.	In X, Y the objective is to increase the current distance achieved $0 \leq Z \leq$ vertical position of the manhole
Impact over others works carried on at the same time in the ship or workshop.	No impact in works at the same area with the exception of the affected tank

Involved measurement equipment.

Sensors mounted in the drone to inspect air quality condition:

- O2 Concentration.
- Air temperature.
- Grade of humidity.

Involved operators, demo supervisors.

Operator of the drone is required to execute the test. Also is recommendable that person of Health department of the shipyard, attend to the test to follow the new methodology proposed.

Pre-demo validation verification

Following components can be tested prior to carry on the final test:

- Battery level of the drone.
- Parameter measurement (temperature, O2 concentration and humidity of the air).
- Communication of sensors with pilot by means of the radio.

Data collection

A register with of the values of the parameter measured in relation with the time operation.

Analysis

The obtained results (data collection) will permit to managers of the shipyard, allow the entrance of workers to confined spaces ensuring the safety conditions inside the space in terms of the quality of the air.

Demonstration Videos

Video of the complete process showing:

- drone accessing the confined space and moving toward areas far from the entry.
- Signal transmission from the sensors to the pilot.

The videos of the demonstration will be included in the following folder: NODOSA

4. HIGH-PAYLOAD ROBOTS IN SHARED SPACE WITH HUMANS

M4Y Business Push (BIS)

Video of the scenario (Public)

WP2. T3_High-payload robots in shared space with humans. Video 1; Video 2; Video 3; Video 4.

Functional requirements (Public)

Possibility to grab and transfer heavy parts of different shapes, compatible with shipyards software.

Precise positioning of grabbed parts,

Non-functional requirements (Public)

Ability to safely work with humans which are within reach of robot arm.

End-user business impact (Public)

It is yet to be decided the usefulness and practicality of such system. But, if proved possible, it could be of great help for positioning hull structure parts (inside assembly hall) and outfitting foundations (on slipway)

M4Y Technology Push (LMS, AIMEN)

Technology claims in nutshell

Table 7. "High Payload robots in shared workspace with humans" claims after three Test Sprints

Claims	Description
C1.	Improved ergonomics as the high payload robot undertakes the strenuous task of manipulating the high payloads around the workspace
C2.	Faster non-expert user robot programming using AR technology for welding operations
C3.	Easy robot autonomous navigation of the industrial robot using digital twin technology and machine vision towards a CAD-less approach.
C4.	Easy robot manipulation for parts positioning and robot programming using manual guidance.
C5.	Safety guarantee for the operators with the deployment of safety sensor network according to the standards
C6.	CAD-less approach for bin picking operations using machine vision
C7.	Minimized assembly time

Technology specification definition and limitations

High payload robots for workspace sharing incorporate various technologies, each aimed at solving different problems. Machine vision is used for bin picking operations, enabling a CAD-less approach for reaching parts without the need for dataset preparation and training. It also helps with avoiding collisions during robot navigation and correcting welding processes. An AR programming suite is being deployed to allow for tasks such as robot control, programming welding paths, and robot teaching without requiring expert knowledge. A vision-based method has been developed to ensure the accuracy of the welding path programmed through the AR interface. To enhance the robot programming suite, a hand-guiding system has been developed and installed, enabling operators to precisely position various parts during the assembly process. Lastly, a safety monitoring system is incorporated to ensure that no operators are in danger near the robot, in compliance with legislation.

There are a few limitations associated with the aforementioned technologies: Safety systems are strictly defined, and in the event of layout changes, trained engineers are required to reconfigure the safety layout. The digital twin and depth camera-based scanning operations are not suitable for simple operators, and these tasks should be handled by trained staff, such as engineers or programmers. The entire system relies on ROS (Robot Operating System), so the robot used in the application scenario must be compatible with the latest ROS1 release, necessitating the availability of a ROS driver for the specific robot. Additionally, the hand-guiding module cannot be used universally, as it may trigger the robot to perform a safety function and stop in cases where singularities are encountered.

List of technology capabilities and suggested validation at sites

Technology	**Demonstration**
High Payload Robot	Manipulation of various light/heavy parts
Digital twin technology and autonomous navigation	Robotic operations without predefined programming
Machine vision for bin picking operations of unknown parts (with CAD files)	Picking of different parts within a bin/surface
AR programming for path teaching aided with computer vision	Teaching of welding paths around the workspace without expert knowledge
Hand guiding for robot control	Points teaching and refining of grasped part positioning
Workspace monitoring solution	Safety zones layout and demonstration of safety functions during operators intrusions

Setting-up of scenarios at sites (BIS, LMS, AIMEN)

Availability of the resources

BIS will provide necessary space for robot installation and testing.

Selected scenario infrastructure or alternative

The scenario to demonstrate this technology consists of an area with different zones for pick and place elements of an assembly and welding processes. It is not necessary to have an area with physical barriers, as security systems will be installed there.

Furthermore, to install all these systems, electrical connections for the different computers, robots and welding machines must be available.

Operators' and management

Operators must be trained prior to testing.

For the Hand Guiding technology, operator must be familiar with applying efforts on the tool and move it to difficult areas. With a small training and tests of 30-60 minutes, an operator should be able to correctly move the robot to the desired positions with and without elements attached on the robot wrist.

Shipyard components and material

Parts designated for assembly.

Risk assessment

During the Hand Guiding module execution, as operator is close to the robot, user must be caring of robot movement to avoid possible collisions. However, as this process is done in manual mode, robot speed is low enough to avoid harm on the operator. It could be possible that during the element manipulation, a piece could fall, causing damage to the operator's foot. To mitigate this, user must be aware that the robot has correctly grasp the element to move and he/she should wear protective shoes to avoid damage.

Logistics of transferring technologies to the sites

To demonstrate the high payload robot, the COMAU NJ 130 - 2.6 must be transported with the following specifications: NJ-130-2.6: characteristics and technical specifics - Comau

For the Hand Guiding module, added to the robot, we have to transport the F/T sensor and the handler if required. These devices are small and light (F/T sensor 9kg and handler 2kg approximately), so their transport can be easily managed.

Last, for the VR/AR technologies, this kit must be transported. Besides, security elements (Safety Eye or SICK lasers) are also required to take there. All these equipment is small to be easily transported.

For welding tasks, if there is not available a welding machine, we need to transport ours.

Pre-demo verification of the technologies at the sites

In the case of the Hand Guiding, we can verify that all the system is working correctly by checking pure efforts after doing sensor and system calibrations. At this point, we can also adjust the response of the controller.

Design and implementation of the demonstrator protocol (BIS, LMS, AIMEN)

Involved performance indicators.

The main KPIs that are involved to the presented solution are focused towards two main pillars. The first one corresponds to the ergonomics of the operators during the process and indicates the improvement of their working conditions, well-being and life quality. The second pillar is related to the productivity improvement, by evaluating cycle time reduction, robot programming time saving compared to conventional robot programming methods and the ease of employing non-expert workers for the assembly operations.

For the Hand Guiding technology, we expect to collect:

- Time for the operation with and without hand guided assistance.
- Number of processes involved (use or not a gantry to transport the loads and robot move the loads.

Relating the WP5 – WP6 performance indicators

Table 8. High-Payload robots in shared space with humans WP5-WP6 performance indicators.

KPI	Target
Time for the operation with and without hand guiding assistance	Difference ≤ 2 min
Number of processes involved (use external elevation systems to move the loads)	0 external assistance

Involved measurement equipment.

To record data from the Hand Guiding module, we can monitor the force and robot position though ROS by reading, so additional equipment is not required to measure elements.

Involved operators, demo supervisors.

Robot operator from BIS and supervisor will be required during the demonstration. In such case an onsite training will be organized.

Pre-demo validation verification

To do the verification of the Hand Guiding module, we can perform movements into the application area without having grasped any component. By doing this, we can ensure that we will have control on the robot movement before having more obstacles.

Data collection

For the data collection, as mentioned above, a number of depth sensors will be placed around the workspace to accurately detect human operators within it. The detection will include complete pose estimation data, using existing software packages, that return the position and orientation of the human joints. Two sets of experiments will be conducted, one with the old/non-robotic cell and one with the developed whole robotic system. In each set of experiments, several iterations will take place. In each iteration, to have more generalized data, the evaluation will include several operators, with different characteristics, such as, different gender, different familiarity with the performed tasks and different physical characteristics such as height etc. Finally, questionnaires will be shared with the operators where their answers will assess their wellbeing among the two set of experiments.

The multiple iterations with the initial production cell and the proposed robotic solution will also serve the collection of the required data for the assessment of the solution's productivity. The records for the multiple iterations and different operators will include the time required for each operator to complete the assembly, the non-value-added times, the robot idle and operations times etc.. After the assembly is completed, an engineer will be responsible to complete the assessment by checking the acceptability of the welds performed by robots and humans for the final comparison.

In the Hand Guiding application, we can obtain information on the force applied and compensated force as well as the robot position command and real position for each time.

Analysis

After the data collection the RULA, REBA and the NASA TLX scores will be calculated. The RULA focuses on the operators' lower upper limp and neck and the REBA focuses on the entire body. Those two methods will be utilized to identify high risk postures within those areas respectfully. Those scores are range between 1-7 and will be calculated for every process and will be used for the ergonomic assessment. The NASA TLX is a subjective workload assessment tool which allows users to perform subjective workload assessment on operator working with various human-machine interface systems. The score is between 1-100 and the final score is determined from a weighted average of six subscales, which are mental, physical, and temporal demand, performance, effort and frustration. This score will be used for the calculation of the wellbeing and satisfaction of the working conditions of the workers. After the scores are calculated, a comparison between the approaches and the approach with the lowest score is more ergonomically efficient and provides better working conditions for the workers.

Following, the overall cycle time and the number of defected parts will be calculated too. Also, the number of operators required for every task, needs to be taken in consideration in the productivity measurement. In the current approach multiple operators are needed in order to carry the heavy parts and requires more workforce than the robotic approach, where the pick and place is executed by the robot. Those results will be compared and will define the efficiency of each approach and also quantify the percentage of the productivity improvement.

In the Hand Guiding module, with collected data, we can analyse the response of the system in movement and time by data graph representation.

Demonstration Videos

Within the demonstration context, the solutions involved within the "High payload robots scenario", can be demonstrated in two videos, one with small extension and one with large extension.

Expected video of the Hand Guiding module is to show that an operator enters to the working area and is able to move the robot with and without loads and approaching them to non-easy accessible areas.

The videos of the demonstration will be included in the following folder: BIS

5. Collaborative Robots

M4Y Business Push (NODOSA)

Video of the scenario (Public)

WP2 T4 Collaborative robotsVideo 1; Video 2; Video 3.

Functional requirements (Public)

Portable and autonomous.

Possibility to perform the repeatable tasks and compatible with shipyards software.

Possibility to operate in the environment dangerous for humans.

Non-functional requirements (Public)

Ability to safely work with humans which are within reach of robot arm.

End-user business impact (Public)

It is yet to be decided the usefulness and practicality of such system. The portability can enhance the robotic usability at the industry especially for the task that are repeatable and require accurate and complicated shapes that may not be possible with human skills. Customized shapes based on the customer requirements.

M4Y Technology Push (CANONICAL, AIMEN)

Technology claims in nutshell

Table 9. Collaborative robots Technology Claims after three Test Sprints

Claims	Description
C1.	Test fast deployment of robots and equipment.
C2.	Automatic detection of welding joint.

C3.	Automatic welding execution.
C4.	HMI assistance to configure parameters and welding points.
C5.	Robot localization inside a double hull.
C6.	Automatic execution of the cut opening.

Technology specification definition and limitations

Collaborative robots are a small and lightweight solution to apply on the industry as they support enough payload to manage welding and cutting tools. All these processes are automated by using a 3D sensor to obtain the interest points and be able to localise them in robot surroundings. Then, by sending commands to the robot with obtained data, it can automatically create the trajectory to perform the movement, all implemented under ROS framework. Communication with the plasma cut machine is done by the robot signals and the welding machine is controlled by a ModBUS TCP-IP server. In the side of the cut operation, CAD file is required to localize the robot inside the space through pointcloud processing tools and localize the real position of the cuts from the robot. Moreover, an HMI by Canonical can be used to define and configure points of the welding trajectory. Here we can also set welding parameters.

Another technology to test with the collaborative robots is the position collection from the robot as well as the cutting process parameters with an ammeter clamp and reading voltage from analog inputs. This data will be published into the OPC-UA server and exchange this data in the vertical integration architecture by getting hdf5 files.

Regarding the limitations of these technologies, we can state that the systems (camera and robot) must provide a ROS interface to connect and be orchestrated by the system. Besides, localization system requires a manual set of the initial guess of the robot positioning inside the space. Furthermore, if we want to perform a different cut operation which is far from the previous one and the movement of the robot system is needed, this localization must be computed again. The robot working area will also limit the length of the welding joint and the cutting height and radio we can obtain. Last, another limitation is that for the cut operation we require the CAD file to localize de robot.

List of technology capabilities and suggested validation at sites

Collaborative robots will be used to weld and cut inside a space, thanks to a 3D camera placed on the robot and corresponding tool to perform the task. The capabilities are stated in the following table:

Capabilities	**Validation**
Fast deployment of the robot and equipment	Measure time required to transfer robot and equipment.
Automatic detection of the welding points	To validate obtained points, first we can execute the trajectory without enabling the welding machine.

Automatic welding joint execution	By an expert welder, get an evaluation of the obtained weld of accuracy and set parameters.
Fast configuration and programming with HMI	Configure and execute a welding to check all systems are exchanging information.
Environment identification and robot localization inside double hull	Check localization inside the double hull comparing with CAD reference frame and real system.
Automatic cut operation	Test the trajectory firstly without cutting machine enabled.
Send information through OPC-UA client-server	Visualize and read obtained data.

Setting-up of scenarios at sites (NODOSA, CANONICAL, AIMEN)

Availability of the resources

NODOSA will provide enough space to deploy robot and equipment.

Selected scenario infrastructure or alternative

The selected scenario is a metallic surface to attach our magnetic base with all the systems. Besides, this environment should have some joints for the welding application and flat areas to perform the cutting operations.

Operators' and management

Operators must be trained before testing. They can be trained to deploy and connect systems, define target points, perform localization, how they can use the HMI.

Shipyard components and material

As previously said, apart from being a magnetic surface, in case of cutting operation, we need the CAD file of the element to localize the robot.

Besides, a power supply of 230 V AC is required for the robot, computer. In the case of plasma cut machine, air supply with 6.5 bar is needed. For plasma cut machine and welding machine, triphasic power supply is also required.

Risk assessment

During the set-up of the scenario, possible risks are identified, splitting them into the hardware setup, referring to the process of moving the items and mounting the demonstrator, and the technology execution with the risks associated with the module and programs running as well as device connection.

5.0.1.1. Hardware set-up deployment

- *Falling components to feet*: To mitigate this risk, we must ensure elements positioning before releasing them and wear protective shoes as a prevention measure.
- *Small and superficial cuts from manipulating pieces*: welding and cutting torches can cut the operator by its shape. Therefore, to prevent this risk, robot could be pointing to a wall or similar, not to the user area when robot is not being used.

5.0.1.2. Technology execution

- *Welding and cutting projections*: specially when cutting, as we are opening the structure, projections can reach people behind the double hull. Hence, people should avoid staying behind the double hull when the equipment is working.
- *Electrical problems*: To avoid some electrical issues related to connecting or disconnecting devices, we must ensure that all the equipment is powered off during the plug-in.
- *Heat in the surface after welding*: user should avoid touching the wall after performing welding operations as surface reaches high temperatures.
- *High noise during cutting or welding*: we can mitigate this direct effect by wearing hearing protection.
- *Light during execution*: welding and cutting emits powerful light. To protect this, operators should wear welding masks.

Logistics of transferring technologies to the sites

To demonstrate this technology, UR10 and ELFIN robot may be required. Moreover, it could be also necessary to send ours weld and cut machines in case these are not available there. Besides, magnetic Switch to mount the robot to place it on different surfaces is needed.

Regarding small equipment, a RealSense camera is needed and its support and protection to mount it on the robot. Besides, measuring equipment of the process may be needed.

Pre-demo verification of the technologies at the sites

To verify the technologies before starting to cut or weld, we will check the movement prior to execute them with the plasma cut or welding machine enabled.

By doing this, we can also verify the accuracy of our calibrations and the obtained points and movement from the vision system.

Design and implementation of the demonstrator protocol (NODOSA, CANONICAL, AIMEN)

Involved performance indicators.

Proposed performance indicators are the following:

- Deployment time of the hardware components.
- Time required for electrical component connection.
- Time required to perform welding joint compared to the manual task.
- Time required to perform cut opening compared to the manual task.
- Accuracy of the robot position and hence, the cut position.

Relating the WP5 – WP6 performance indicators

Table 10. Collaborative robots WP5-WP6 performance indicators.

KPI	Target
Deployment time of the hardware components	< 10 min
Time required for electrical component connection	< 5 min
Time required to perform welding joint compared to the manual task	≤ 40% production improvement
Time required to perform cut opening compared to the manual task	≤ 40% production improvement
Accuracy of the robot position and cut position	≤ 20 mm error

Involved measurement equipment.

From the robot, we can obtain its data through the ROS framework reading provided topics, robot signals and the ammeter clamp.

Involved operators, demo supervisors.

Operators could help with the welding and cutting result evaluation and with setting the parameters to the machine to improve obtained results. Besides, one supervisor can be there to monitor all the process.

Pre-demo validation verification

We can consider the third test sprints and the workshop training activities as pre-demo verification.

Data collection

From the welding operation we can obtain:

- Parameters set to the machine.
- Robot tool position during the welding execution.
- Partial pointclouds processed for obtaining each welding point.

In the case of cutting operation, we could collect:

- Parameters set to the machine.
- Voltage and intensity of the cutting machine (hdf5).
- Robot tool position during the cutting execution (hdf5).
- Programmed cut centre CAD-referenced.
- Pointcloud of the performed reconstruction.

Analysis

From the welding joint, in the robot movement, we can compare it to the ideal trajectory (lineal movement) to verify if it has performed the correct path.

Then, for the cutting operation, we can compute the disparity between the centre obtained from the cad and the real centre performed by the robot to check the accuracy of the system. We can also represent stored variables in hdf5 files.

Demonstration Videos

Obtained videos of these demonstrations can be:

Welding operation: hardware components deployment, robot moving to set points for obtaining welding points, (simulate welding to see trajectory) and welding trajectory. It will also show HMI to configure parameters and points.

Cutting operation: hardware components deployment, robot localization procedure, (optional: robot performing cut opening simulated) and robot performing the cut.

The videos of the demonstration will be included in the following folder: NODOSA

6. Mobile Manipulator

M4Y Business Push (NODOSA)

Video of the scenario (Public)

WP2 T5 Mobile robots. Video 1; Video 2.

Functional requirements (Public)

Automated solution to pick and/or transport raw materials and individually manufactured parts between stores and workshops, as well as between workshops and subassembly areas.

Non-functional requirements (Public)

Easy to operate and deploy.

Ability to safely work with humans which are within reach of the robot.

End-user business impact (Public)

During shipbuilding, a wide range of components are handled and transported, such as, structural steel, pipes, cables, valves, and outfitting. These parts are usually stored in warehouses or pallets and are placed on shelves, big containers and/or boxes. This transportation is typically performed by hand or using self-propelled, pulled, or pushed platforms.

These logistic tasks are dull, dirty, and dangerous for the human operator, owing to the specific characteristics of the parts to be transported, such as geometry and weight, as well as due to the unstructured environment that is common to see in shipyards. Moreover, due to the ageing of the European population, it is essential to empower the current human workforce to other tasks that effectively contribute to the added value of the product produced and the well-being of the human operator. So, there is a high interest, not only in the shipbuilding sector but also from many other sectors, to automate as much as possible these intra-logistic operations.

M4Y Technology Push (INESC TEC)

Technology claims in nutshell

Table 11. Mobile ManipulatorClaims after three Test Sprints

Claims	Description
C1.	Able to autonomously navigate in the environment (e.g. warehouse)

C2.	Able to localize and grasp objects (CAD model required) from shelves, containers, anlocaliser them at a defined location
C3.	Faster non-expert user robot programming and configuration/interfacing using both AR Technology and the Task Manager
C4.	Safety guarantee for the operators with the deployment of safety sensor according to the standards
C5.	Empowerment of the current human workforce to other tasks that effectively contribute not only to the added value of the product produced, but also to the wellbeing of the human operator.

Technology specification definition and limitations

Compared with traditional AGV/AMR solutions, the significant advantage of mobile manipulators is that they combine the capacity to transport the load on top of the mobile platform and add the manipulation capabilities well recognised in industrial robotic arms.

In terms of Hardware, the mobile manipulator is equipped with (i) an omnidirectional mobile platform, (ii) a collaborative robotic arm (UR10), with a payload of 10kg, (iii) a 3D sensor (Photoneo) and (iv) a Robotiq gripper 2F-85 or 2F-140.

Two safety lidars are installed in two opposite corners of the robotic platform. With this sensing setup, it is possible to create safety zones that cover the entire 360º area around the mobile platform, allowing the implementation of the seep and separation monitoring stop type of collaboration. These lidars are also used for robot localisation purposes.

In terms of software, the mobile manipulator is installed with a software stack that enables its operation in different environments and for other applications scenarios:

- A multi-robot coordination and navigation pipeline, encapsulated under the Drive Skill, ensures the mobile robot's proper localisation and navigation in the environment and coordination with other autonomous robots. For localisation, the robotic system combines odometry data with data from two Sick Lidar lasers, which allow the extraction of the natural contours of the environment or to detect artificial markers. Furthermore, these same lasers are used to ensure the safety of operation by detecting the presence of people or obstacles and triggering a speed reduction or even a stop of the robotic platform.
- 3D object perception and grasping systems, implemented within the Pick and Place Skill, allows the robotic arm to localise and manipulate different objects. It resorts to the Photoneo 3D sensor and the Robotiq gripper, mounted on the robotic arm flange to acquire the scene information and pick the detected objects.
- Regarding the interaction with the human operator, the robot system also allows using an augmented reality system (AR) based on HoloLens, to visualise the robot status and programming production tasks

using skills through an intuitive interface. During these interactions, the system allows for the creation of a 3D safety fence to provide the operator with additional safety.

- The Production Manager and Task Manager, acting as the task planner and local orchestration modules, being responsible, respectively, for the assignment of the logistic tasks to the robotic system, supervision and to perform the supervision of the execution of different modular robotic skills, such as Drive Skill and Pick and Place Skill. The task Manager is also responsible for capturing operational data from the robotic system to be integrated and processed in the upper layers of the manufacturing stack.

Due to the HW of the current platform, only parts until 2,5kg/5kg can be manipulated, depending if the gripper configuration 2F-140/2F-85. Other grippers could easily be considered for the demonstration if necessary, keeping in mind that the robotic arm has a free payload of 8,5 kg..

Moreover, as it is a omnidirectional platform, the wheels are more sensible to floor irregularities, requiring a flatter floor for testing and demonstrating.

However, all the software modules are agnostic in the relation to the HW. Therefore, in the future the robot can be customized for the specific needs of each shipyard.

List of technology capabilities and suggested validation at sites

The developed solution proposed:

- Is able to navigate in unstructured environments. The robot localization relies on the of artificial markers placed on the environment or use the environment natural contours.
- Has integrated a decentralized multi-robot coordination system for path planning to guarantee the system operation by avoiding deadlock and live locks in a multi-robot scenario.
- Can autonomously grasp objects with different geometries, stacked in side bins, containers or shelves in an autonomous manner.
- The complete robot is programmed using the concept of Skills, facilitating its programming.

The solution can be used at warehouse for picking up part and deliver them at a predefined location.

Setting-up of scenarios at sites (NODOSA, INESC TEC)

Availability of the resources

Nodosa will provide all necessary resources.

Selected scenario infrastructure or alternative

To test the solution different scenarios can be considered such as:

- Operation at a Warehouse: Pick parts at a Warehouse stored inside bins, pallets, table, etc, and deliver them at a subassembly area. Heavier parts could be placed on top of the robotic platform.

- Operation at Mechanical Workshops or Subassembly areas: Transport the parts outside a CNC machine to a given expedition or subassembly area, or Warehouse. Heavier parts could be placed on top of the robotic platform.

Operators' and management

Operators and their superiors must be trained prior to testing.

Shipyard components and material

CAD models of the individual parts to be grasped.

Risk assessment

The platform already has hardware and safety sensors installed, enabling testing of the solution in shared environments with human operators. Further risks will be identified in the testing scenario.

Logistics of transferring technologies to the sites

To demonstrate this technology the mobile manipulator, weighting 500kg, must be transported to the end-user's premises. A mini crane or forklift with extended forks is required to take the robot out of the shipping case.

Pre-demo verification of the technologies at the sites

The technology has been verified at the testbenches present on AIMEN's facilities, during test sprints.

Design and implementation of the demonstrator protocol (NODOSA, INESC TEC)

Involved performance indicators.

- Time required to set-up the full system in place.
- Time required to pick up a set of objects.
- Reliability of the system (number of assigned tasks versus total task fully completed)
- Number of operators /times that was free for other operations.

Relating the WP5 – WP6 performance indicators

Table 12. Mobile manipulator WP5-WP6 performance indicators.

KPI	Target
Time required to set-up the full system in place	One and half days

Reliability of the system (number of assigned tasks versus total task fully completed)	95%
Number of operators/time that was free for other operations.	At least 1 operator removed from logistic activities.
Reduction on the number of accidents and operator's injuries	

Involved measurement equipment.

From the robot, we can obtain its data through the ROS framework reading provided topics.

Involved operators, demo supervisors.

Operator is required to assign a logistic task to the robotic system.

Operator is required to execute the same task in the traditional way.

Pre-demo validation verification

Each of the main robotic components can be tested individually:

- Verify the ability of the robot to autonomously localize and navigate along the warehouse and stop at a given location with relative precision (HW and SW)
- Movement of the robotic arm (HW and SW)
- Verify the robotic arm perception system to localize the parts to be grasped ((HW and SW).
- Validate the ability of the robotic gripper to grasp the identified parts (HW and SW).
- Pick and Place of the part by the robotic arm.
- Verify the existence of the CAD of the parts to be picked by the robotic solution.

Data collection

All the data acquired by the robot sensors can be made available, namely:

- 2D data coming from the two-lasers used for navigation of the mobile platform (Environment Map constructed during set-up phase; contours of the environment acquired in real-time during robot operation).
- Partial point cloud of the objects to be grasped.
- Estimated grasping position of each object.
- Robot Speed (Mobile platform and robotic arm).
- Robot full task execution time (time required for the robot to navigate to each picking place, time required to pick each object (movement of the robotic arm, object perception and grasping, and deposition), and the respective delivering to the end station).

Analysis

Regarding object picking and grasping, we can compute the success of grasping attempts and workpiece segmentation and localisation capability, given the shipbuilding environment. Therefore, the success rate regarding stable grasping and object recognition can be assessed.

Demonstration Videos

Expected video of the complete process, showing the mobile manipulator executing the grasping of different objects in a warehouse and deliver them to a human operator.

The videos of the demonstration will be included in the following folder: NODOSA

7. Augmented Reality with Handheld Devices

M4Y Business Push (BIS)

Video of the scenario (Public)

1 video from BIS recently recorded (table below).

WP3. Augmented reality

Functional requirements (Public)

Software should be compatible with shipyard ERP system.

Must provide all necessary information regarding working parts.

Precise initialization and tracking

Non-functional requirements (Public)

It should function inside ship hull.

It should be user friendly.

End-user business impact (Public)

At the moment information about details of the ship assembly process are gathered on a weekly or two-weekly basis. Possible plan deviations and errors therefore are not visible at the time of making, only later. That kind of information delay could cause further problems downstream. Suggested technology should provide real-time plan checking regarding number and positions of installed parts.

M4Y Technology Push (TUHH)

Technology claims in nutshell

Table 13. Handheld Devices Technology Claims after three Test Sprints

Claims	Description
C1.	Higher workers satisfaction by reduction of task repetition due to faulty performed tasks.
C2.	Lowers time consumption of searching for information and fulfilling tasks.
C3.	Better planning due to higher level of digitalisation. More standardized and easier to access data storage and information preservation.
C4.	The technology can be used on a daily basis for a whole work shift.

Technology specification definition and limitations.

List of technology capabilities and suggested validation at sites

Setting-up of scenarios at sites (BIS, TUHH)

Availability of the resources

Tablets and Wi-Fi (internet) connection.

Selected scenario infrastructure or alternative

Operators' and management

Worker, Supervisor

Shipyard components and material

Something to work and, e.g., an assembly task.

Risk assessment

Risk of the hardware to be damaged while working, protection recommended.

Logistics of transferring technologies to the sites

Since it is a handheld device, there should be no logistic issues.

Pre-demo verification of the technologies at the sites

Design and implementation of the demonstrator protocol (BIS)

Involved performance indicators.

Relating the WP5 – WP6 performance indicators

Table 14. Augmented reality with handled devices WP5-WP6 performance indicators.

KPI	Target
Time needed to perform a working task with the assistant vs with paper based instructions Also: number of errors & satisfaction of workers & acceptance of workers	Time in minutes Number of errors (severity?) Satisfaction and acceptance of workers, based on UEQ (?)
Time needed to prepare a working task with web based tool vs with "word" for paper based	Time in minutes
Time needed to report an issue and reviewing it with the assistant vs paper based	Time in minutes
Time needed to document the state of certain machine/operation with assistant vs paper based Also: number of errors & satisfaction of supervisor & acceptance of supervisors	Time in minutes Number of errors (severity?) Satisfaction and acceptance of supervisors, based on UEQ (?)

Involved measurement equipment.

stopwatch

Involved operators, demo supervisors.

Ratko Mimica, Ivana Željković, Ivan Grgić

Pre-demo validation verification

It was verified during last online remote testing

Data collection

Each task will define will stopwatch or shipyards working normative will be used

Analysis

comparison with real time situations in shipyard without such equipment.

Demonstration Videos

The videos of the demonstration will be included in the following folder: BIS

8. MIXED REALITY WITH HEADSETS

M4Y Business Push (BIS)

Video of the scenario (Public)

Skillworx Assisted worker for welding machine training	WP3. Mixed reality 1
Skillworx Assisted Worker for remote collaboration	WP3. Mixed reality 2

Functional requirements (Public)

Device should be:

- Easy to use, provide all necessary information
- Able to function in a normal working environment (noise cancelation, harsh conditions)

Non-functional requirements (Public)

Dustproof, water resistant, drop resistant.

End-user business impact (Public)

The needs of today's market dictates adaptability for different kinds of products and their related technologies. On the other hand, technologies have become more complicated while the workforce is scarce and relatively random, with a lot of people coming and going through the shipyard. There is a need for educational tools which could be adapted for different jobs. With it new technologies could be easily adapted and skills for old ones transferred more easily.

M4Y Technology Push (TTPSC)

Technology claims in nutshell

Table 15. Wearable Devices Technology Claims after three Test Sprints

Claims	Description
C1.	Provide contextual information for object in front of user
C2.	Accelerate training cycle by immersive training instead of paper-based one
C3.	Contextual 3D information located precisely
C4.	Boost of information flow between departments
n	

Technology specification definition and limitations.

List of technology capabilities and suggested validation at sites

Setting-up of scenarios at sites (BIS, TTPSC)

Availability of the resources

Shipyard will provide all necessary resources, including knowledge that should be transferred trough headset.

Selected scenario infrastructure or alternative

First scenario is for RealWear in combination with Skillworx Assisted Worker (remote collaboration and decorating scanned environment with digital conent) and/or Skillworx Guided Worker (step-by-step 2D instructions), with it should be possible to educate workers for skills previously unknown to them. Skills would be selected in accordance with future shipyards plans and technologies. User manual and working manual of selected technology will be converted for RealWear usage.

Second scenario would be leveraging Skillworx Assisted Worker for internal- and cross-department communication improvements. This is especially vital for cases when some defects are being recognized by field workers comparing to design coming from design office (project office) or check of construction readiness is needed. This normally requires visits people from different departments which is a long process.

Operators' and management

Workers needed for education and their superior

Shipyard components and material

Welding systems for education, random material needed for training.

Risk assessment

Maybe it would cause nausea od disorientation on workers. Environment too harsh for technology

Logistics of transferring technologies to the sites

Technology is relatively simple and light, so logistics shouldn't be a problem.

Pre-demo verification of the technologies at the sites

It was verified during last TTPSC visit.

Design and implementation of the demonstrator protocol (BIS, TTPSC)

Involved performance indicators.

- Time needed to perform an interactive training (after training user how to use device) vs time spent on regular training.
- Need of written training material for user
- Time needed to access written training material.
- Time needed to document a defect while reviewing ship building progress.
- Time needed to communicate a defect to responsible department while reviewing ship building progress.

Knowledge retention is hard to assess.

Relating the WP5 – WP6 performance indicators

Table 16. Mixed reality with headsets WP5-WP6 performance indicators.

KPI	Target
Training time	reduction time of at least 25% in comparison with normal training
Written training material	training material reduced by 80%

Involved measurement equipment.

Stopwatch, computer to keep measurement.

Involved operators, demo supervisors.

Operator is required to perform a traditional training, Operator is required to perform an interactive training

Pre-demo validation verification

Created interactive digital step-by-step instructions.

Checking network access to platform hosting interactive instructions.

Data collection

Training completion time.

Feedback on ease of use.

Analysis

For evaluating overall system, there should be a comparison on time needed to execute an interactive training and traditional one. Additionally, it should be examined if operator has a need of checking traditional written material during training.

Demonstration Videos

Video of the complete training should be created, from first and third perspective to see how operator is performing step-by-step training and to see what data is presented for the operator.

The videos of the demonstration will be included in the following folder: BIS

9. MIXED REALITY WITH AR GLASSES

M4Y Business Push (BIS)

Video of the scenario (Public)

WP3. Digital 1st Training at BIS [HoloLens].mp4

Functional requirements (Public)

Device should be:

- Easy to use.
- Able to function in a laser welding working environment (clean, not too noisy).

Non-functional requirements (Public)

Ability to wear laser welding protective glasses and if needed protective gloves.

End-user business impact (Public)

The needs of today's market dictates adaptability for different kinds of products and their related technologies. On the other hand, technologies have become more complicated while the workforce is scarce and relatively random, with a lot of people coming and going through the shipyard. There is a need for educational tools which could be adapted for different jobs. With it new technologies could be easily adapted and skills for old ones transferred more easily.

M4Y Technology Push (TTPSC)

Technology claims in nutshell

Table 17. Wearable Devices Technology Claims after three Test Sprints

Claims	Description
C1.	Providing guides for laser welding pace for user
C2.	Accelerate training cycle by immersive training instead of paper-based one
C3.	Contextual 3D information located precisely on welding surfaces
C4.	Flexibility in arranging welding path
n	

Technology specification definition and limitations.

List of technology capabilities and suggested validation at sites

Setting-up of scenarios at sites (BIS, TTPSC)

Availability of the resources

Shipyard will provide all necessary resources, including knowledge that should be transferred trough headset.

Selected scenario infrastructure or alternative

Scenario is for HoloLens2 AR glasses, with it should be possible to train workers skills for different tasks regarding precise hand coordination. Selected process should be digitalized in a way that there is a ghost of a welding gun augmented over real welding surfaces. Upon voice commands, movements and position of a welding gun should be matched with ghost one.

Operators' and management

Workers needed for education and their superior

Shipyard components and material

Welding systems for education, random material needed for training.

Risk assessment

Maybe it would cause nausea od disorientation on workers. Environment too harsh for technology

Logistics of transferring technologies to the sites

Technology is relatively simple and light, so logistics shouldn't be a problem.

Pre-demo verification of the technologies at the sites

Waiting for development and verification

Design and implementation of the demonstrator protocol (BIS, TTPSC)

Involved performance indicators.

- Time needed to perform an interactive training (after training user how to use device) vs time spent on regular training.
- Need of written training material for user.
- Time needed to access written training material.

Knowledge retention is hard to assess.

Relating the WP5 – WP6 performance indicators

KPI	Target
Training time	reduction time of at least 25% in comparison with normal training
Written training material	reduced by 80%

Involved measurement equipment.

Stopwatch, computer to keep measurement.

Involved operators, demo supervisors.

Operator is required to perform a traditional training, operator is required to perform an interactive training

Pre-demo validation verification

Prepared training resources (laser welding machine, plates for welding), setting up training scenario (adjusting welding parameters in laser welding gun and in training application)

Data collection

Training completion time.
Feedback on ease of use.

Analysis

For evaluating overall system, there should be a comparison on time needed to execute an interactive training and traditional one. Additionally it should be examined if operator has a need of checking traditional written material during training.

Demonstration Videos

Video of the complete training should be created, from first and third perspective to see how operator is performing training and to see what data is presented for the operator.

The videos of the demonstration will be included in the following folder: BIS

10. HIGH PRECISION PROJECTION SYSTEM

M4Y Business Push (BIS)

Video of the scenario (Public)

WP3. T8 High precision projection system

Functional requirements (Public)

The projector should be able work in harsh environment, and it should be able to project task-oriented information directly into the environment using the 3D model of the structure obtained from the design software. The projected image must be visible during day, and it should be placed in slightly irregular floors.

Non-functional requirements (Public)

Should be easy to carry, to move, to set-up and use.

End-user business impact (Public)

Improved productivity and efficiency by reducing the use of printed documents while also avoiding the measurement and marking tasks, leading also to a reduction of human errors and the need for rework.

The quality of the finished products, such as: Cut-opening, are performed with higher precision.

Standardization, digitization and systematization of the production information.

M4Y Technology Push (All TECH PARTNERS)

Technology claims in nutshell

Table 18. Handheld Devices Technology Claims after three Test Sprints

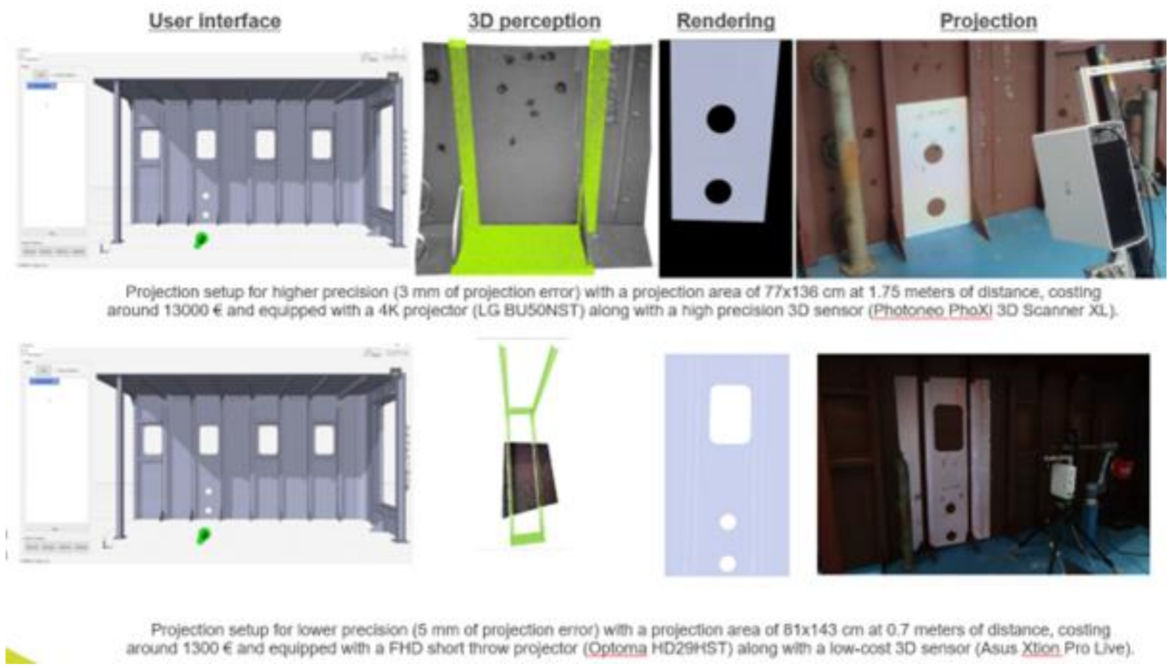
Claims	Description
C1.	Accurately displays alignment and cutting information directly into the target environment with (projection error bellow 5mm)
C2.	No changes to the production process or environment are required
C3.	Avoids the usage of printed drawings and manual measuring tools
C4.	Improves reliability and process efficiency.
C5.	Reduces errors leading to less rework.
C6.	Reduction of the operator's level of attention required to execute the tasks, while also reducing anxiety, stress and fatigue.

Technology specification definition and limitations.

The high-precision projection system is capable of projecting information into the ship walls for helping the operator perform cutting, welding, and assembly operations. The system relies on a 3D perception system, a 3D rendering SDK and a DLP projector. As such, it does not require the placement of markers in the environment.

The system includes several modules, ranging from the initial setup phase, which consists of the calibration of the hardware, to the operational phase, which relies on a graphical user interface to allow a human operator to quickly load new CAD models and project the alignment and cutting information into the environment.

Two different solutions with different HW arrangements were developed, having the characteristic presented in the image below:



List of technology capabilities and suggested validation at sites

The projection system lowers the amount of operator measurement errors and improves productivity, since the operator no longer needs to analyse the ship schematics, make environment measurements and perform surface markings for preparing the cutting and welding operations. Instead, the operator only needs to load the ship section CAD file, point the projector to the ship wall and trigger the projection system.

The projected information can be used to guide the operator during cutting, welding and assembling operations in the ship wall, such as, outfitting and hull assembly operations.

Setting-up of scenarios at sites (ALL WP5)

Availability of the resources

- BIS will provide all necessary resources.

Selected scenario infrastructure or alternative

Possible scenarios:

- Use the system during the outfitting phase, when all hull parts are assembled, for projecting structure openings which were not done during the plate cutting phase. This avoids delays caused by blind openings that someone during process forgot to open.
- Use the system during the hull assembly, for projecting the outlines of parts to assemble.
- Utilize the system to assist an operator during the programming of cobots for accurate cutting and welding tasks.

Operators' and management

Operators and their superiors must be trained prior to testing.

Shipyard components and material

- The projection system needs the CAD file in STEP format of the ship structure with the 3D geometry that needs to be projected, such as the holes for the cut opening operations. The hardware requires a 230 V AC power supply.

Risk assessment

No specific interference risk of using the devices in the shipyard is identified.

Logistics of transferring technologies to the sites

The system is relatively compact, and easy to store inside a case. The case will be shipped, and the training/demonstration will be delivered by technology developers on-site.

Pre-demo verification of the technologies at the sites

The technology has been verified at the testbenches present on AIMEN's facilities, during test sprints.

Design and implementation of the demonstrator protocol (ALL WP5)

Involved performance indicators.

- Time required to setup the projection system.
- Time required to load the CAD information into the system;
- Time required of the system to scan the environment and project the information.
- Precision of the projected information.
- Time saved by the human operator when compared with the traditional approach.
- Reduction (in percentage) of the rework required when comparing the projection system with the traditional approach.

Relating the WP5 – WP6 performance indicators

KPI	Target
Time to Set-up the projection system	10 minutes
Precision of the projected information	Less than 5 mm of projection error
Time saved by human operator when comparing with the traditional approach;	Around 70% of time reduction

Reduction (in percentage) of the rework	around 80%

Involved measurement equipment.

Stopwatch, Computer and manual measurement tools.

Involved operators, demo supervisors.

Operator is required to test the system.

Operator is required to execute the same task in the traditional way.

Pre-demo validation verification

- Electrical verification of the system.
- Checking to make sure that all the of hardware is powered on and operating as intended.
- Checking if all the CAD models are available and can be loaded in the projection software.
- Verify the perception module and verify its accuracy.
- Verify that the expected information is projected and visible for the human operator.

Data collection

- Partial point cloud of the ship structure
- Time elapsed between loading the CAD model in the HMI and the projection of the information into the environment.

Analysis

For evaluating the precision of the projection system, the projected information can be compared with manual measurements, for checking how much they deviate. Moreover, it can be compared the time to perform the marking tasks using the projection system and without relying on it (using manual measurements only).

Demonstration Videos

Video of the complete process, showing the human operator setting up the projection system, marking and performing the cutting task.

The videos of the demonstration will be included in the following folder: BIS

11. COST EFFECTIVE PROJECTION

M4Y Business Push (BIS)

Video of the scenario (Public)

WP3. T9_Cost effective projection Video 1; Video 2.

Functional requirements (Public)

Projector should work in harsh environment; it should be able to project 3d model from design software and from scanned point cloud. Light must be visible during daylight. It should be positioned somewhere where it is not possible for worker to obstruct line of projection. Possibly on workshop ceiling similar positions.

Non-functional requirements (Public)

Should be easy to carry, to move, to set-up and use.

End-user business impact (Public)

If it is cost effective technology, it should provide more information about assembly position and sequence directly on the shop floor. Nowadays a lot of time is lost in adequate planning of assemblies. Additionally, if possible, it could provide real-time production tracking.

M4Y Technology Push (AIMEN)

Technology claims in nutshell

Table 19. Handheld Devices Technology Claims after three Test Sprints

Claims	Description
C1.	Avoid using manual measuring tools and printed drawings.
C2.	Possibility of positioning in different orientations.
C3.	No changes to the production process or environment are required.
C4.	Quick and easy handling.

Technology specification definition and limitations.

The cost-effective projection system comprises several key components, including a pan/tilt unit, a projector, a camera, a computer, and a magnet. The pan/tilt unit serves to enhance the system's functionality by providing two axes of freedom, enabling a range of motion from -66.5º to 66.5º in the tilt axis and from 0º to 306º in the pan axis. This expanded range of motion significantly widens the system's operational capabilities.

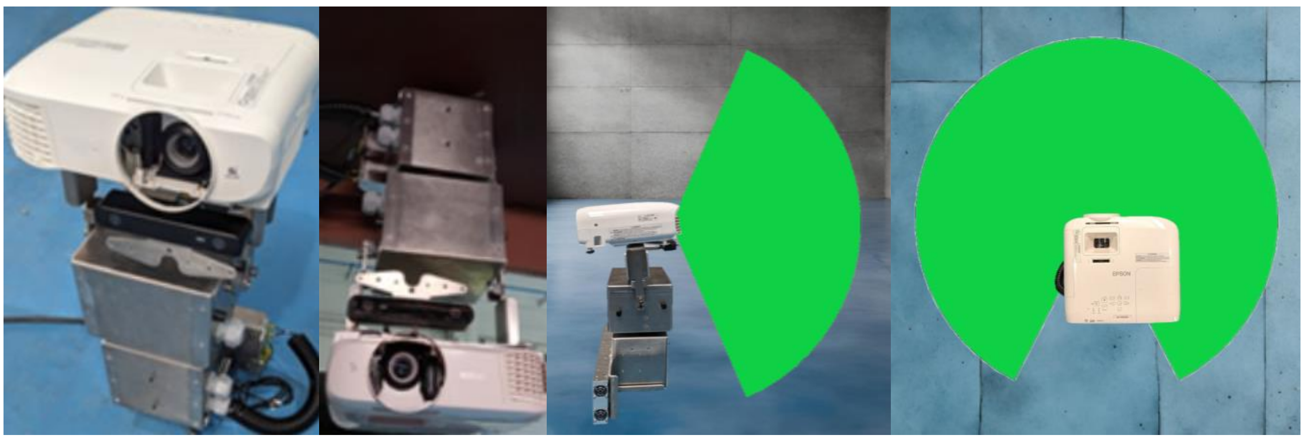
The EPSON EH-TW 5400 projector plays a pivotal role in simplifying the tasks of system operators. It projects supplementary information directly into the real environment, enhancing the overall user experience and the system's effectiveness.

The camera utilized in this setup is the Zed 2i, boasting a resolution of 1280x720 at 60 fps. This high-quality camera facilitates the scanning and monitoring of the working area, ensuring precision and accuracy in its operation.

The system's software is executed on a personal computer, where the necessary algorithms and controls are implemented to manage the projection, camera input, and overall system functionality.

To enhance the system's versatility, the MagMount Superior 300 MagSwitch magnet is a valuable addition. It grants the system the flexibility to attach securely to various flat ferromagnetic surfaces in different orientations, making it adaptable to a wide range of real-world scenarios.

The operation of this system involves a sequence of steps. Initially, the operator is required to perform calibration and upload the CAD (Computer-Aided Design) of the designated work area. Following these preliminary actions, the system will commence scanning the specified region, conduct a comparison with the provided CAD data, and subsequently initiate the projection onto the actual environment.



List of technology capabilities and suggested validation at sites

Low-cost projection system will be used to recognise a scene and project the desired CAD file. The capabilities of this system are the ones explained in the next table. First, we need to calibrate camera and the projector to the kinematics chain origin.

Capabilities	**Validation**
Fast deployment of the projector	Measuring required time to put this system into the double hull to evaluate the effort put in this task
Environment identification and projection	We can see it directly from the projected scene in the double hull. It will be clear when projecting lines or superposed characteristics.

Besides, to obtain the evaluation of the whole system, we can check differences between doing this process without the projection aid and with this help when a task by the operator is performed.

Setting-up of scenarios at sites (BIS, AIMEN)

Availability of the resources

BIS will provide all necessary resources.

In this case, CAD file with the target elements must be provided by BIS.

Selected scenario infrastructure or alternative

First scenario is attaching a projection system inside hull assembly hall. With this system, outlines of a future parts could be projected on shopfloor.

Second scenario involves outfitting phase. When all hull parts are assembled, projector is fixed on ceiling of an empty room. After initialization, it projects all structure openings which were left during plate cutting phase. In that way we avoid delays caused by blind openings that someone during process forgot to open.

Third scenario could maybe use laser guidance to guide cobots (like guided missiles) to a precise opening position.

Operators' and management

A BIS supervisor will be required during the demonstration.

Shipyard components and material

A stable metal horizontal structure to place the 3D projector, table with 2 chairs, screen and AC plug 230V

Risk assessment

Risk of falling of the projector with the mechanism. To prevent this, operator could wear a protective helmet and boots to protect him/her from superficial cuts and the falling objects.

Logistics of transferring technologies to the sites

To test this system, the equipment corresponding to the projector, computer, camera and motors with controllers must be transported to the final demonstrator.

The physical dimensions of the assembled system are 311,2 x 627,5 x 317,2 mm with an approximate weight of 15 kg.

Pre-demo verification of the technologies at the sites

Tests done prior to send all the equipment to the final demonstration can be considered as pre-demo validation.

Design and implementation of the demonstrator protocol (BIS, AIMEN)

Involved performance indicators.

- Eliminate the classical usage of the paper drawing for the given use-case.
- Ability to be mounted on ceiling, wall and floor.
- Zero modifications to onsite operates at the shipyard.
- Time to install and remove the projector.

Relating the WP5 – WP6 performance indicators

KPI	Target
Eliminate the classical usage of the paper drawing for the given use-case	< 1 query to physical paper
Ability to be mounted on ceiling, wall and floor	2 configurations
Zero modifications to onsite operates at the shipyard	≤ 60% rework and changes
Time to install and remove the projector	< 5 min

Involved measurement equipment

To measure data, we could need some physical element to compare projection and reality to check localization and projection accuracy.

Involved operators, demo supervisors

For the demonstration 2 operators may be needed to deploy and configure the system, and one supervisor during all the process.

Pre-demo validation verification

Tests done prior to send all the equipment to the final demonstration can be considered as pre-demo validation.

Data collection

From this process, we can extract the user experience of the technology. Besides, data from the projection error and positioning of the elements can be also collected.

Analysis

In the analysis to do, error of the projection and reality can be obtained as well as time. Besides, the operator experience of integrating these technologies and not having to check the drawing of the scenario to perform the tasks.

Demonstration Videos

A video of the whole process can be recorded: system deployment, projector configuration and calibration, project desired CAD file and the operator executing different tasks on the projected scenario.

The videos of the demonstration will be included in the following folder: BIS

12. Exoskeleton for support of shoulder flexion and for support of trunk flexion

M4Y Business Push (NODOSA)

Video of the scenario (Public)

WP4 T10 Exoskeleton for support of shoulder flexion

WP4 T11 Exoskeleton for lumbar support

Functional requirements (Public)

Main functional requirements provided by the shipyard were resistance to specific environment-related aspects. Specific requirements have not been reported in this document for reason of confidentiality.

Non-functional requirements (Public)

Compact and lightweight design to allow operators to move in confined space with no interferences in terms of freedom of movement and encumbrance.

End-user business impact (Public)

Reduction of the risk of ergonomics risk of injury, increased well-being of operators, increased productivity and reduction of errors.

M4Y Technology Push (IUVO)

Technology claims in nutshell

Table 20. Handheld Devices Technology Claims after three Test Sprints

Claims	Description
C1.	Usability in harsh environments with no interference with respect to the regular working activity
C2.	Reduction of the physical workload while performing working activities (e.g. welding)
C3.	Reduction of the perceived effort while performing demanding working activities

C4.	Improve working quality and efficiency by decreasing the number of errors

Technology specification definition and limitations.

- Mari4S_Exo is a semi-active sensorized exoskeleton for upper-limb support. It is composed of a physical human robot interface constituted of the parts in contact with the user and size adjustments to cover the wide range population. Two semi-active torque generating boxes (one per arm) delivers mechanical power to the user through adaptive spring-loaded mechanism. A backpack containing battery and control electronics.
- Mari4L_Exo is a passive sensorized exoskeleton for lumbar support. It is composed of a physical human robot interface constituted of the parts in contact with the user and size adjustments to cover wide range of population. Two passive sensorized torque generating boxes (one per arm) delivers mechanical power to the user.

Exception made for uncontrolled events that may damage the devices, there should not be any limitation to their use in the shipyard. It is strongly recommended not to use the devices without having verified absence of interference with personal protective equipment.

List of technology capabilities and suggested validation at sites

The technology is expected to reduce the physical effort of workers in performing manual working activities. A reduction of the physical effort could have positive consequences on a twofold perspective: 1) improve the quality of the working condition and therefore have an impact on the health and well-being of operators reducing risk of injuries, pain and discomfort; 2) from a productivity perspective, healthier or less fatigued operators will perform faster, more accurately and efficiently with a possible consequent improvement in productivity and production quality.

The suggested validation protocol is structured in a two-steps phase involving a maximum of five operators in the shipyard using Mari4S_Exo and Mari4L_Exo during the working activities. The first phase is defined as Baseline (BL). During BL phase, the identified operators will be requested to regularly perform their working routines and periodically fill questionnaires about their normal working experience. BL could last one month. The second phase of the validation protocol is called Monitoring Period (MP). MP will last the same duration as the BL. During MP, operators will be requested to regularly perform their working activities but wearing the exoskeletons at their need and preference. During MP, operators will be requested to periodically answers the same questionnaires administered during BL and a datalog about the exoskeleton utilization.

Setting-up of scenarios at sites (NODOSA, BIS, IUVO)

Availability of the resources

Prototypes are available and ready to be deployed. None redesign action of the working activity is requested to the shipyard. Shipyard will be requested to identify a supervisor and a group of operators who are willing to take part to the activities for at least two months (one without and one with) the exoskeleton.

Selected scenario infrastructure or alternative

The technology will be tested in the shipyard with no restriction on the working activities. A dedicated space will be identified in the shipyard to stock the device and where operators can wear/unwear the exoskeletons and answers use-related questionnaires.

Operators' and management

One supervisor among shipyard managers will be identified to monitor on-site activities. Five operators who are willing to take part to the activities for at least two months (one without and one with) the exoskeletons will be identified as "participants".

Shipyard components and material

No specific material or components are required.

Risk assessment

Risk assessment will be completed in the next months. No specific interference risk of using the devices in the shipyard is identified. Residual risk is reported in the Risk Assessment document. Specific requirements related to safety have not been reported in this document for reasons of confidentiality. All the information related to safety requirements can be found in related Deliverables.

Logistics of transferring technologies to the sites

Exoskeletons will be shipped, and a training will be delivered by technology developers on-site prior to the demonstration execution.

Pre-demo verification of the technologies at the sites

The technology has been already verified on-site during the test-sprint.

Design and implementation of the demonstrator protocol (NODOSA, IUVO)

Involved performance indicators.

Three main classes of indicators will be considered for exoskeletons based on the claims. Usability-related indicators will describe the usability of the exoskeletons in the shipyard in terms of actual utilization time, percentage of target applications in which the exoskeleton can be deployed without interfering with the regular working activity and ease-of-use including wearing and unwearing time. Well-being and health related indicators will describe the capabilities of exoskeletons in having an impact on the safety (ergonomic risk indexes) and on stress (reduction of perceived effort). Productivity-related indicators will describe the potential impact of exoskeletons in reducing stress-induced errors and increase working speed.

Relating the WP5 – WP6 performance indicators

Table 21. Exoskeleton for support of shoulder flexion WP5-WP6 performance indicators.

KPI	Target
Time of utilization of the exoskeletons	20% of the weekly workshift
Usability	≥ 5.0
Percentage of target applications with no interference	> 70%
Wearing/unwearing time	< 60 sec
Feasibility proof of ergonomics risk reduction	Feasible
Events of pain at shoulder or lumbar level	-50% (EXO wrt BL)
Fatigue felt by operators	-25% (EXO wrt BL)
Assembly time of standard components	-10% (EXO wrt BL)
Reduction of assembly errors by operators	-30% (EXO wrt BL)

Involved measurement equipment.

Questionnaires and datalog will be administered to participants during the demonstration. Video will be recorded to assess feasibility of ergonomics risk reduction.

Involved operators, demo supervisors.

The demonstration will involve at least one supervisor and possibly 4 to 5 operators.

Pre-demo validation verification

Third TestSprint can be considered as pre-demo validation verification.

Data collection

Data collection will be performed through questionnaire and datalog that will be printed and shared with operators. Questionnaires will be stored in the same area identified for stocking, wearing and unwearing the exoskeletons. Datalog and questionnaires will be reported weekly by the supervisor to IUVO. Informed consent will be requested to the operators.

Analysis

Data analysis will be conducted by IUVO analysing the answers provided through questionnaires and datalog.

Demonstration Videos

Informed consent will be requested to the operators to be recorded during the training session and during utilization of the device by the supervisor.

The videos of the demonstration will be included in the following folder: NODOSA

PERFORMANCE INDICATORS

Performance metrics will provide valuable insight into their task and function-level performance capabilities. These measures will then help to match capabilities to end-user needs as well as to help provide technical partners insight for improving the hardware and software designs. These metrics will be used to evaluate the portfolio of solutions, identifying weakness, and providing insight into Mari4_YARD improvement, identifying factors that could affect the final application performance. For each metric, a common definition must be provided, including how the metric is calculated, the data collecting frequency, the collection interval and data synchronization, and some categorisation data that allows collecting a well-rounded set of metrics.

The performance indicators are further divided into the Mari4_YARD technologies wise:

WP	No.	Technologies	Shipyards	Scenarios
1	**T1**	**Advance monitoring using 3D scanner**	**BIS**	Block under construction
1	**T2**	**Shipyard production planning based on aerial surveillance**	**NODOSA**	Big drone for production planning
1	**T3**	**Small drone for confined spaces**	**NODOSA**	Small drone for confined spaces 1 Small drone for confined spaces 2
2	**T4**	**High-payload robots in shared space with humans**	**BIS**	High-payload robots 1 High-payload robots 2 High-payload robots 3 High-payload robots 4
2	**T5**	**Collaborative robots**	**NODOSA**	Collaborative robots 1 Collaborative robots 2 Collaborative robots 3 Collaborative robots 4

2	T6	**Mobile robots**	**NODOSA**	Mobile robots 1 Mobile robots 2
3	T7	**Augmented reality with handheld devices**	**BIS**	Augmented reality
3	T8	**Mixed reality with headsets**	**BIS**	Mixed reality 1 Mixed reality 2
5	T9	**Mixed reality with AR glasses**	**BIS**	Digital 1st Training at BIS [HoloLens].mp4
3	T10	**High precision projection system**	**BIS**	High precision projection system
3	T11	**Cost effective projection**	**BIS**	Cost effective projection 1 Cost effective projection 2
4	T12	**Exoskeletons for shoulder and trunk support**	**NODOSA**	Exoskeleton for shoulder Exoskeleton for lumbar

Mapping the project global, the WP5 and the WP6 indicators

Mari4_YARD global technical key performance indicators are shown below:

To develop intuitive human-robot collaborative solutions allowing symbiotically integration of operators' skills and dexterity into flexible and reconfigurable solutions in shared workspaces

- Safe, modular and collaborative robot solutions.
- Programming and setting time reduction up to 60% by skill-based and intuitive robot programming.
- Production improvement up to 40% of process time.

a. Robot-based solutions sharing the workspace with operators

i) Assisted calibration and re-calibration.

ii) Mobile robot manipulators operating in cluttered and unstructured environments difficult to reach by workers or providing flexibility in various operations assisting workers.

iii) High-payload collaborative robots assisting in the processing of large-scale parts or as work-holding devices.

iv) Small manipulators for executing tasks in confined and/or hazardous spaces.

b. Safe human-robot interaction

i) Safe workspace monitoring. Estimation of the relative position of the shipyard workers in relation to the robot.

a. Shipyard workers detection and localisation in dynamic and shared workspaces.

b. Adaptive path planning for collision avoidance.

ii) Speed and separation monitoring. Definition of dynamic safety robot areas for collision avoidance.

a. Compliance with ISO/TS 15066:2016 (safety requirements for collaborative industrial robots)

b. Monitoring of relative operator position and speed.

i. Slow down robot speed if a worker enters in the collaborative space to avoid collisions.

ii. Safety-rated stop for stopping the robot if a human enters in the critical collaborative space.

iii) Power and force limitation to avoid harming the worker if there is a collision.

c. Novel and intuitive programming

i) Skill based programming

a. Task-level programming tools for allowing robotic novices to program industrial tasks.

b. High abstraction-level for programming a robot. The shipyard worker only must specify what the robot should do.

iii. High-level of representation. Neutral from vendor-specific robot programming language.

ii) Fast and intuitive programming:

a. CAD/CAM offline programming.

b. On-line hand-guiding for precision positioning.

d. Reconfigurable, multifunctional and interoperable

i) Connectivity based on open standards.

a. ROS-based on OPC-UA for seamless integration of robots with production networks.

b. AutomationML providing open and neutral data exchange for interconnecting heterogeneous data.

ii) Adaptive operation based on perception.

iii) Multifunctional operation.

a. Novel collaborative grippers oriented to the shipbuilding needs.

b. Different manufacturing operations –e.g., welding, grinding, polishing, assembly, picking…— would be addressed.

To develop handheld and portable AR/MR tools for assisting shipyard workers

- Reducing up to 60% reworks and changes, particularly in the latest phases of the construction. Nowadays, the lack of a detailed construction supervision plan imposes continuous reworks that forces continuous adaptation of the work planning, representing up to 4-8% of total costs in a vessel construction.
- Increasing precision and quality up to 60% by relying on AR/MR tools (i.e., laser and video projection, as well as superimposing CAD information) for a precise positioning of the different subassemblies.
- 30% to 40% of more efficiently training for new shipyard workforce in machinery and deck equipment.

a. a) Handheld and portable solutions for increasing precision and quality in manual operations

i) Digital solutions for 3D modelling.

ii) Projection tools for assisting workers in a precise positioning of auxiliary elements.

iii) Mixed Reality tools for providing onsite step-by-step instructions and/or training.

iv) Augmented Reality tools and surveillance technologies for construction supervision and shipyard planning.

b. b) Modelling CAD/engineering information

i) Generation of 3D models from 3D scans for retrofitting/repairing operations –i.e. reverse engineering—.

a. Point cloud extraction.

b. Registration and stitching of point cloud.

c. 3D CAD model extraction.

ii) Semantic model and definition of the information exchange

a. 3D modelling representation based on STEP (ISO 10303-11 neutral format).

b. Hierarchical ontology description for describing relation and attributes from the CAD model.

c. Localisation and tracking

i) Scene localisation.

a. Localisation strategies based on natural landmarks minimizing the use of markers.

b. Matching CAD model and image features for localisation.

ii) Vision-based SLAM for aligning the scene.

a. Visual servoing for real-time tracking.

b. IMU7 measurements for orientation estimation.

d. Human interaction technologies

i) Laser and video-projection displays.

a. Onsite projection of the position of the elements/subassemblies to be assembled.

ii) Touchscreen/tablet for superimposing of 3D CAD models into real status of the construction.

a. Construction supervision and shipyard planning.

b. Onsite replanning by on-the-fly detection and marking of missing/deviated elements.

c. Step-by-step instructions for machinery assembly guidance.

iii) Head Mounted Displays.

a. Step-by-step instructions for deck equipment assembly.

b. Workforce training.

e. Vertical integration and interoperable with shipyard management and engineering

i) Connectivity with specific shipyard engineering tools –e.g., AVEVA, FORAN, CADMATIC…–

a. IFC8 providing a neutral format for 3D modelling data exchange.

b. AutomationML for extending IFC data format to provide orchestration of heterogeneous digital tools.

ii) Feedback loop to engineering and management about the real shipbuilding/retrofitting status.

To develop AI-assisted exoskeletons for reducing fatigue and physical stress

- Reduction of workers physical effort in the execution of the target tasks; reduction of the physical effort will be measured through superficial electromyography (sEMG; expected reduction: >20% in the comparing with/without exoskeleton) and questionnaires (e.g., Borg Scale, NASA workload).
- Usability and acceptability assessed through standard questionnaires.
- Estimation in the improvement of the ergonomics risk factor in the target workstations measured through standard indexes such as NIOSH and EAWS/OCRA Index.

a. Wearable semi-active spring-loaded exoskeleton for upper-limb support

iii) An innovative spring-loaded exoskeleton will be used for value-added manual tasks where workers can benefit from antigravitational physical support to reduce the physical strain in tasks with overhead manipulation or/and intensive shoulder flexion-extension.

ii) Exoskeleton garment will be developed to provide partial back support for improving ergonomics of workers' postures.

iii) Use of the exoskeleton will foster a more efficient (from the delivery time and quality) execution of the manual tasks because of the reduced workload on shoulders.

b. Wearable sensorized spring-loaded exoskeleton for lumbar support

iii) An innovative sensorized pelvic exoskeleton will support workers' handling up-to-20 kg loads with the ultimate goal to reduce the physical effort done by trunk extensors muscles (e.g., thoracic and lumbar trunk extensors).

ii) Lumbar exoskeleton will be extremely light-weighted and will not interfere with usual movements and activity of workers within the shipyard.

c. AI-based computation engine and real-time feedback to worker

iii) Exoskeleton and additional wearable sensors will provide valuable information for monitoring workers activity and elaborate task- and subject-specific exoskeleton settings to optimize reduce the workers' effort throughout the working days.

ii) A real-time feedback system providing instruction and feedback to the workers from the time they don the exoskeleton until they doff it.

iii) Stored data will be considered to improve AI-based computation engine algorithms over time and make it specific for the needs of each shipyard worker.

Mari4_YARD performance indicators are shown below based on the technologies developed:

No.	Technologies	WP5 PI's Section
T1	**Advance monitoring using 3D scanning**	• **How much time is saved by having assembly information faster than shipyard usual system.** • **How much accuracy on the work done is obtained versus the usual system of the shipyard.** • **How many collision problems due to differences between reality and 3D model have been avoided.**
T2	**Shipyard production planning based on aerial surveillance**	• **Number of different point cloud formats able to be ready.** • **Number of different CAD formats able to be imported.** • **Time required to import point clouds.** • **Time required to import 3D CAD elements.** • **Time used to import a Ship Block and locate it in an open storage area.**

		• Time used to import a Ship Block and locate it in the slipway. • Percentage deviation measuring the length of the dock with the 3D user interface Vs the real dock. • Percentage deviation measuring the area of an open storage area with the 3D user interface Vs the real area.
T3	**Small drone for confined spaces**	• Time required to set-up the system. • Time required to read the measured parameters. • Distance, in X, Y and Z direction, from the access to the local where parameters can be measured. • Impact over others works carried on at the same time in the ship or workshop.
T4	**High-payload robots in shared space with humans**	• Cycle time reduction (before and after HRC) • Reduction of robot programming time for welding paths (before and after HRIM) • Improved ergonomics (before and after HRC using ergonomics evaluation and questionnaires) • Time for the operation with and without hand guiding assistance • Number of processes involved (use external elevation systems to move the loads)
T5	**Collaborative robots**	• Deployment time of the hardware components. • Time required for electrical component connection. • Time required to perform welding joint compared to the manual task. • Time required to perform cut opening compared to the manual task. • Accuracy of the robot position and hence, the cut position.
T6	**Mobile robots**	• Time required to set-up the full system in place • Time required to pick up a set of objects • Reliability of the system (number of assigned tasks versus total task fully completed) • Number of operators and respective time that was free for other operations.
T7	**Augmented reality with handheld devices**	• Time needed to perform a working task with the assistant vs with paper based instructions • Also: number of errors & satisfaction of workers & acceptance of workers

		• Time needed to prepare a working task with web based tool vs with "word" for paper based • Time needed to report an issue and reviewing it with the assistant vs paper based • Time needed to document the state of certain machine/operation with assistant vs paper based • Also: number of errors & satisfaction of supervisor & acceptance of supervisors
T8	**Mixed reality with headsets**	• Time needed to perform a training (after training user how to use device) vs time spent on regular training? • Need of written training material for user, time to access such information? • Knowledge retention (a test of skills 10 days after regular training and interactive training with wearables)? • Time needed to document a defect while reviewing ship building progress? • Time needed to communicate a defect to responsible department while reviewing ship building progress?
T9	**Mixed reality with AR glasses**	• Time needed to perform a training (after training user how to use device) vs time spent on regular training? • Need of written training material for user, time to access such information? • Knowledge retention (a test of skills 10 days after regular training and interactive training with wearables)?
T10	**High precision projection system**	• Time Required to setup projection system in place • Time Required to load the CAD information into the system • Time required of the system to scan the environment and project the information • Precision of the projected information • Time saved by human operator when comparing with the traditional approach • Reduction (in percentage) traditional rework required when comparing the projection system with the traditional approach
T11	**Cost effective projection**	• No. of reduced paper drawings. Eliminate the classical usage of the paper drawing for the given use-case • No. of instalment configurations. Ability to be mounted on ceiling, wall and floor

		• **No. of operations effected. Zero modifications to onsite operates at the shipyard** • **Time to install and remove the projector**
T12	**Exoskeletons for shoulder and trunk support**	• **Level of usability of exoskeletons in real environment** • **Time to wear/unwear the exoskeletons** • **Effect on physical effort (objective and/or subjective) in performing the working activities with respect to the normal condition, i.e. without exoskeletons** • **Capability to have an impact on ergonomics risk indexes** • **No. of stress-induced errors** • **Time required to perform an assembly task**

CONCLUSIONS

This deliverable presents a demonstration of the Mari4_YARD technologies at two shipyards, NODOSA and BIS. The focus is on the business and technology push, presented in terms of the requirements and technology claims. The setup of the technologies is detailed, with an emphasis on the major factors necessary for the smooth deployment and integration of technologies at the shipyards. The design and implementation of the demonstration protocol are based on performance indicators and corresponding measurements. A key aspect of this demonstration is the emphasis on linking the performance indicators with the WP6 indicators. The analysis in WP6 will focus on economic, environmental, and social impact (in this order of importance). In the indicator list, the majority deals with saving time or improved quality which can be translated into cost savings. A few indicators cover social aspects, and we could only identify one environmental KPI (reduction of paper amount). Future emphasis will be paid to including some social and environmental KPIs[1] to be analysed during the demonstrations with mutual discussion between technology providers and the end-users. In conclusion, a list of the technologies and their corresponding performance indicators is presented.

[1] The extension of the KPI will be included in the demonstrator D5.2 and D5.3 which will be officially submitted at M48. However, these KPI must be defined with WP6 collaboration as early as possible during WP5 meetings but not later than M38 of the project.