MAGICIAN: iMmersive leArninG for ImperfeCtion detectIon and repAir through human-robot interactioN

MAGICIAN

List of participants

Participant No. *	**Participant organisation name**	**Short name**	**Country**
1 (Coordinator)	Università degli Studi di Trento	UNITN	Italy
2	Fondazione Istituto Italiano di Tecnologia	IIT	Italy
3	Lunds Universitet	LU	Sweden
4	Idryma Technologias kai Erevnas	FORTH	Greece
5	Centro Ricerche FIAT SCPA	CRF	Italy
6	Tofas Turk Otomobil Fabrikasi	TOFAS	Turkey
7	Altinay Robot Teknolojileri Sanayi ve Ticaret A.S.	ALT	Turkey
8	Steinbeis Europa Zentrum	SIG	Germany
9	Zabala Brussels	ZAB	Belgium
10	Pipple B.V.	PIP	Netherlands
11	Harms & Wende GMBH & CO KG	HWH	Germany

* Please use the same participant numbering and name as that used in the administrative proposal forms.

1. Excellence

The MAGICIAN project proposes a robotic approach for autonomous classification and reworking of defects from semi-finished products before starting their final aesthetic process. This activity is a paradigmatic example of a broader class of physically and cognitively demanding operations in manufacturing production lines. It is commonly executed by skilled operators working in a dirty and unsafe environment, much to the detriment of their physical and psychological well-being. Figure 1 illustrates the current workflow. When the semi-finished piece (e.g., a car-body) approaches the operation areas, the operators make their first decision based on visual perception. If the defect is grossly evident, the classification can be made immediately. In other cases, the defect is observed from different viewpoints with special lighting. When required, the defect is further inspected by touching and feeling it. The defect is classified by type (e.g., weld spatter, deformations, scratches, dents), and by severity. In a next phase, another team plans and executes a sequence of rework operations by a grinding tool, prioritising the most visible areas and the most severe defects. These operations are predominantly executed by humans because i) localising and classifying the defects in a short time is difficult, and ii) the reworking operation requires that the grinding tools exert forces with angles dictated by the nature and the position of the defect, and by the worker's experience.

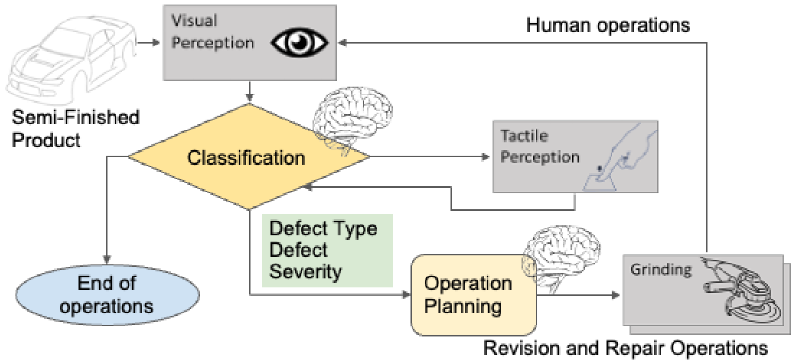


Figure 1: the human-based workflow

Recent developments in Artificial Intelligence (AI) have paved the way towards human-centred approaches to the robotic automation of such operations. The MAGICIAN project will bring them to industrial maturity. We will develop sensing technologies and methodological approaches to learn the human expertise in defect classification and reworking. Then, the development of advanced robotic technologies will allow us to reproduce the human operations with the required accuracy, satisfying the timing constraints of the production process.

The MAGICIAN project aims to bring a profound innovation in the manufacturing world addressing the "improving human working condition and satisfaction" use-case. The strong social and psychological implications will be considered throughout the whole development process and the validation phase. An equal consideration will receive the needs of potential adopters and system integrators. The developed solutions will meet the requirements of the use-cases identified in the first phases of the project and will be demonstrated and validated through a complete prototype. In order to prove the generality of the solution, in the final phases of the project, we will involve a number of operators adopting a FSTP scheme. This approach will allow, on one side, to expand the functionalities/solutions embedded in the main project use cases (scalability of the solution), and, on the other side, to experiment new application use-cases with a view on demonstrating the replicability of the solution.

Project Overview

The possibility of applying robotic technologies in defect reworking requires a correct understanding of how humans sense and classify defects, of the strategies they apply to scan relatively large areas in search of very small defects, of the way they schedule and execute their cleaning operations. A key requirement is the respect of the strict timing constraints (e.g., dictated by the cycle time of the production process), which requires an adequate prioritisation of the activities and optimisation of their sequence.

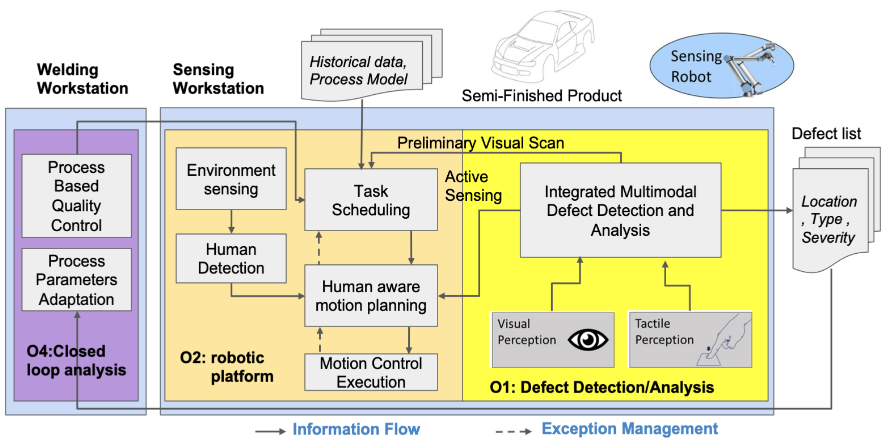


Figure 2: the robotic framework for defect analysis and classification

Robot based defect classification. The robotic architecture that we envision for sensing/perception operations is called sensing robot (SR) and is shown in Figure 2. When the semi-finished piece reaches the working phase devoted to defect detection, one or more SRs start a sequence of perception tasks. The sequence of tasks is decided based on historical data (i.e., considering the areas where the analytics of the previous operations report that defects are the most likely to appear), and on a preliminary visual scan. Additional information on the possible location of defects can come from the current monitoring in the welding workstation. The tasks are picked up from a list and executed in sequence. If more SRs are deployed to the station, the task scheduler generates a list for each, reducing the possible interferences. In order to execute each task, the motion planner has to decide a trajectory considering the presence of the humans detected in the area. If no motion plan can be generated within adequate safety margins, an exception is raised to trigger a change in the task schedule. If the motion plan can be generated, it is passed on to a motion controller, which executes the plan monitoring the position of the humans in the working area. If one is found within the safety area, an exception is generated in order to seek an alternative motion plan (reactive planning). If no such plan exists, the problem is propagated to the level above. The defect classification task will consist of a first visual inspection from a relatively far distance using multi-spectral sensors to detect telltale signs for possible defects such as the presence of oxides deposited on the car body surface. The first inspection is followed by a closer one using standard 3D cameras and sensors, and tactile sensing. The different sensor data are integrated producing an assessment of the considered defect, which is classified by position, type and severity. When the robot completes its analysis, it can spray some ink onto the area, which will be used as a colour code in a subsequent phase. The list of defects is also fed-back into the previous phases of the project, e.g., to adapt the welding parameters.

Robot based defect reworking. The main functional blocks for defect reworking are shown in Figure 3. When the car-body reaches the defect reworking work-station, it comes along with an annotated list of defects coming from the defect analysis. Such a list is processed by the task scheduler module, which determines the optimal sequence of reworking operations, which will be executed by a robot endowed with a specialised end-effector, the cleaning robot (CR). If multiple CRs are used the schedule will minimise the interference in their operations. When a defect is processed, it is dispatched to the Cleaning Policy Decision module. Given the defect type, location and severity, the policy decides operation parameters (the tool angle, the direction of motion, the force to be applied). Such decisions are passed to the human-aware motion planner to decide the operation trajectories, accounting for the possible presence of humans, and then to the controller module, which approaches the operation area following the decided trajectory. During the operation phase, the controller controls motion, impedance and/or force. As for the SR, the detection of humans inside the safety area is managed, modifying the trajectory if possible. When the task is completed, the defect is analysed by a camera on the end-effector to verify the correct reworking.

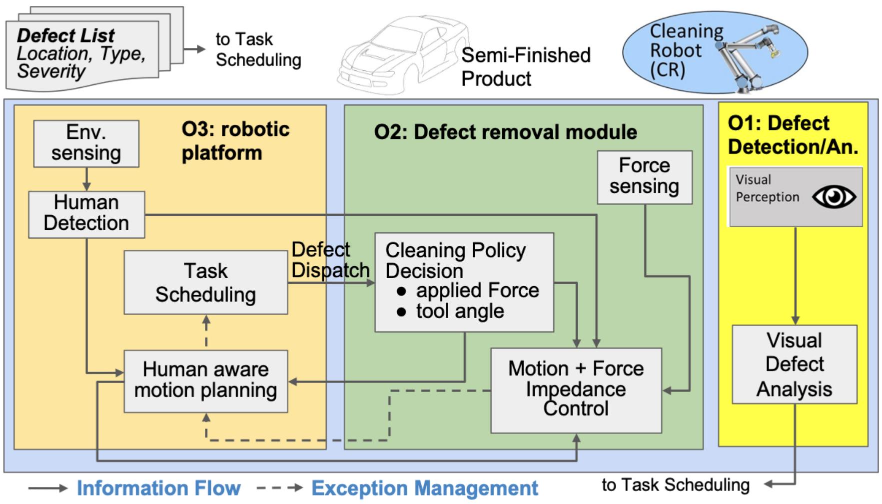


Figure 3: the robotic framework for defect removal

The learning pipeline. A key aspect of MAGICIAN is to reproduce human skills in classifying the defect and in using the grinder to remove them. The operation pipeline for each of the two objectives are shown respectively in the top and in the bottom half of Figure 4. The procedure that we envision for learning the defect classification skills is initiated by the arrival of the semi-worked piece into the station. The operators inspect and classify the defect using a sensing glove (which allows recording tactile data). For each defect, the operator decides type and severity level. The defect is pinpointed by an instrumented marker that enables its electronic localisation and the application of a coloured mark. The SR comes back on each classified defect to acquire visual data that will define a database with all the collected data sets. The acquired visual and tactile information will be used to train the

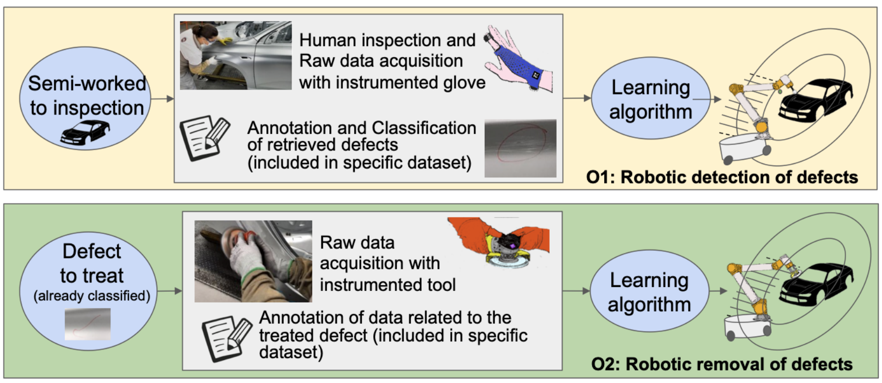


Figure 4: Overview of the learning operations

components inside the "multi-modal Defect Detection and Analysis" module. The data collection for learning the working skills starts again with the arrival of a semi-worked piece within the data acquisition area. The car-body has been previously analysed and its defects classified. The operator uses an interface to point the defect he/she is going to process. Then she/he uses an instrumented device to execute the reworking operation. The instrumentation consists of: a. visual markers that are captured by an external camera, b. a set of IMUs that are used to reconstruct the attitude of the tool and to sense the vibrations, c. a multi-axial force sensor that is used to reconstruct the force applied to the tool. The data collected from the different devices are associated with the tool and are used to train the "Cleaning Policy Decision" block and to design the end-effector.

Implementation and modularity in using the framework. Based on the different customer needs, the two modules described above can be used in different ways. The most complete application that we envisage is to first use the SR technology to detect and classify the defects and then proceed with the CR to remove the identified defects. The two operations can be done in sequence within the same workstation or in two different workstations. If the customer is interested only in the defect analysis component, the SR could mark with an inkjet head each identified defect, or could simply note them in a digital log. The operator will localise and remove the defects using the colored spot or the digital marks. Otherwise, the CR could be used only to remove defects that can either be grossly evident or be identified by a human operator in a previous phase. In the former case, the defects will be identified through a visual sensor posed on the end-effector (similarly to defect reworking in Figure 3). In the latter case, the operator can use the same instrumented marker as for the data collection in the learning phase (see Figure 4). This interface enables the system to localise the defects and memorise their levels of criticality. Finally, for highly integrated production lines it is possible to connect the SR with a previous workstation in charge of welding in order to receive feed-forward information on the possible presence and location of the defects and to enable the adaptation of the welding parameters.

1.1. Objectives and ambition

Scientific and technological objectives

(O1) A robotic perception module integrating visual and tactile sensors. The module will be embedded in a robotic sensor module (the SR, hereafter) and will be used for defects analysis and classification. The SR will replicate the skills of human workers through a learning scheme.

Ambition: The ambitious challenge that we will tackle is to autonomously scan the potentially large surface of a semi-finished product in order to quickly and effectively pinpoint and classify (sub)millimetric defects. Known alternatives to this approach are based on adhoc systems with extremely high resolution and responsiveness, e.g., the AMETEK Metrascan3D device. These devices are very expensive, and cannot be easily integrated into a real-time application (large computation times) or routinely used in industrial scenarios (mechanical stress and dust can compromise them). The MAGICIAN's SR, on the contrary, will be a low-cost solution able to produce accurate, reliable and robust results in the detection and classification of the defects through the use of multi-modal (visual-tactile) and multi-scale (distant-close) sensing. The vision based sensing of the SR will combine traditional computer vision techniques based on multi-modal visual input (RGB, depth, Hyper-spectral) and advanced machine learning algorithms which will leverage the workers' expertise in defect detection into a highly reliable and explainable computer vision system. The transfer of knowledge of human workers into the SR will be achieved through a learning process. We will create a multi-modal dataset of imperfections by annotating the data with the results of human visual and tactile inspection. Through data analysis we will find the optimal balance between the number of samples collected and the respective accuracy. Through proven methods of supervised learning we will build a robust baseline for defect detection. Additionally we will also investigate the use of parametric models and GANs. After the system roll-out, we will put in place a continuous learning approach based on reinforcement learning. Using its sensing capabilities the SR will autonomously accomplish tasks that are unhealthy for workers.

KPI
KPI-SR1: Smallest size of defect that can be sensed/detected by the perception module (Target: ≤ 0.3mm).
KPI-SR2: Detection success rate vs humans: false positives (Target: $\leq 120\%$), skipped defects: (Target: $\leq 110\%$).
KPI-SR3: Car-body scan time compared vs humans on a benchmark set (Target: $\leq 110\%$).
KPI-LRN-SR1: Misclassification rate w.r.t. human (Target: $\leq 10\%$).
KPI-LRN-SR2: Time to convergence (Target: observation time $\leq$ 15h to achieve KPI-LRN-SR1).

Major Outcomes	MO1: A multi-sensor perception module, embeddable on a robotic platform. MO2: Data analysis and classification software. MO3: A modular framework for automated learning, based on multi-modal perception.

(O2) A robotic cleaning module attached to a robotic platform (the CR hereafter) equipped with a specialised end-effector to rework defects. The system will learn the necessary skills by observing humans.

Ambition: While industrial end-effectors to remove defects exist and are already used in industry, their cost/performance ratio is pretty low, compared to that of a human worker. In addition, commercial solutions like the Ferrobotics AAK commercial grinder, operate within quite strict operating parameters. On the contrary, the envisioned application requires a good degree of flexibility to accommodate for different types of defects and for difficult-to-reach locations. MAGICIAN aims for a robotic solution able to operate with a level of mobility and dexterity comparable to a human operator. We will develop a specialised end-effector endowed with an engage/disengage mechanism for quickly (un)mounting a grinding tool. The end-effector will also feature a vibration suppression system necessary to prolong the robotic arm activity and to simplify the sensor data acquisition and processing, and it will be part of the CR module, along with the algorithmic solutions for force sensing and motion + force impedance control to ensure that i) prescribed angles and forces are applied to rework a defect; ii) the wear of the grinding disk is properly accounted for (see Figure 3).

When a human operates with a grinding tool to decide a *grinding policy*, she/he considers a number of parameters such as position and type of the defect, level of severity. We will associate a *grinding policy* with the triple (motion primitive, tool angle, applied force). The MAGICIAN's goal is to learn the human skills related to a defect removal operation in the form of policies. To this end, we will develop a multi-modal imitation learning approach exploiting data from different sources (grinding tool's position and orientation, interaction forces). Gaussian Mixture Models[1], Hidden Markov Models[2], Dynamic Motion Primitives, Probabilistic Movement primitives[3], and Deep Neural Networks[4] have been investigated, within the umbrella of Imitation Learning, to define motion primitives from human demonstrations. In tasks where the robot interacts with the environment, force[5,6] or tactile[7] or visual[8] information can be included to increase the robustness during task execution. Unfortunately, the fusion of multi-modal data is rarely used as a means to learning. The MAGICIAN's challenges are i) to exploit the synergistic interplay between different data sources to learn a skill (or a policy), rather than a specific action; ii) the ability to "clean" data sets to build an effective AI based procedure. In order to validate the system, we will use a test set made of two sets of identical defects. We will have the first half treated by the human operator and the second half by the CR and compare the results.

KPI

KPI-CR-1: Percentage of defects removed w.r.t. humans (Target: ≥ 98%).

KPI-CR-2: Time to remove the defect (Target: ≤ 110% of the time required by the human).

KPI-CR-3: Residual level of vibration (for grinding it is about 8.5m/s^2; Target: ≤ 1 m/s^2).

KPI-LRN-CR1: Reduction of measurement uncertainty (Target: RMSE ≤ 5%).

KPI-LRN-CR2: Time synchronisation error among data coming from different sources (Target: ≤ 0.1 ms).

KPI-LRN-CR3: Number of samples to converge to a satisfactory policy. (Target: ≤ 10h of observations).

KPI-LRN-CR4: Similarity measures between the learnt and the human policies. (Target: position error ≤ 1mm, orientation error ≤1°, force error ≤ 5N, moment error ≤ 2Nm).

---

[1] Khansari-Zadeh S.M., and Billard A. Learning stable nonlinear dynamical systems with gaussian mixture models. Transactions on Robotics, 27(5): 943–957, 2011

[2] Calinon S., et al.. Learning and reproduction of gestures by imitation: An approach based on hidden Markov model and Gaussian mixture regression. IEEE Robotics and Automation Magazine, 17(2): 44–54, 2010

[3] Paraschos A., Daniel C., Peters J. and Neumann G. Probabilistic movement primitives. In Advances in Neural Information Processing Systems, 26:2616–2624, 2013

[4] Finn, C., Yu, T., Zhang, T., Abbeel, P., and Levine, S. One-Shot Visual Imitation Learning via Meta-Learning. In Proceedings of Machine Learning Research, 78:357-359, 2017

[5] Kalakrishnan, M., Righetti, L., Pastor, P., and Schaal, S. Learning force control policies for compliant manipulation. In 2011 IEEE/RSJ International Conference on Intelligent Robots and Systems, 4639–4644, 2011

[6] Kormushev P., Calinon S., and Caldwell D.G. Imitation learning of positional and force skills demonstrated via kinesthetic teaching and haptic input. Advanced Robotics, 25:581–603, 2011

[7] Kronander, K., and Billard, A. Learning compliant manipulation through kinesthetic and tactile human-robot interaction. IEEE Trans. Haptics, 7(3):367–380, 2014

[8] Finn, C., and Levine, S. Deep visual foresight for planning robot motion. In 2017 IEEE International Conference on Robotics and Automation (ICRA), 2786–2793, 2017

Major Outcomes	[MO4] A specialised end effector that allows mounting human operated grinders. [MO5] Software for active suppression of vibration and endowed with a force control algorithm. [MO6] A combination of learning solutions ("transferable" to a robotics system) representing accurately how humans use a grinding tool for car-body defect reworking.

(O3) A software robotic platform including: a) the basic services needed to implement the SR (**O1**) and the CR (**O2**), b) a modular infrastructure to integrate external services and components, c) a toolset to support quick system deployment and configuration.

Ambition: A common group of services will enable the collaborative operations of both the SR and of the CR. The most important will be: task planning, environment sensing and human detection, human-aware motion planning, motion controller (see Figure 2 and Figure 3). Task planning (a.k.a. Planning and Scheduling) is a subfield of AI devoted to the study of techniques to automatically synthesise courses of actions, with associated times, in order to optimally achieve a desired goal given a specification of the environment and agent capabilities[9] [10] and considering user preferences[11]. In MAGICIAN, we will model cost functions and constraints and adapt standard techniques in order to produce an optimised sequence of sensing and cleaning actions. The solution will be scaled to the application of multiple resources (robots) within the same station. Motion Planning will be used to produce timed sequences of way-points to reach the defect and to perform the analysis or cleaning without generating safety hazards for the humans. In collaborative robotics, the safety standards (ISO10218-1/2, ISO/TS15066) provide four distinct modes for establishing a human-robot collaboration: safety-rated monitored stop (mode 1), hand-guiding (mode 2), speed and separation monitoring (mode 3), power and force limiting (mode 4). All these solutions have an important impact on productivity. The state of the art in robotic research offers solutions to meet the safety requirements without sacrificing performance, such as localised modifications of the trajectory to reduce the probability of accidents[12]. We will implement this novel paradigm. If the developed solution is difficult to certify, we will implement standard solutions (mode 3, 4), without modifying the rest of the system. For the motion controller, we will adopt a modular structure to also consider force/compliance control and active sensing. The active sensing solution will be applied both to the acquisitions of visual data and of tactile data. All the services will be integrated within a modular software infrastructure leveraging: 1) standard real–time operating system and middleware solutions, 2) architectural patterns inspired by those developed in RobMoSys whenever applicable; 3) a clear API to facilitate the integration of third-party components (e.g., those provided by third-parties through the FSTP founding scheme).
The software configuration and deployment tool will support the data collection and analysis needed to carry out classification learning (**O1**) and the defect removal learning (**O2).** Specifically, it will generate and manage the databases needed to store samples collected from human observations. It will allow the user to set and control the learning tools hyper-parameters, and speed-up the learning phase by enabling the transfer of knowledge from previous applications of the system. It will also support the configuration of the task planning and motion planning modules and control within the robotic platform (e.g., to fine-tune the parameters). The efficacy of the deployment and configuration tool will be measured through the use-cases hired using the FSTP scheme.

KPI
KPI-TP-1: Time needed to scan the whole surface of the vehicle w.r.t human operators. (Target: ≤ 80%).
KPI-TP-2: Probability of missing major defects during the scanning phase. (Target: ≤5%).
KPI-MP-1: Probability to have an accident, evaluated in simulation. (Target: less ≤ 10^{-6}).
KPI-MP-2: Average time to execute a sensing or defect reworking task w.r.t. humans. (Target: ≤60%).
KPI-MP-3: With respect to the KPI for **O1**, active sensing error reduction. (Target: ≥10% reduction).
KPI-PP-1: Reduce the learning time to adapt to new use cases of the 20% using knowledge transfer.
KPI-PP-2: Successful integration of at least 3 third party COTS found through the FSTP.
KPI-PP-3: Successful application of the approach to at least three new use-cases found through the FSTP.

Major Outcomes	[MO7]: A SW component to detect humans inside the robot workspace. [MO8]: A SW component for scalable (multi-agent) optimal sensing and cleaning planning.

[9] M. Fox and D. Long. PDDL2. 1: An extension to PDDL for expressing temporal planning domains. Journal of art. int. research, 20:61–124,2003.
[10] F. Ingrand, M. Ghallab. Deliberation for autonomous robots: A survey. Art. Int., 247:10–44, 2017 .
[11] A. Jorge, S. A. McIlraith, et al. Planning with preferences. AI Magazine, 29(4):25–25, 2008.
[12] Magrini, E., et al. "Human-robot coexistence and interaction in open industrial cells." RCMI 61 (2020): 101846.

	[MO9]: A SW component for human aware motion planning and optimising sensing. [MO17] : A software tool for system configuration and parameter tuning. [MO18]: A software infrastructure supporting the integration of new COTS.

(O4) A closed-loop defect detection and avoidance system for robot and welding processes.

Ambition: The ambition of this objective is to identify potential perturbation factors, causing defects in robotic and welding process execution inline and to automatically and optimally adjust the respective process execution parameters. A majority of perturbations during the execution of joining processes is caused by defects in the raw materials (e.g. surface conditions, alloy) and sub-components (e.g. tolerances in geometry) or by inappropriate conditions of the joining process (e.g. worn out electrodes, tolerances in grippers or welding guns, wrong positioning of robot arms, etc.). (**O1**). Besides the negative impact of such perturbations on the strength of the joint, very often spatters occur which lead to defects on the surface of the car body. Up to now, there are only a few systems that allow for a proper classification of those defects (**O3**), and thus the assembly process is not optimally performed. MAGICIAN aims to identify and to classify such defects by performing deep-learning algorithms of process signals such as welding current and voltage online during the welding execution. It will perform root cause reasoning analysis to identify the perturbations causing the defect. By combining the defect analysis with the location of the defect, workers are enabled to identify the location of the defect easily. In case of automatic defect rework (CR), the positioning of the robot to the correct location can automatically be done.
In addition to that, this objective also includes the implementation of an analysis system to detect the defect occurrence, feeding back this information to the welding control and to the robot, and adapting the process parameters. By this, a closed-loop control is realised, targeting on less rework, better throughput, reduction of energy consumption and waste, and a better product quality. This learning system is based on learning Bayesian networks, and takes advantage of the workers feedback by feeding back their skills on defect classification.

KPI
KPI-CL-1: Probability of faulty classification of a defect. (Target: ≤8%).
KPI-CL-2: Time needed for inline defect identification and classification. (Target: < process cycle time).
KPI-CL-3: Success rate of closed-loop process optimization. (Target: ≥ 90%).

Major Outcomes	[MO19] An identification and classification sw for major joining process defects. [MO20] A combined worker-robot sw-assistance tool for fast geometrical defect localisation. [MO21] A closed-loop optimisation algorithm for the inline adaptation of process parameters.

(O5) Two TRL 7 integrated prototypes: one for defect analysis and one for defect reworking.

Ambition: The perception and cleaning modules with a robotic platform will be integrated to produce the two prototypes of SR and CR that will be able to interact by exchanging information on the defects, to operate in presence of workers. The system will also be endowed with the necessary HRI to collaborate with human operators, e.g. to use the SR/CR solo with the humans performing the cleaning operation/defect annotation.

KPI
KPI-INTEGRATED-1: The two prototypes will be deployed in two distinct work-stations and will successfully carry out defect analysis and reworking in sequence.

Major Outcomes	[MO10] A completely integrated prototype for defect analysis. [MO11] A completely integrated prototype for defect reworking.

SSH Objectives

(O6) A human-centred approach to human-robot collaboration.

Ambition: The ambition is to enable sustainable transition towards human-robot collaboration in manufacturing through **understanding of human experience, motivation, and behaviour.** To do this, the system as a whole, must be perceived as **easy to use**, **reliable**, **safe** and **trustworthy** by all stakeholders. Not only must the workers be able to use it but embrace it. Unfortunately, the typical focus in automation ignores the need to consider human motivation, and readiness for change. By true integration of the human perspective, including change in mindset and behaviour, we will design the human-collaboration system to **promote upskilling**, helping workers to **advance their career into roles working with robots** (e.g humans instruct the robots, supervise their operations, share their spaces and in some cases, engage with the robots in direct forms of collaboration). We aim to move away from the current trend of automation as “technology push” towards “value based human-robot collaboration” derived from human needs, wants and desires. To this end, the MAGICIAN project adopts a human-centred approach, to understand the problems from the point of view of the individual, the collective and society. We will involve researchers, developers, workers, managers and union representatives, through iterative, creative and user-centred methods for ideation, prototyping, testing and implementation in real contexts to better align both the process itself and its outcomes; testing with users and stakeholders is done continuously to gradually move towards validated, satisfying human-robot solutions which are **desirable for use, safe, trustworthy, feasible to implement and societally viable**. Thus the human perspective is thoroughly integrated in the development of the MAGICIAN starting from the design of the system as a whole, down to the different interfaces between its different components and the human operators.

KPI

KPI-SSH-1: Number of stakeholder workshops (Target: > 8).

KPI-SSH-2: Number of testing (feasibility/ demo) activities (Target: > 8).

KPI-SSH-3: Number of stakeholders (workers, managers and union representatives) involved in the study, development and real-life trials of the human-robot collaboration system (Target: > 40).

KPI-SSH-4: Number of presentations at non-academic conferences within the area of manufacturing. Targeting manufacturing workers, governments, policy makers, decision makers and unions (Target: > 6).

Major Outcomes	[MO12] a human-robot collaboration system, understandable, usable, enabling workers to accomplish the desired tasks, and perceived as valuable by the stakeholders.. [MO13] a set of future guidelines and recommendations on human-centred design and human-robot collaborative systems, taking into account sustainability, ethical and social consequences to minimise negative impacts and maximise human acceptance: promoting interest and acceptance of human-robot collaboration in manufacturing. [MO14] novel interdisciplinary methodologies to allow transferability of good practice to increase the efficiency, effectiveness and satisfaction of human-robot collaborative systems, and to decrease non-adoption.

Demonstration Objectives

(O7) To demonstrate the two prototypes (see **O5**) in an operational scenario.

Ambition: We will set-up a demonstrator in the ALT premises. The demonstrator will be a realistic instantiation of the actual work environment and will reflect the same type of timing constraints. The demonstrator will be used to collect performance figures and for disseminating the results of the project. The technology deployed in the demonstrator will make for its easy replicability in other sites.

KPI

KPI-DEMO-1: Realism: the demonstrator will satisfy the production constraints.

KPI-DEMO-2: Accessibility. (Target: 2 months of physical accessibility and 4 months for remote accessibility).

KPI-DEMO-3: Number of business oriented visits. (Target: at least 100 business oriented visits).

Major Outcomes	[MO15] Description of the demo and video material usable for dissemination.

(O8) To expand scope and applicability of MAGICIAN via Financial Support to Third Parties (FSTP)**.**

Ambition: The consortium will define, launch and manage 2 open calls for proposal (FSTP) to select up to 10 SMEs/start-ups for implementation of ad-hoc experimentation aiming respectively at: 1) deepening and expanding the functionalities implemented in the project core pilots, 2) extending the applications of the intelligences embedded in the systems (AI) towards new use cases. The implementation of selected application experiments will be continuously monitored by the consortium partners in order to guarantee the appropriate use of the resources allocated, but also to extract and orient possible emerging exploitation opportunities.

KPI

KPI-DEMO-4: min 40 application proposals received within the 2 OCs

KPI-DEMO-5: min 12 month implementation period per selected experiment/application

KPI-DEMO-6: 2 Mln/EUR distributed via FSTP

KPI-DEMO-7: >3 possible exploitation opportunities identified based on the selected applications/experiments

Major Outcomes	[MO16] Application final results and potential exploitation opportunities

1.1.1. Relation to the Work Programme

Call Text	Addressed in MAGICIAN

Proposal results are expected to contribute to at least one of the following expected outcomes: […] Demonstrators able to show the added value of robotics and their performances in addressing challenges in major application sectors, *or in dangerous, dull, dirty tasks or those strenuous for humans or in extreme environments* […]. Systems able to show high levels of reactivity and responsiveness *and intelligibility when performing human-robot and robot-robot* interactions in major application sectors.	MAGICIAN will produce technologies to classify defects (**O1**) and to remove them (**O2**). Both tasks are executed in difficult environments and put a strain on human workers. The role of the human will shift toward instructing the system, supervising its operation and intervening only in the limited cases in which the robot fails to remove the defect. This will reduce the "physical" barriers of this particular work activity and address the first outcome. Our human-aware planning and control (**O3**) will also provide intelligible responses enabling seamless human-robot collaboration and creating a connection between welding and quality control **(O4**), thus contributing to the third outcome.
The proposals should be primarily application driven, with a concrete problem-solving approach, exploiting the most suitable robotics technologies at hand. The focus should be on real-world scenarios which can benefit in the short term from the technology and demonstrate substantial impact on the chosen application, also taking into account the maturity of the technologies which can solve the problems at hand.	The project development will be guided by a clear recognition of the needs of our industrial partners. The collection of data on the field, the discussion with workers, engineers and unions, will provide us with clear guidelines on how to develop our solutions. The most important pieces of the developed technology **(O1,O2,O3)** will build on the strong expertise of the partners, on their portfolio of mature technologies, and will be integrated on working prototypes (**O5**). We will define clear KPIs to measure the benefits of the project outcomes, and we will measure them in realistic scenarios (**O7**). The use of learning technologies **(O1,O2)** and the development of tools enabling knowledge transfer **(O3)** will enable a quick deployment of the system. This will allow us to prove the generality of the solution (**O8)**.
A human-centred approach will be key in all proposals, with deep involvement of the workers, professionals and other relevant stakeholders including experts in human-centred design, work safety, ergonomics, …. They will closely collaborate with the technology providers and integrators.	LU has a recognised international expertise in the area of human-centred design and LU will be actively involved in the development of the MAGICIAN system in order to contribute to systemic changes that will result in smart, more efficient, and safe human-robot collaboration (**O6**). We will devote specific attention to the human workforce perception of the system intelligibility and trustworthiness.
Proposals are requested to dedicate ≥ 20% of their requested amount for FSTP to support SMEs/Start-ups [...] The consortium will provide technical support […] to the selected SMEs/start-ups acting as technology providers to demonstrate the added value of their solutions	MAGICIAN will adopt the FSTP scheme to engage with new partners with two objectives: enriching the portfolio of technologies usable in our platform with new components (e.g., for sensing, and manipulation) that can further enhance the performance on the use-case, finding additional use-cases that can show the generality of our technology.

1.1.2. Positioning of the Project / TRL Move / R&I Maturity

Key Technology (KT) and TRL move	Obj.	Starting TRL	Final TRL
KT 1 – Passive and active vision algorithms for industrial cobots	**O1**	4	7
KT 2 – High precision 3D object scanning and 4D pose estimation infrastructure	**O1**	5	7
KT 3 – Wearable interfaces and touch sensors	**O1**	4	7
KT 4 – Impedance and force control methodologies	**O2**	4	7
KT 5 – End-Effector modular interfaces	**O2**	4	7
KT 6 – Motion Planner for 2D and 3D spaces	**O3**	4	7
KT 7 – Model Based Task Planning	**O3**	4	7
KT 8 – Human motion tracking and prediction	**O3**	5	7
KT 9 – Algorithms for human skills transferring	**O1,4**	4	7

1.2. Methodology

There is a relatively large class of manufacturing applications, in which the harsh working conditions justify the adoption of robots. The main challenges are: 1. the high level of skills required by some checking and manual precision work operations are not easily developed in a robot surrogate, 2. the constant interaction required between humans and robots generates conflicting safety/productivity requirements, 3. the strict cooperation between humans and robots has profound implications on the psychology of the workers and on the organisation of the production. As discussed below, our methodology takes on these challenges by an ambitious approach tapping into the potential of several disciplines: AI, Robotics and Social Science and Humanities.

1.2.1 Application scenarios and assumptions

The MAGICIAN use-case is a representative paradigm of a much larger class of applications sharing some common traits and a few basic assumptions. We consider manufacturing scenarios where the production is organised in phases (e.g., an automotive assembly line). At some point, a semi-finished product needs to be prepared for the final operations, which will determine its aesthetic appearance. The residual defects (especially the most visible) have to be detected and reworked. The rework operation is particularly demanding from the physical point of view because of the weight of the tool, of the vibrations received by the user during the process, and of the unsafe conditions in which the operation is executed. We make the following assumptions:

Assumption 1 [A1]: the workers performing the defect analysis use a combination of visual and tactile sensing. Their level of skills and experience is sufficient to make the probability of a misclassification negligible. We assume that the human operators are "near-perfect" sensors: when a defect falls within their area of attention it is correctly classified. Indeed, as confirmed by TOFAS, the defects considered in this project are clearly visible to the end-user of the product, thus they will be *a fortiori* evident to a trained worker.

Assumption 2 [A2]: the semi-finished pieces have a complex and varied geometry and they have to be reworked in a small time. Currently, the use of human-operated grinding/polishing machines outperforms standard robot-operated grinding end-effectors, which operate with low dexterity and constrained angles and forces.

Assumption 3 [**A3]**: human workers are ready to accept the collaboration with robots (i.e., to train and supervise their operations) if the process is developed around their needs and if their concerns are carefully recognised and translated into design specifications.

A1 allows us to base a *learning phase* on the observations collected from a relatively low number of humans avoiding the need of a third (independent) measurement system that validates the correctness of their choices. **A2** underlies the development of an innovative robotic technology with the use of human tools, supported by a learning method to acquire the human skills, which could have a strong impact on future development of cobot technologies in its own right. **A3** will give prominence to the analysis of the human aspects as a first class citizen in the design of the system. A concise description of the use-case is now useful to show a concrete instantiation of these ideas.

1.2.2. The automotive use case

In modern automotive factories, the car-body is produced through the following phases: 1) Stamping: the metal is cut and stamped in order to produce the different parts of the body. 2) Body in White: welding - the different parts are welded together to form the chassis. 3) Painting: the welded body is polished, sealed, prepared, then different layers of primers and paints are applied. 4) Assembly: the other components are mounted on the body. Our use-case will be on the preparation of the body parts for the painting phase, and specifically, on the reworking of imperfections on the chassis that could result from the welding phase (weld spatters) and that would degrade the final quality. This activity is currently carried out by a team of specialised workers that identify possible imperfections through visual-tactile inspection. The workers rework the detected imperfections and check the final quality. The intervention has to be proportionate to the severity of the defect and to its location., e.g., an imperfection in the back side of a door is not nearly as critical as one in the most visible areas of the cart can be critical. The workstations related to these phases are depicted in Figure 4 for the current production process of TOFAS. Specifically, station 102 is located right after the spot-welding phase.

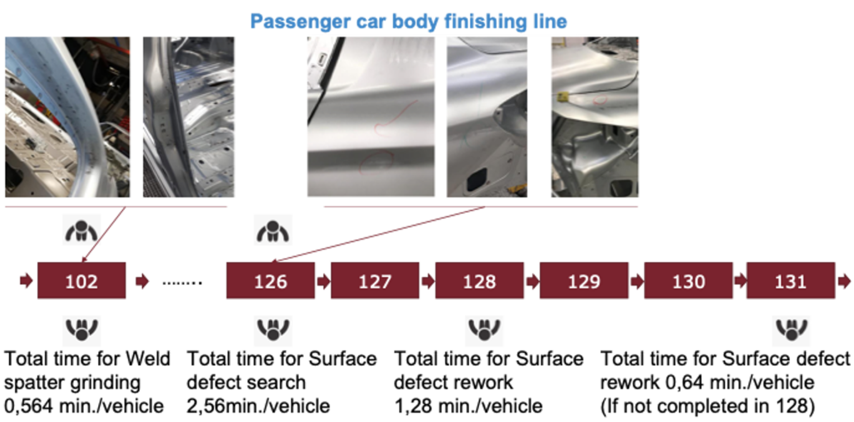


Figure 5: Aesthetic defects

Two operators inspect the body and remove the spatters by grinding all the visible areas. Particularly important is the reworking of the splatters in the door area, because in the next phases the doors will be mounted. In the stations from 103 to 125, the engine hood, front and rear doors, fenders and decklid parts are assembled and aligned to the body. Very important for our purposes is station 126, where under special lighting conditions two operators look for any residual spatter and for other defects, such as dents, scratches and indentations using a marker to pinpoint them. These defects are revised and repaired at station 128. If this operation cannot be performed within the cycle time, the body is marked as "nok" (not ok) and it will be moved to a side repairing line at station 131. The activity at station 102 is particularly demanding from the physical point of view: the defects are relatively gross and easy to identify, they are localised in a precise area but the time allocated for their reworking is very short. On the contrary, the activity at station 126 and 128 requires fine skills: the defects are marked (station 126) and removed (station 128) by specialised operators; they have to quickly identify the area of intervention assessing the severity of the damage and its visibility in the final product. With reference to the considered use case, the application of the MAGICIAN technologies will lead us to the following scenario: 1. when the car-body reaches station 102, the areas of interest in the proximity of the doors will be quickly scanned by an SR, closely followed by the CR that removes the defects; 2. in station 126, the sensing operations will be performed by a team of SRs, which will scan the surface of the body and apply a marker (e.g., by an inkjet head) related to the type and severity of the defect, 3. in station 128, one or more CR will operate to remove some of the defects, while the human operators will operate on other defects.

1.2.3. Methods contributing to O1.

Robust autonomous detection and classification of (sub)millimetric defects: the synergistic interplay of visual and tactile data (see **O1**) is what differentiates the defect detection module of MAGICIAN from existing slow and not robust commercial solutions that rely on a full car-body scanning with a single sensor [13] [14] [15]. In MAGICIAN, as soon as the piece enters the cell devoted to defect detection, a far-off, initial visual inspection using a special light and multispectral sensors identifies the candidate areas for defects, generating a mask identifying the pixels and generating a confidence level for each. Defects with high confidence will be queued for processing by the CR without any further analysis. Detections with low confidence will be prioritised based on location on the car body for a close-up visual inspection with additional sensors (e.g. depth sensor). Depth information is crucial for identifying some classes of defects (e.g. small dents, scratches). Finally, the regions with high severity scores (e.g. visible by the end-user) that have low confidence will be queued for tactile inspection. In tactile inspection, the robot will be commanded to contact those areas, and start “touch and feel” (i.e., sliding its end-effector) on the surface in order to collect tactile data, i.e., force and acceleration measurements generated by the interaction of an instrumented tool with the chassis. To this aim, the SR end-effector will be equipped with a haptic interface embedding force and acceleration sensors capable of generating signals that accurately represent the texture of the contacted surfaces. Piezoelectric PVDF[16] sensors could be used to improve the texture sensing and acquire data sufficiently descriptive of (sub)millimetric defects. The tactile interfaces required in MAGICIAN will rely on state-of-the-art wearable haptic technologies, and the IIT will develop reliable, accurate and responsive haptic solutions [17]. Static, force-based signals relying on arrays of tractors and dynamic, acceleration-based signals will be acquired to better capture the nature of the defects[18]. To retrieve meaningful measurements, a preliminary calibration of the robotic sensing system will be conducted by acquiring signals related to the interaction of the robot with a non-damaged chassis (baseline), and these signals will be used as reference. Synchronised, dynamic mapping of multi-modal data (acceleration, force and visual) will be established between baseline and newly acquired data. Moreover, proper policies to autonomously scan the chassis will be devised.

Learning human skills. One of MAGICIAN’s highest ambitions is transferring human ability in searching defects to a robotic platform. This can be done by developing active sensing[19] of the surfaces, i.e., controlling the robot

[13] https://www.itwm.fraunhofer.de/en/departments/bv/quality-assurance-and-optimization.html

[14] https://robovis.de/index.php/products/robopicker

[15] https://www.zeiss.com/metrology/solutions/car-body.html

[16] Yi, Z. et al.Zhang, Y., Peters, J. Bioinspired tactile sensor for surface roughness discrimination. *Sensors and Actuators A: Physical*, 255:46-53, 2017

[17] Pacchierotti, C., et. al. Wearable Haptic Systems for the Fingertip and the Hand: Taxonomy, Review, and Perspectives. *IEEE Transactions on Haptics*, *10*(4): 580–600, 2017

[18] Kappassov, Z., Corrales Ramon, J.A., Perdereau, V. Tactile sensing in dexterous robot hands - Review. In *Robotics and Autonomous Systems*, *Elsevier*, 74:195-220,2015

[19] Seminara, L., et al. Active haptic perception in robots: a review. In *Front. Neurorobot*, 13:53, 2019

motion to look for additional data revealing the presence of a defect or the defect features. We will provide the robot with this ability, by implementing multi-modal Learning from Demonstration on movements performed by human workers. If successful, this approach will allow us to extract the workers' expertise (which, based on A1, is the main avenue to obtain an accurate analysis in a short time). The fall-back solution will be to exploit Bayesian approaches[20] or to scan the surface in heuristic fashion with a force/velocity hybrid controller to avoid exerting excessive forces. In order to collect a rich dataset, the workers will wear an instrumented glove equipped with fiducial marker, acceleration, piezoelectric, force and tactile sensors. Visible light (RGB), depth and multispectral images of the defect and tactile data related to the shape of the defect will constitute parts of the datasets as well as annotations (i.e defect class, severity, etc) provided by the workers. For the visual defect detection and classification, we will leverage the knowledge gained from traditional methods[21] [22]and adapt state-of-the-art ANN[23] architectures to the specific requirements of the defect detection[24] [25] tasks of the project. We will optimise for inference speed, accuracy, and the number of examples used for training. As MAGICIAN is gradually deployed and more data are made available, semi[26] and unsupervised[27] techniques will be evaluated as well as techniques that can be robust using RGB input only. The latter will broaden the adaptability and applications of the defect detection module. However, there are limits to the vision based defect detection. This is why the sense of touch plays an important role in MAGICIAN, enabling us to distinguish object textures by exploiting properly-generated haptic cutaneous[28] cues. Mechanoreceptors, indeed, are effective means to convey exploratory information on the environment[29]. To encapsulate the workers' expertise and transfer the knowledge to robots, three different haptic learning tasks will be carried out: 1) defect detection 2) movements for defect inspection 3) defect classification. Concerning 1) and 3), an RGB picture of the defect and tactile data related to the shape of the defect will constitute the vector of the features combined according to a sensor-fusion approach or particle filtering[30]. Regarding 2), the tracked motion of the operator hand will be exploited together with tactile data to have information on the applied forces for defect inspection. Concerning 1) and 3), a supervised learning approach will be implemented, while 2) is the most ambitious learning task that we will pursue, and will rely on multi-modal Learning from Demonstration. In such a way, active sensing of surfaces will be implicitly achieved, because the knowledge of the robot will encapsulate both exploratory motion primitives and forces to apply depending on the defect shape. The haptic technology for recording the human-fashion of accomplishing defect detection will rely on state-of-the-art wearable haptic technologies[31], and will be especially targeted for realistic rendering of the interaction forces experienced during inspection and for user comfort and ergonomics.

1.2.4 Methods contributing to O2. The CR will consist of a collaborative arm whose end-effector will be attached to a grinder for defects reworking. Properly designed controllers will be implemented to safely regulate the applied

---

[20] M.-Hernandez, et al. "Active sensorimotor control for tactile exploration." *Rob. & Auton. Sys.* 87 (2017): 15-27.

[21] A. Kumar and G. K. Pang, "Defect detection in textured materials using gabor filters," *IEEE Transactions on Industry Application*, vol. 38, no. 2, pp. 425–440, 2002

[22] A. Tosca, et al. "Development of a three-dimensional surface imaging system for melanocytic skin lesion evaluation", *Journal Biomedical Optics,* 18 (1), 016009, January 07, 2013

[23] F. Gouidis, et al., "A Review on Intelligent Object Perception Methods Combining Knowledge-based Reasoning and Machine Learning", In *AAAI-MAKE*, 2020

[24] Weimer, D. et al. "Design of deep convolutional neural network architectures for automated feature extraction in industrial inspection." *CIRP Annals* 65.1 (2016): 417-420.

[25] Roth, Karsten, et al. "Towards total recall in industrial anomaly detection." *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)*. 2022.

[26] Božič, Jakob, Domen Tabernik, and Danijel Skočaj. "Mixed supervision for surface-defect detection: from weakly to fully supervised learning." Computers in Industry 129 (2021): 103459.

[27] Zavrtanik, Vitjan, Matej Kristan, and Danijel Skočaj. "DSR–A dual subspace re-projection network for surface anomaly detection." European Conference on Computer Vision (ECCV). Springer, Cham, 2022.

[28] Holmes E, Hughes B, Jansson G. Haptic perception of texture gradients. In *Perception,* 27, 1998

[29] Johansson, R. S., and Vallbo, A. B. Tactile sensibility in the human hand: relative and absolute densities of four types of mechanoreceptive units in glabrous skin. *The Journal of Physiology*, *286*: 283–300, 1979

[30] Zhang L. and J. C. Trinkle, J.C. The application of particle filtering to grasping acquisition with visual occlusion and tactile sensing. In *2012 IEEE International Conference on Robotics and Automation*, 3805–3812, 2012

[31] Prattichizzo, D., Chinello, F., Pacchierotti, C., and Malvezzi, M. Towards Wearability in Fingertip Haptics: A 3-DoF Wearable Device for Cutaneous Force Feedback. *IEEE Transactions on Haptics*, *6*(4): 506–516, 2013

force. The current industrial trend is to produce metallic items requiring an accurate finishing before commercialisation.Thus autonomous grinding has been studied in literature. Whilst in many manufacturing areas multi-axis CNC have become the mainstream approach, in the automotive industry the cost and the lack of flexibility of CNC grinding machines discourage their use. Hence, robots are an appealing alternative: large workspace, flexibility and powerful sensing for easy adaptation to changing conditions (e.g., presence of humans in the area, variable shape of the defect to treat)[32]. The main challenges related to robot grinding are[33]: accuracy control (estimating the rigid transformation between the tool and the robot base in the face of system variability); compliance control (how to realise the force/position coupling to ensure a precise force control along the direction orthogonal to the surface while precisely tracking accuracy along the tangential plan); chattering of the machine limitation/suppression (chattering can reduce the quality of the grinding[34], besides disrupting the system calibration). Various force control techniques have been realised for industrial systems[35] [36]. To this aim, leveraging IIT expertise, we will explore and implement different control solutions[37] [38] to effectively ensure reasonable contact force, guaranteeing also the safety of the grinding process[39]. To accomplish chattering suppression, the grinder will be connected to the robot through a specific hardware interface that will allow it both to adapt to the car-body surface, and adequately reduce the vibrations on the workpiece surface: pneumatic artificial muscle[40], damping compliant[41] or series elastic actuators[42] will be investigated to retrieve the best fit-to-purpose solution. Finally, in control design we will explicitly consider the problem of avoiding unnecessary disk-wear[43] using standard models developed in the literature[44]. Our primary goal is to develop an end-effector and a package of control software solutions allowing the exploitation of standard man-operated grinder, in order to learn and mimic the cleaning policy of skilled workers (which, based on A2, are the most effective to carry out the grinding work quickly and accurately). A fall-back solution will be to define heuristics to carry out the cleaning operations based on the direct observations of the workers' task execution.

Learning human skills: MAGICIAN will take inspiration from a few recent papers. Maric et al.[45] recently proposed an LfD for delicate sanding, relying on a compliance control algorithm mimicking the motion of human hands. We will apply similar techniques for compliance control but the teaching activity will crucially rely on the exploitation of a properly-instrumented manual grinder, capable of providing the teachers/workers with the freedom of performing the movements that they usually do when accomplishing the grinding task. Directly related to

---

[32] A. Klimchik, et al., Efficiency evaluation of robots in machining applications using industrial performance measure, Robot. Comput. Integr. Manuf. 48 (2017) 12–29.

[33] Zhu, D, et al. "Robotic grinding of complex components: a step towards efficient and intelligent machining–challenges, solutions, and applications." Rob. & Comp, -Int. Manufacturing 65 (2020): 101908.

[34] Zhu, D., Xu, X., Yang, Z., Zhuang, K., Yan, S., and Ding, H. Analysis and assessment of robotic belt grinding mechanisms by force modeling and force control experiments. In *Tribology International*, 120: 93–98, 2018

[35] Lopes, A. and Almeida, F. A force-impedance controlled industrial robot using an active robotic auxiliary device, In *Robotics and Computer Integrated Manufacturing*, 24:299–309, 2008

[36]Mendes, N. and Neto, P. Indirect adaptive fuzzy control for industrial robots: A solution for contact applications. *Expert Systems with Applications*, 42(22): 8929–8935, 2015

[37] Balatti, P., Kanoulas, D., Rigano, G.F., Muratore, L., Tsagarakis, N., and Ajoudani, A. A self-tuning impedance controller for autonomous robotic manipulation. In *IEEE Int. Conf. on Intel. Robots and Systems*, 5885-5891, 2018

[38] Hoffman, E.M., et al.. Multi-priority cartesian impedance control based on quadratic programming optimization, In *IEEE Int. Conf. on Robotics and Automation*, 309-315, 2018

[39] Xie, X., and Sun, L. Force control based robotic grinding system and application. In *2016 12th World Congress on Intelligent Control and Automation*, 2552–2555, 2016

[40] Wang, Q., Wang, W., Zheng, .L., and Yun, C. Force control-based vibration suppression in robotic grinding of large thin-wall shells. In *Robotics and Computer Integrated Manufacturing*, 67:1–12, 2021

[41] Kashiri, N., Medrano-Cerda, G. A., Tsagarakis, N., Laffranchi, M., and Caldwell D.G. Damping control of variable damping compliant actuators, In *Proc. Int. Conf. Robot. Autom.*, 850–856, 2015

[42]Roozing, W., Ren, Z., and Tsagarakis, N. An Efficient Leg with Series–Parallel and Biarticular Compliant Actuation: Design Optimization, Modeling, and Control of the eLeg. *Int. J. Robotics Res,* 2019

[43]Linke, B.S. Review on grinding tool wear with regard to sustainability. J. of Manuf. Sci. and Eng. 137(6), 2015.

[44] Srivastava, A. K., B. J. Ulrich, and M. A. Elbestawi. "Analysis of rigid-disk wear during robotic grinding." *International Journal of Machine Tools and Manufacture* 30.4 (1990): 521-534.

[45] B. Maric, A. Mutka and M. Orsag, "Collaborative Human-Robot Framework for Delicate Sanding of Complex Shape Surfaces," in *IEEE Robotics and Automation Letters*, vol. 5, no. 2, pp. 2848-2855, April 2020.

MAGICIAN is the work of Ng et al.[46], where motion primitives for specific machining operations are learnt by exploiting an instrumented grinder. Our learning framework for acquiring the workers' skills will consist of : *i)* sensorised grinder; *ii)* demonstrations of task execution from expert workers; *iii)* data acquisition system; *iv)* machine learning-based algorithm. Leveraging IIT expertise on wearable devices, we will instrument a commercial grinder with a force/torque sensor to perceive the interaction forces during cleaning operations; IMUs and fiducial markers will be used to track the pose of the device over time. To acquire raw data related to the grinding task, expert users will be asked to perform grinding operations on the car-body. For data collection, two strategies have been identified. In the first one (denoted A hereafter), data will be acquired by recording the actions of expert users, who will perform firsthand a regular grinding operation employing the sensorised manual tool. In the fall-back solution (denoted with B hereafter), data will be collected by guiding the CR in kinaesthetic teaching mode with gravity compensation. In both the cases A and B, the pose of the tool and the interaction forces exerted on the chassis will be collected. Solution A guarantees a more natural, usual way to perform the task; however, the sensed forces will be strongly affected by noise and vibration due to the highly-vibratory motion of the grinding tool. Vice versa, in solution B, less noisy signals can be acquired, since position and force signals would be directly tracked by the robot. Before feeding the machine learning algorithm, data pre-processing will be required to filter out the noise (mostly due to vibrations) injected in pose and force data. Then, to transfer the skills from humans to robots, we will leverage state-of-the-art machine learning techniques. Multi-modal and multi-task learning can be obtained by combining demonstrations with GAN[47]. Furthermore, the exploitation of visual information will increase the robustness[48] of the cleaning operation, and can be used in synergy with force data[49]. Moreover, explicit mathematical constraints based on the defect tomography (retrieved via visual and tactile data) will be injected into the learning problem formulation to border the grinding action in areas surrounding the defect.

1.2.5. Methods contributing to O3. Our robotic platform will consist of four main components: task scheduling, motion planning, motion control, and human detection and tracking. In addition, we will define a software architecture and develop configuration tools for easy deployment of the system. The **task scheduling problem** can be seen as an optimisation problem in which the cost function is the timespan of the sensing or cleaning activities, and the constraints are given by the use of a finite number of resources (the robots deployed in the cell), by the potential limit of using two resources in areas that are too close, and by the time needed to operate on each identified point. The problem has a probabilistic nature. For instance, for the sensing tasks, the areas where the defects are more likely to be can be estimated from statistical analysis or from a preliminary visual scan from a distant point of view and the hints coming from the welding phase (O4). Likewise, the time needed to remove a defect can change according to its type and severity. We will cast the problem either as a Partially Observable Markov Decision Process or as a classical planning problem depending on the precise definition of the requirements. The resulting complexity of the problem will have to be sufficiently low to permit the real-time execution of tools like STORM (https://www.stormchecker.org/) or OPTIC[50]. As a possible alternative, we will also consider the formalisation of the problem through the formal setting of Optimisation Modulo Theory[51]. For this type of solution, we will adapt existing solvers such as OptiMathSAT (https://optimathsat.disi.unitn.it/). For **motion planning**, our main challenge is to make the operation of the robot compatible with the presence of humans. The standard strategy is to reduce force and speed of the robot whenever a human enters into the workspace. Our approach is to use a human motion predictor that allows the robot to compute the probability of an accident in an imminent future as a function of the motion choice. This way it is possible to set-up the motion problem as an optimisation of a performance metric subject to the probability of an accident being lower that a specified margin.

---

[46] Ng, W. X., et al. "Programming robotic tool-path and tool-orientations for conformance grinding based on human demonstration." In *IEEE/RSJ International Conference on Intelligent Robots and Systems*, 1246-1253, 2016

[47] Hausman K., et.al. . Multi-modal imitation learning from unstructured demonstrations using generative adversarial nets. In *Advances in Neural Information Processing Systems,* 2017

[48] Levine, S., Finn, C., Darrell, T., and Abbeel, P. End-to-end training of deep visuomotor policies. *The Journal of Machine Learning Research*, 17(1):1334–1373, 2016

[49] Lee, M. A., et al. Making sense of vision and touch: Self Supervised learning of multimodal representations for contact-rich tasks. In *2019 International Conference on Robotics and Automation (ICRA)*, 8943–8950, 2019

[50] J. Benton, et.al.: Temporal Planning with Preferences and Time-Dependent Continuous Costs. ICAPS 2012

[51] F. Imeson and S. L. Smith. An SMT-based approach to motion planning for multiple robots with complex constraints. *IEEE Transactions on Robotics,* 35 (3):669–684, 2019

We have successfully implemented this idea in the context of mobile robotics[52]. In MAGICIAN, we will apply a sampling based approach to constructing a probabilistic roadmap (PRM), where nodes are reference configuration of the robot and links are associated to transitions that can be taken avoiding unacceptable configuration. The PRM will be constructed offline, solving for each transition an optimal control problem that accounts for time and for the level of energy spent. During the execution, when the prediction on the human motion are available, we will decorate the transitions with a different information related to the probability of having an accident, estimated by motion models and empirically evaluated with virtual reality tools[53]. Therefore, the generated path will be the result of an optimisation problem accounting for the time to reach the objective, for the energy spent and the probability of having an accident. In a similar way, we will integrate a strategy into the motion planner for viewpoint scheduling that can maximise the probability of producing a correct visual assessment of the defects. This result will be achieved estimating the configurations of the end effector associated with the viewpoint that produces a high quality evaluation with a high probability[54] and increasing the reward associated with these points in the PRM. The problem of **human detection[55] and tracking** is very well known in the literature. The challenge here is to make the solution efficient, reliable and robust. At the same time, our human aware motion planner requires the possibility of making reliable predictions for the human's position. To this end, we will apply to robotic manipulation the the technique successfully developed for mobile robots based on the Social Force Model[56] [57] The motion controller will be developed by integrating off-the-shelf controllers with external modules to manage the interaction with the car-body surface. These modules will be used as an active sensing solution for the tactile exploration (**O1**) and as a force/compliance solution (**O2**). Even if the event "having an accident" is tolerated at the motion planning level, we will have a continuous detection of the human position that will trigger an immediate reaction at the motion controller level in the imminence of a possible collision.
As regards the **software infrastructure,** the most important task related to the integration of the two prototypes (CR and SR) along with the different services they need is to construct a suitable software infrastructure for the different components to interact with each other and use the hardware resources of the system. Our solution will be based on the adoption of Linux (endowed with real-time patches: https://wiki.linuxfoundation.org/realtime/start) at the OS layer, and of ROS 2.0 at the middleware level (https://docs.ros.org/). This combination of solutions will allow us to combine a good level of portability with low latency and real-time performance. Much care will be given to modularity in software design and, in the adoption of RobMoSys standard patterns, to foster the creation of an open-source MAGICIAN ecosystem. The purpose of the **configuration tool** is to find the optimal system settings in new use cases. Based on an initial data collection from a new use case, the tool can leverage unsupervised learning techniques to find comparable use cases from previous applications. From this set of use case configurations, a combination of supervised learning techniques (such as k-nearest neighbours) and modern deep learning based approaches can be used to find the optimal configuration[58] [59].

1.2.6 Methods contributing to O4. For the **identification of the root cause** of a defect, statistical and physical process models of the welding process will be combined with deep learning methods to reveal the hidden information within the welding signals. To do so, the existing process signals current and voltage will be recorded in real time. For a typical automotive welding process, typically 6.000 samples need to be processed (300ms welding time) inline and subsequently processed. The postprocessing includes the calculation of derived signals, e.g. resistance and energy and proper signal analysis methods such as Fast Fourier Transformations (FFT). For the statistical and physical models, a flexible model architecture is envisaged to include further data (e.g. welding force) if applicable. In order to provide the relevant welding data, realtime access of the signals need to be

---

[52] Bevilacqua, P. , et al. "Reactive planning for assistive robots." *IEEE Robotics and Aut. Let* 3.2 (2018)
[53] Asaula, Ruslan, Daniele Fontanelli, and Luigi Palopoli. "Safety provisions for human/robot interactions using stochastic discrete abstractions." *2010 IEEE/RSJ Int. Conference on Intelligent Robots and Systems*. IEEE, 2010.
[54] M. S. Ramanagopal,et.al, "A Motion Planning Strategy for the Active Vision-Based Mapping of Ground-Level Structures," in *IEEE Trans, on Autom, Science and Eng,*, vol. 15, no. 1, pp. 356-368, Jan. 2018.
[55] A. Qammaz and A.A. Argyros, "Towards Holistic Real-time Human 3D Pose Estimation using MocapNETs", In *British Machine Vision Conference (BMVC 2021), (to appear)*, BMVA, Virtual, UK, November 2021
[56] Helbing, Dirk, Peter Molnar. "Social force model for pedestrian dynamics." *Physical review E* 51.5 (1995): 4282.
[57] Antonucci, A., et al. "Humans as Path-Finders for Safe Navigation." *arXiv preprint arXiv:2107.03079* (2021).
[58] Zhai, Xiaohua, et al. "S4l: Self-supervised semi-supervised learning." *Int. Conf. on Comp. Vision.* 2019.
[59] Ohri, Kriti, and Mukesh Kumar. "Review on self-supervised image recognition using deep neural networks." *Knowledge-Based Systems* 224 (2021): 107090.

guaranteed by the welding control. Therefore, proper interfaces need to be developed. All these original and derived process data together with joining process parameters form a set of input parameters for MAGICIAN algorithm, output of which is inference about unknown perturbing factors, and defects, such as spatters. This diagnosis answers the main question on the origin of a defect. The next step of the inference algorithm is to answer on a proper mitigation action. I.e., which process parameters should be tuned to react on perturbation factors and defects, thus closing the automatic control loop. In both inference steps we will rely again on the combination of deep-learning algorithms and expert knowledge of workers. Deep learning is used to analyse huge amounts of historical data for deriving the best fitting welding control strategy in general. However, the specific challenges of a certain manufacturing setup are best known by the workers. They do have knowledge on best practices in the event of a specific failure or malfunction. The inference of MAGICIAN algorithms will be compared with this expert knowledge of workers and this result can be used for continuous Bayesian Networks learning process.

The **welding process optimization** itself is based on the already existing control algorithms such as KSR (constant current regulation), IQR (adaptive quality control) and IQf (reference-based control). Depending on the use-case identified, the proper algorithm will be selected. Proper process adoption methods will be applied. The human worker will be kept in the loop before and during applying an optimisation in order to make the decision support as transparent as possible.

1.2.7. Methods contributing to O6. The MAGICIAN project focuses on a **human-centred design** strategy that aims to drive the progress of automation and human-robot collaboration in manufacturing through empathy, creativity, and design. This approach requires **input from all key stakeholders**. The human dimension is necessary to develop human-robot collaboration systems that are **sustainable, accepted and adopted** by the individual and the collective, and for understanding the supporting and hindering factors of behavioural change. It is about understanding and starting from the stakeholders needs and wants, when we create robotic technologies and experiences that last in the long run. This means that the **human is at the centre** of the **iterative development process**. Conducting user research is the foundation of all human-centred design. It is only when we understand the **needs and goals of the stakeholders** that we can create solutions that really help them[60]. To make this possible, **ethnographic research/field studies** are initially conducted in the natural settings of the workers to identify both logistical and emotional needs of workers. We need to understand the current situation before robotic technologies to reproduce human operations are deployed (baseline study) and follow the transition of work and work processes when the robotic technologies to reproduce human operations are implemented and put to use. Furthermore, desk-top research is carried out to establish what is already known. Based on this data, the next step is to imagine and create robotic technologies, interactions and ideas that meet these needs**. Co-design** is crucial, as one of the most important aspects of the MAGICIAN project is worker- and organisational engagement and involvement. The MAGICIAN project will involve all stakeholders related to automation/robotic technologies in car manufacturing. Workers, managers, and union representatives will be working together in the development process by participating in workshops and providing insights and impressions (**co-design/participatory design**), with the ultimate aim to better align both the process itself and its outcomes with the values, needs and expectations of the stakeholders. This includes promoting gender equality, developing automation/ robotic technologies designed for and with society that are ethically acceptable and socially desirable[61]. Commercial and system engineering considerations will also be considered through the direct involvement of ALT as the system integrator During the workshops, robotic prototypes will be developed and refined. In fact, there is no more effective way to communicate or validate an idea than to create prototypes[62]. With prototypes, everyone can see and feel what a solution will look like and work. It will help us to prototype and test our idea and support our work towards **workable solutions** that are **accepted** by the users/workers and the management. In the last phase, the robotic technologies will be evaluated and refined in the natural settings (e.g., at the car manufacturer). Thus, the project outcomes will generate research and human-centred processes in automation/robotics that considers effects and potential impacts on the workers and society. Thus, the MAGICIAN project has the potential to lead to **human-robot collaboration breakthroughs**.

---

[60] Shneiderman B. Bridging the gap between ethics and practice: Guidelines for reliable, safe, and trustworthy Human-Centered AI systems. ACM Transactions on Interactive Intelligent Systems (TiiS). 2020;10(4):1-31

[61] Shneiderman B. Human-centered artificial intelligence: Three fresh ideas. *AIS Trans. on HCI*. 2020;12(3):109-24

[62] Höök K, Löwgren J. Strong concepts: Intermediate-level knowledge in interaction design research. A*CM Transactions on Computer-Human Interaction (TOCHI)*. 2012;19(3):1-18

1.2.8. Methods contributing to O8. An **accessible, simple and lean open call design will be implemented to facilitate the submission and selection of large amounts of well-focused proposals.** The MAGICIAN financial support scheme (FSTP) has been structured in 2 **open calls that will distribute up to 2M€ of funding to SMEs and startups. The stages and the main elements of the open call** (call for applicants, external evaluation, sub-grant agreement and implementation) will be designed **based on a fast-track scheme**, paying special emphasis to the **effectiveness of internal plus external evaluation** (1-2 months max) and fast **contract signature** (1 month max). In detail, under WP6, 2 open calls for proposals will be launched aimed respectively at 1) deepening and expanding the functionalities implemented in the project core pilots, 2) experiment the applications of the intelligences embedded in the systems (AI) towards new use cases. The following schema summarised the GANTT of intended OCs launch and implementation phases (full methodological details reported in the dedicated annex) illustrated in Figure 6. As concerns open call management, MAGICIAN will guarantee full GDPR-compliance (e.g. in the management of applicants and evaluators data), as well as fair and equitable selection process, preventing in particular any conflict of interest. All applicants (selected and non-selected) will receive a detailed feedback file (ESR-like format) explaining in details their achieved score and rationale in the different selection criteria (i.e. Excellence, Impact and Implementation), with recommendation on possible alternative opportunities for funding (where possible) and technical improvements possible. The selected applicants will sign a sub-grant agreement with MAGICIAN to fulfil the project's commitments, as well as the commitments required by the financial support scheme. During this stage, selected applicants will receive support to manage its signature in an appropriate manner. The proper development of the selected experiments during the implementation phase will be monitored by MAGICIAN partners (monthly monitoring call), with a view on preventing potential delays or major technical issues. Finally, the impact and exploitation potential of selected experiments will be ensured through ad hoc analysis implemented following EC EDIHs maturity assessment tool[63].

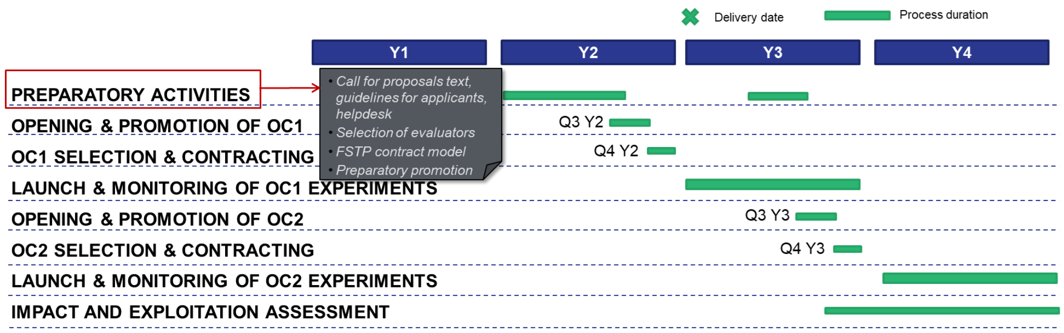


Figure 6. GANTT of intended OCs launch and implementation phases

1.2.9. Related Research and Innovation

- Cogimon (H2020, ICT-23-2014, GA ID: 644727), SOPHIA (H2020-ICT-2019-2, GA ID: 871237). The impedance and force control regulators developed here are the basis for KT4. Contribution to **O2**.
- CENTAURO (H2020-EU.2.1.1.5, Grant agreement ID: 644839). The modular interfaces and end-effector components developed within this EU project will be explored and adapted to develop the specialised grinding tool interfaces within the key technology KT5. Contribution to **O2**.
- Co4Robots (H2020-ICT-2016-2017, GA ID: 731869) and HOBBIT (FP7/2007-2013, GA ID: 288146). The Computer vision algorithms for robots operating in cooperation with humans (cobots) in industrial and home environments developed in this project will form the basis for KT1. Contribution to **O1**.
- I.C.HUMANS (HFRI-FM17C3-0091). The software and hardware solutions developed will enable 3D object scanning and 4D motion reconstruction, which is at the heart of KT2. Contribution to **O1**.
- GIraffPlus (FP7-ICT-2011-7, Grant Agreement ID: 288173), HOBBIT (FP7/2007-2013, Grant Agreement ID: 288146), INBOTS (H2020-ICT 28-2017, GA ID: 780073). The Human centred methodology/co-design applied in this project will be applied in MAGICIAN. Contribution to **O6**.
- WEARHAP (FP7-ICT-2011, GA ID: 601165): The wearable interfaces will be used for KT2. The state-of-art tactile technologies will be the base for fit-to-purpose wearable interfaces focused on proper rendering of interaction forces arising during inspections. Contribution to **O1, O2**.
- PICKPLACE (H2020-ICT-2016-2017, GA ID: 780488). The tactile interface and the grasping technology will be used in KT 5 and KT 3. Contribution to **O1, O2**.

[63] JRC & Tecnalia (2021), Digital Maturity assessment tool for European Digital Innovation Hub customers T0 Enterprises Questionnaire (v3.1).

- ACANTO (H2020-PHC.19.2014, GA ID; 643644). The human tracking technology and human aware motion planning will be used in KT 7 and KT8. Contribution to **O3**.

1.2.10. Interdisciplinarity of Methods. The development of the MAGICIAN solution will be a truly interdisciplinary effort. Interdisciplinarity will be at the basis of the system design, which will not be limited to a technical dimension, but will require an in-depth understanding of how to make the presence of the robots acceptable to humans and how to maximise the positive impact of the technology within the production cycle. At the technical level, the grand challenge beneath the project is understanding how to give intelligence flesh and bones, i.e., how to transfer into hardware devices and software the ability to sense different types of defects and treat them with the same level of sensitivity as a human. This challenge will require the convergence between different disciplines that lie at the foundation of modern robotic engineering: 1. mechatronic design, 2. sensing algorithms, 3. control design, 4. artificial intelligence.

Interdisciplinarity to achieve O1

Objective **O1** requires the integration of visual data with tactile data in order to detect and classify defects of different nature. Therefore, the activities leading to **O1** stay at the confluence of sensing technology, computer vision, haptic sensing and Artificial Intelligence (for the classification part).

Interdisciplinarity to achieve O2

Objective **O2** has a clear mechatronic component (the design of the end-effector), which is complemented by an essential activity of control design (for force control and suppression of vibrations) and artificial intelligence (i.e., learning the cleaning policy from the worker).

Interdisciplinarity to achieve O6

Human-centred design will drive the convergence between the understanding of human behaviour, change and diversity, with considerations to technical requirements and technological feasibility.

1.2.11. Social Science and Humanities (SSH). The complexity and the applied nature of addressing the challenges of human-robot collaboration systems call for **interdisciplinary efforts**. The gap between social science, humanities and technology development is still a weak point in many robotic projects. Indeed, while the focus of the project is on technology, the SSH perspective will contribute to an increased emphasis on what robotic solutions to reproduce human operations in car manufacturing 'does' (i.e., end values, trust/comfort, ethics, capabilities, and impacts on humans and working environments) in contrast to what it 'is' (i.e., requirements and functionality). In SSH, processes of design, implementation and use of technology are treated as sociotechnical processes[64] [65]. This means that technologies and the social contexts they are part of are understood as co-constitutive of each other. Thus, the application of robotic technologies to reproduce human operations is essentially a socio-technical activity, as everyday human-robot collaborative work practices involve interactions and communications among humans and robots in complex infrastructures, social settings, and organisations. Robotics and AI in car manufacturing can't be treated as a separate technical issue if the aim is successful application. An understanding of robotic technology to reproduce human operations as sociotechnical systems requires both knowledge about robotics, technology, and human behaviours at work and in organisations[66]. It requires a team with multidisciplinary skills and perspectives. Theories of AI, robotics, and mechanical engineering, as well as social science and humanities need to be joined together to form a holistic image of the prerequisites for **successful development, implementation, and deployment** of robotic technologies to reproduce human operations in organisations. The involvement of researchers within the fields of social science and humanities helps to reorientate the application of robotic solutions around the people it serves e.g., being cognizant of the role that humans play in the loop and aiming to take advantage of automation while still using human skills and capabilities to fill in technological shortfalls. Combining engineering with understanding of human behaviour and diversity offers a unique possibility to advance robotic technology beyond incremental steps towards the transformation into human and robot collaborative systems. Through increased understanding of human behaviour, the human-robot interface may be customised to contexts and situations, and personalised to meet human diversity, thereby improving the potential to

[64] Bijker, W.E., T.P. Hughes, and T. Pinch, *The social construction of technological systems: New directions in the sociology and history of technology*. 2012, Cambridge: MIT press.

[65] Pinch, T.J. and W.E. Bijker, *The social construction of facts and artefacts: Or how the sociology of science and the sociology of technology might benefit each other.* Social Studies of Science, 1984. **14**(3): p. 399-441.

[66] Feenberg, A., *What is philosophy of technology?*, in *International Handbook of Research and Development in Technology Education*. 2009, Brill Sense. p. 159-166.

reduce the current gap between what is possible to develop by robotic technologies and what is accepted by the users. This will be achieved by combining different disciplines and by combining and/or developing interdisciplinary perspectives. Furthermore, convergence of scientific knowledge and knowledge from manufacturing in practice is crucial. The MAGICIAN project will contribute to **mutual learning and skills development** among workers and managers of **all genders and age**. Through collaborations with various stakeholders (employers, production engineers and workers, unions), publications, press releases MAGICIAN will raise awareness across the manufacturing community about what robotics in manufacturing can achieve and what is needed for user acceptance. In the MAGICIAN project we will strive to **addressing the fundamental assumptions**, **values, norms, and believes** on what makes employment, work, and an organisation what it is and shift the perspective from isolated robotic technologies to reproduce human operations to a human-centred perspective e.g. focusing on deploying automation to **produce more and better jobs for humans,** driving economic growth while also **promoting societal well-being**. This makes the MAGICIAN project uniquely positioned to aid the adoption of a human-robot collaboration system and a resilient solution that **address current sustainability challenges**, including understanding of interaction between the individual, the collective, society and collaborative robotics in manufacturing.
Within the project we will collect personal data while defining user requirements, studying the interaction between humans and the solution as well as during evaluation of the solutions. Details of the informed consent procedures have been described also in the self-assessment. For handling the personal data, we will create a Data Protection Plan that will be set up at the beginning of the project and will be updated during the project. Within the template we have some general and specific questions for documentation, data storage duration, data protection responsibility, and the data protection impact assessment, that will be answered by the whole consortium. In this vein we make sure to be compliant to the EU General Data Protection Regulation (GDPR) propositions for data management task 1.2. Personal data will be only stored as long as necessary (data minimisation principle) – and deleted six months after the project's end.

1.2.12 The Gender Dimension. Are women workers more likely to seek jobs in car manufacturing due to robot-based automation in manufacturing production processes? And will the acceptance of robotic technologies in car manufacturing differ between gender and/or younger and older workers? The answer to these questions is not yet known, as we do not know the impact on gender in regard to robot-based automation in manufacturing. What we do know is that males are dominant in manufacturing and that technical solutions have been male-coded[67]. Unintentionally or intentionally, men have constructed technology based on male norms and values. This in turn results in women being excluded in the development such that certain technical solutions do not match female desires, expectations or their view of who they are[68]. Evidence strongly suggests that gender diversity in technology teams have a number of benefits including better problem-solving, increased innovation, better group performance (amongst a number of other benefits)[69]. In the MAGICIAN project, we apply a holistic, interdisciplinary and human-centred research approach. We will apply co-design and involve female and male stakeholders (e.g., workers, managers and union representatives), in order to get diversified views and inputs on the development of robotic technologies to reproduce human operations. We also know that robotic technologies and automation in manufacturing carries higher displacement risks (machines can perform an increasingly wider range of tasks). On the other hand, automation and robotic technologies have difficulty in substituting humans for more abstract tasks (e.g. those involving creativity, problem-solving, complex coordination), or non-routine tasks (e.g. requiring artistic dexterity or flexible interpersonal skills). These are tasks that can be carried out by people of all genders and ages. To make robot-based manufacturing environments more attractive to women, we need to understand more about the organisational culture in manufacturing. Therefore, the baseline study will involve a gender analysis, asking questions such as: how many men and women work in the organisation? what do they work with? Are there any differences in the emotional burden in different jobs? Are there differences between female and male-dominated tasks regarding how the workplace is physically designed and physical strain? Are there any differences between female and male-dominated activities in how the work is organised, or in the working conditions?. The goal of this

[67] Wajcman, J., *Feminist theories of technology.* Cambridge journal of Economics, 2010. **34**(1): p. 143-152.
[68] van Oost, E.C., Materialized gender: how shavers configure the users' feminity and masculinity. How users matter. *The co-construction of users and technology,* 2003: p. 193-208.
[69] He, X. and S. Jiang, Does gender diversity matter for green innovation? *Business Strategy and the Environment,* 2019. **28**(7): p. 1341-1356.

analysis is to unveil the design and cultural bias surrounding manufacturing and automation in its complex set of norms, stereotypes, and practices. The results will feed into the development process and we will try to address the most prominent issues that are related to our project focus: robotic technologies to reproduce human operations. By including workers, managers and union representatives of all genders and ages in the development of the proposed robotic solutions and by including them in rules-making and decision taking we aim for an inclusive development process. Furthermore, the group of experts selecting the experiments under the cascade funding will consist of a diversity of people in regard to gender, age and discipline. Hopefully, our approach will result in strengthening mutual learning and skills development of workers of all genders and ages. In the longer term, our inclusive development process may decompose gender norms, for instance with women taking on jobs normally associated with males.

1.2.13 Open Science. The MAGICIAN project will fully embrace the EU motto: 'as open as possible, as closed as necessary': we will follow an Open Science approach to the maximum extent allowed by an Innovation Action, while protecting the legitimate interests of the partners, especially of those involved in commercial activities. First of all, we will produce a Data Management Plan, which along with the requirement of the Grant Agreement and of the Consortium Agreement, will set the stage for our open science policy and define its boundaries. An entire task (T1.2) will provide for the correct implementation of the policy throughout the whole duration of the process. The main inspiring principles will be the following: a) Every scientific and technological achievement of the project will be promptly and carefully scrutinised to verify if there is ground, urgency and willingness to file a patent request; b) In the affirmative case, the process will be started with the agreement that scientific or technical publication will be submitted to a relevant venue as soon as permitted by the patenting process; c) In the negative case, a publication will be immediately planned by exclusively following an open access "gold" policy; the target conference and journals will be selected based on this criterion and adequate coverage in the budget is reserved for the related "Author Processing Charges".
Research on data management will be implemented as described in the next section. The guidelines on "FAIR" data management will be observed and meta-data will be added, in order to enable the re-use of data by other researchers. In addition to these basic requirements, the project will use the opportunity to publish (intermediate) results early, e.g. by enhancing relevant parts of deliverables with additional information and converting them into a technical report. The Open Research Europe (ORE) platform will be the main tool to facilitate this early sharing of information. Reproducibility of the research results is particularly difficult in focused projects. In order to help other researchers to understand the processes involved in the research, specific use will be made of videos acquired during the integration and demonstration (WP5). These videos will be made publicly available, e.g. on youtube, and referred to in reports and other documents, wherever possible.

1.2.14 Management of Research Data & Outputs. Research data & outputs generated in the project include new knowledge in the engineering and implementation of robotic systems for defect analysis (MO1, MO2) and defect reworking (MO4, MO5). On each of these outcomes, we will produce either scientific publications or patents followed by scientific publications. Importantly, each of these subsystems will be based on the application of learning approaches (MO3, and MO6), for which we will generate datasets of significant size and relevance. In addition, the human-centred approaches that will lead us to MO12, MO13 will be based on a massive collection of qualitative data, which are interesting in their own right and beyond their initial goals. The datasets that, according to our knowledge of the project at the time of this writing, are the following: The data will be scrutinised and, following the provisions of the data management plan, we will decide which ones can be published and which ones need to be protected because they are confidential or related to an intellectual property generated by the project that needs some form of protection. All the data classified as "publishable" (e.g., the data generated by the Academic Partners in their own laboratories) will be managed following the "FAIR"-approach as specified in the HE Guidelines on Open Data: we will use standard formats, introduce meta-data and create vocabularies to facilitate their re-use, we will make them findable, accessible and interoperable to facilitate re-use. A possibility that we will seriously consider is to adopt the format defined by the Big Data Europe project.

Data Sets	Type of Data
Data Set 1 - Defects analysis	Experimental: images, tactile information, defect annotation.
Data Set 2 - Defect Removal	Experimental: sensory data collected & annotated from the instrumented tools
Data Set 3 - Fully anonymised data set of the analysis of social and psychological Implications of using Cobots	Observational

Personal data will be processed in full accordance with the General Data Protection Regulation (GDPR, 2016/679). Confidentiality levels as given by the EC will be considered in detail in D1.1 and for each relevant collection of data the lead researcher will assume the role of the data manager. As regards data sharing and re-use, we will adopt

Creative Commons/Open Data Commons licences. We will also distribute software components to facilitate data interpretation and validation. The cost for the production and the long-term archiving of the data will be borne by the scientific tasks that will produce the data. Generally speaking, the costs for the implementation of the FAIR approach will be sustained within the budget reserved for data management (T1.2) and within the exploitation and dissemination Work Package (WP 6). The general policy of the project will be to guarantee the storage of the data and the publicity of the publications for at least 10 years.

2. Impact

2.1. Project's pathway towards impact

2.1.1. MAGICIAN unique contribution to topic outcomes

Outcome 1: Demonstrators able to show the added value of robotics in addressing challenges in major application sectors, or in dangerous, dull, dirty tasks or those strenuous for humans or in extreme environments.

The technologies tested and piloted in MAGICIAN, particularly the CR (See MO4, MO11), will prevent workers from engaging in strenuous and hazardous tasks, e.g. mechanical vibrations on wrists and limbs and exposition to metallic dust associated to the task of grinding defects from products in assembly lines, thus improving their safety and well-being. This will translate into a reduction of workers engaging in health hazardous activities[70]. The increased accuracy and velocity in the detection and removal of defects by the SR and CR (See KPI-SR1–3, KPI-CR-1–3), either as separate units as well as in integrated and closed-loop processes, will increase productivity and flexibility derived from its implementation methodology will facilitate its adoption in different configurations.
Both SR and CR will physically embed AI into robotic systems that will operate with levels of accuracy and productivity comparable, and superior, to humans. This result will be obtained by learning the policies and criteria used by humans to detect and remove defects using multi-modal approaches. This methodology will guarantee a rapid convergence of the learnt criteria and its competitiveness to that utilised by humans (See KPI-LRN-CR1–4). The expected performance will demonstrate the value of integrating AI, data analysis, and robotics with human-centred approaches into the development of innovative industrial solutions.

Outcome 2: Systems able to demonstrate beyond human performance in complex tasks, with high impact in key sectors, that show extended levels of adaptation and flexibility.

MAGICIAN builds on state-of-the-art AI, machine learning, and data analysis knowledge to develop and implement two learning frameworks to transfer and improve on human knowledge regarding the detection and classification of defects and their subsequent treatment and removal (See Outcomes O1 and O2). The system training will use innovative multi-modal AI technologies, where the combined use of models and of machine learning will guarantee a high level of performance, robustness, and fast convergence (See Section 1,1, KPI-LRN-SR1–3 and KPI-LRN-CR1–4). Human-robot interfaces will be developed and tested to enable the successful transfer of expert knowledge into the embedded intelligence of the robots. Experts will supervise the learning process. Moreover, both processes may also be separated and integrated in concordance with industrial needs (See Outcomes O3 and O5). The innovations will be prototyped and demonstrated in a simulated production environment (TRL7) within ALT premises (See MO15). In addition to performance results, the demonstrator will enable the evaluation of our human-centred design to facilitate acceptability, interaction, and trust experienced by workers and end-users in their direct use of the system (See Section 1.1, KPI-SSH-2–3 and KPI-SSH-7).
The MAGICIAN approach and methodology for knowledge transfer and implementation into collaborative robots, will also be generalised such that it can be easily replicated in other applications and scenarios beyond the pilot cases considered in the project (See Outcome O5 and O8). Thus, although obvious applications are those requiring grinding or sanding operations, the core industrial activities that could be addressed by MAGICIAN-based innovations include: (i) Production organised into phases, e.g. assembly lines, (ii) Quality control (visual and tactile sensing) and preparation of semi-finished products for final operations/procedures, where defects should be detected and removed, (iii) The task of removing defects is physically demanding and hazardous to health.

Outcome 3: Systems able to show high levels of reactivity and responsiveness and intelligibility when performing human-robot and robot-robot interactions in major application sectors.

The SR module of MAGICIAN will combine visual and tactile information to directly support workers in their decision-making process for the identification of defects during manufacturing. In an operational scenario, end-users will work side-by-side with the SR, identifying and classifying defects. The high accuracy of the analysis, success rate, and efficiency in detecting defects will allow workers to prioritise their focus and efforts in

---

[70] Parmar, J.M., Patel, C.M., Shukla, A. N. *Health risks associated with the grinding process*. In *International Research Conference on Innovations, Startup and Investments (ICOSTART-2019)*

other tasks of the manufacturing process. Thus, in settings where the SR operates in combination with the CR (See MO11), the worker will concentrate mostly on the areas that have been treated. Moreover, the self-assessment of the reworking made through the visual sensor on the arm, will enable the system to further attract the human attention on the areas where the defect reworking may have failed, i.e. the MAGICIAN system as a whole provides a comprehensive support for human decision making exploring the complementarities and the trade-off between human and robot operations. MAGICIAN will empower workers, who will concentrate on operations with higher added value and with reduced physical strain. This will also translate into reducing possible gender and age imbalance due to access-barriers related to physical strength and endurance. These aspects will be galvanised through the implementation of human-centred design methodologies to ensure that solutions will be perfectly compatible with the specific needs of operators (See MO13). The MAGICIAN SSH-activities will also ensure that the introduction of the CR will have a positive impact on the organisation of the work at large.

2.1.2. Project wider impact in relation to the destination

KSO A – Promoting an open strategic autonomy by leading the development of key digital, enabling, and emerging technologies, sectors and value chains

MAGICIAN will have a direct impact on Innovation in AI, Data and Robotics. This achievement does not only refer to the transfer of basic research results to a demonstrator, but to the development, refinement, and implementation of tools to embed knowledge captured through AI, machine learning, and data analysis in cyber-physical systems that work hand-in-hand with human operators. This will translate into clear benefits, particularly in the selected pilot cases that will be extrapolated to other sectors. The proposed tools, techniques, and methodologies constitute a package of technologies that is applicable across a wide range of automation scenarios, from automotive to the aerospace manufacturing industry. MAGICIAN also comprehensively addresses the EC-Sustainable Development Goals (SDG), particularly SDG3, i.e. ensuring healthy lives and promoting well-being for all at all ages, by implementing human-centred design to successfully engage and involve operators, and promoting health improvements by removing workers from strenuous and hazardous activities. These results will come as part of outcomes MO13 and MO14, under WP2. Thus, MAGICIAN will contribute to autonomy of the EU-industry by increasing productivity, competitiveness, sustainability and innovation capacity of its manufacturing sector.

KSO B – Making Europe the first digitally led circular, climate-neutral and sustainable economy

The force control algorithms developed by MAGICIAN will explicitly consider sustainability aspects, such as the disc-wear as one of the optimisation cost functions. The CR will treat the same type of defects with a consistent policy, i.e. force and angle, guaranteeing that the abrasive disk will wear with the same rate, translating into more efficient usage of resources, infrastructure, and energy. This constitutes an example of robotic modules outperforming human workers, since even the most skilled grinding technician will always make minor mistakes, typically at the end of a shift, when physical tiredness and mental stress materialise. Such consistent treatment of the semi-finished products also decreases the probability that it will receive unrecoverable damages, thus generating wastes. Moreover, the motion planning algorithms developed will factor energy consumption as a key cost function to optimise. Finally, MAGICIAN follows the "*Do No Significant Harm Principle*"[71] in terms of environmental impact, i.e. less material usage, shorter processing time, less energy consumption by optimised operations, achieved through more efficient, effective, and intelligent use of resources.

KSO C – Setting up a credible **pathway to open strategic autonomy in digital technologies**

MAGICIAN will drastically advance digital technologies, particularly the implementation of AI and machine learning (MO2–3, MO5–9, MO21), in manufacturing by developing a modular and human-centred solution for identifying and removing defects from semi-finished products (MO10–11). MAGICIAN will mainly focus on how to transfer the human expertise into collaborative robots (MO3, MO6). Although related to the specific application considered in MAGICIAN, this ground-breaking development will result in ideas and expertise to replicate this experience in a number of manufacturing applications. Additional MAGICIAN impacts can be broadly categorised in: 1) Scientific, by contributing to the creation of robotics components executing machining operations; by designing immediate and easy to use human-robot interfaces; by reinforcing the knowledge on multi-modal perception and learning systems through relevant industrial applications. 2) Technological, by defining new paradigms to endure a safe coexistence of human workers and robots in production areas, by integrating tactile and visual information in quality evaluation. 3) Economic, by increasing productivity and quality in the production

[71] REGULATION (EU) 2020/852 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 18 June 2020 on the establishment of a framework to facilitate sustainable investment.

area; by extending the market size for cobots and robotic components; by reducing the turnover for physically intensive working activities; by enabling immediate knowledge transfer between different sites, preventing the loss of the skills gained by the human operators when they are assigned to a different position, i.e. digital-skills preservation. 4) Societal, by changing the paradigm in the manufacturing industry towards a class of skilled and motivated workforce; by improving ergonomics in the worksite; by removing humans from unhealthy/hazardous activities; by revitalising industrial districts and improving labour relations.

2.1.3. Potential Barriers to achieve Expected Outcomes & Impact

Barriers and description	Mitigation Measures
Reticence to adoption. Performance is strongly influenced by a successful transfer of knowledge from workers. Hence, a negative disposition of workers, during the development and training of the system, would be critically harmful.	Strong communication campaign highlighting the benefits of MAGICIAN to health and wellbeing of workers highlighting the possible advantages of moving from execution to supervision roles. Strong involvement of workers in the development process through human-centred design principles. For the SR, the sensing component will be promoted as a working aid.
Technology qualification, certification & standards. Existing standards and practices will need to be adapted to the proposed innovations.	MAGICIAN-innovations integrate many *off-the-shelves* components that already comply with industrial standards. In addition, participation of industrial stakeholders (TOFAS,ALT,HWH), and communication with the corresponding EU-bodies on standardisation will reassure the compliance and industrial update of the proposed solutions.
Risk aversion by potential uptakers. Due to the required investment in infrastructure and training, unwillingness to adopt new processes may occur.	MAGICIAN will tackle this aspect by promoting success stories through market leaders, releasing relevant technology information, benchmarking, and assessment for further replication (WP7). Demonstration days will also be performed with the support of the technical partners that are implementing the proposed innovations.

2.1.4. Scale of the project contribution

The market for automation in manufacturing is growing rapidly worldwide. The global robotics market was valued at USD 27.73B in 2020 and it is expected to reach USD 74.1B by 2026 (https://www.mordorintelligence.com). Meanwhile, the defects detection in manufacturing market is estimated to grow from USD 3.5B in 2021 to USD 5.0 billion in 2026, focusing on automation of quality control, stringent health and safety measures, as well as dearth of skilled professionals (https://www.marketsandmarkets.com). Relevant technologies implemented to improve operational efficiency and performance include defect detection systems, machine vision systems, etc. In this sense, the global market in artificial intelligence in manufacturing is valued at USD 2.3B in 2022, expected to grow to USD 16.3B by 2027 (https://www.researchandmarkets.com).

The MAGICIAN-outcomes are expected to generate significant benefits in the selected pilot cases by reducing the turnover and improving working conditions of workers involved in non-ergonomic, physically strenuous/stressful, and hazardous activities, e.g. grinding operations. The robotic sensing perception modules, the fulfilment of O1, will have major impacts removing access barriers to the working force, since the detection of defects requires specific physical characteristics from the human workers, e.g. height, weight, agility.

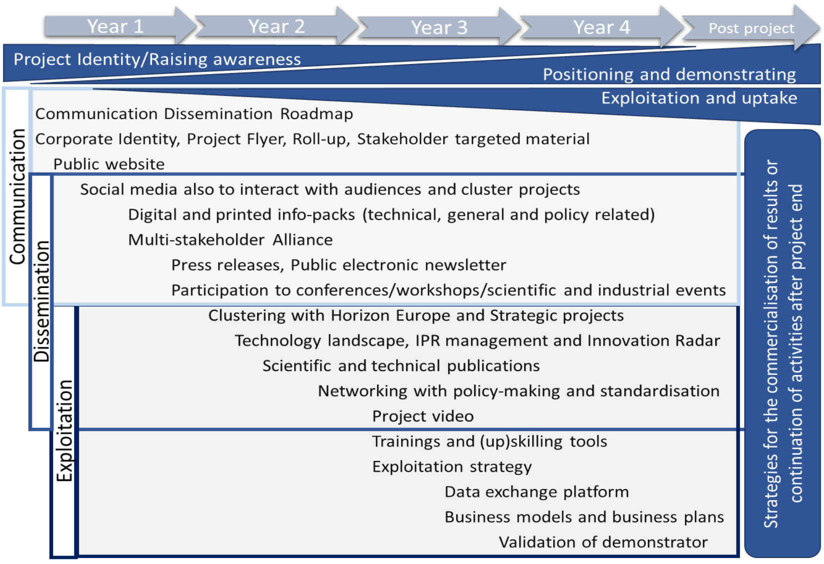
Regarding the CR, MAGICIAN will succeed if at the end of the project the amount of operations performed by human-workers in the cleaning module of the pilot cases are reduced by 90% (O2), reducing also workers turnover and the detrimental effects on the human health (See additional KPIs in Section 1.1).

Another significant long-term impact relates to the grinding operation per se and the requirement of expert operators. In this case, the high costs of dedicated grinding machines constitute a deciding factor for the implementation of the process, which is accentuated in cases of shortage of skilled personnel. Thus, robotic grinding turns out to be a valuable alternative in several fields, since robots are consistent, and achieve optimised wear of abrasive grinding disk, repeatable grinding quality, constant throughput throughout the assembly or production line, and faster cleaning operations. Therefore, the contribution of MAGICIAN grinding automated operations will reach well beyond the scope of the project.

Finally, the integration of autonomous robots in these tasks and the generalisation of MAGICIAN-innovations is expected to generate long-term impacts in the quality of working conditions in several additional fields, especially in manufacturing, e.g. aerospace industry, ship building, production of manufacturing components, etc. This extended impact will also be consolidated through the implementation of an FTSP-strategy aimed to effectively evaluate additional pilot cases and scale up MAGICIAN-innovations to other scenarios.

2.2. Measures to maximise impact - Dissemination, exploitation and communication

The multi-level **Plan for Communication, Dissemination and Exploitation** (PCDE) of MAGICIAN and its measures are designed to maximise its impact and effectively deliver its innovations to the market. These impacts rely on seven Key Exploitable Results (KER, see Subsection 2.2.3 for the detailed description of the KERs), which consolidate the results of the project into long-term effects that support the consolidation of the EU's leading position in AI and robotics, particularly in manufacturing, while improving the well-being of end-users.



The PCDE will be updated by M6 within D7.1, and periodically during reporting. During the final reporting period, specific measures will be specified to guarantee long-term impacts beyond project runtime. The PCDE pursues four overarching objectives: (1) communicating knowledge to the general public of the innovations developed by MAGICIAN, i.e. embedded AI in cyber-physical systems and human-robot collaboration (particularly overtaking hazardous tasks) in industrial settings, (2) promoting and facilitating the access of suitable SMEs/start-ups to the MAGICIAN-Open Calls, (3) maximising the success and visibility of the project and ensuring that the expected impacts are achieved through effective dissemination and open science practices, (4) setting up the foundations and consolidating the long-term impacts of the project. The corresponding activities and potential adaptations will be undertaken within Task 7.3, and are organised into three overlapping phases: **Phase I** focuses on establishing a common project identity and raising awareness/interest on the expected results of MAGICIAN through the promotion and distribution of tailored D&C material in several venues, e.g. social media, strategic events, sister projects activities, etc. A Stakeholder Management Plan (SMP) will be developed as part of the PCDE to ensure effective engagement of strategic stakeholders and target groups. Activities within this phase will also set up the conditions for the successful launch of the project Open Call strategy. **Phase II** focuses on positioning and disseminating MAGICIAN's KERs, demonstrating preliminary solutions and supporting future exploitation of results. Key activities include publications of results in business, industrial, and scientific venues, participation in conferences, events, workshops, and promoting results. This phase will also actively focus on promoting the progress, results, and impacts of the experiments to be demonstrated by the Open Call winners. **Phase III** focuses on promoting the commercial and non-commercial KERs produced by MAGICIAN and developing a path towards a broader scalability/replication of the results, thus galvanising the long-term impact of the project. The end-goal of Phase III is to facilitate the market uptake of its KERs and ensure impact beyond the project runtime. Partners will actively participate in dissemination and exploitation activities and use their own network to reach the target groups.

Target group	Main message
End-users / Customers (e.g. automotive, and aerospace)	Cost reduction and reliability. Constant and controllable levels of quality (e.g., not dependent form the experience and level of weariness of the worker)
Developers' community	Adaptability, flexibility, and modularity of the deployed platform. Potential and opportunities for patenting and licensing, e.g. end-effector, opening business opportunities. Increased portfolio of products for system integrators. Scalability (under a licence) and modularity of computer vision modules for anomaly detection and defect detection, and classification. Demonstrated and refined through the MAGICIAN-FTPs.
Policy makers	More competitive manufacturing. Additional lines of business related to robotics and AI. Better work conditions and reduction of wastes. More resilient, autonomous, and robust manufacturing system.

Researchers (new tools and methodologies for sustainable manufacturing)	New multi-modal computer vision datasets for anomaly defect detection and classification. New evaluation methodologies for computer vision-based defect detection and classification in industrial (real world) settings. New techniques for vision-based anomaly detection and classification from multimodal input. Research opportunities emerging from human-robot interactions in industrial settings. Concrete realisation of the cobot paradigm, that could translate into business, collaborations, and funding opportunities.
Wider society	**End-users**: improvements of the value-for-money of their product (better finishing in smaller times). **Workers/Unions**: Better working conditions derived from shifting dullest / physically demanding operations to robots. (i.e., moving from the direct execution of the work to supervision and control)

2.2.1. Communication measures of MAGICIAN

Communication activities (T7.1) aim to engage the wider society and set the foundations for the replicability and large-scale adoption of the innovations proposed by MAGICIAN. The communication strategy also rationalises activities such that project partners may effectively transmit the project's vision correspondingly. Thus, each partner will be responsible for communicating the project to different extents. MAGICIAN will deploy several communication activities through specific, pre-identified communication channels, which are also monitored accordingly (KPIs – Key Performance Indicators).

Activity	Description	KPI
Website	The MAGICIAN website will provide updated information on the progress of the project, activities and outcomes, partners, calendar of events and links partner organisations	1 project website > 10,000 page visits by M48
Corporate Image	A corporate identity will be created, including templates for official documents and presentation of the project, and other aspects of a consolidated corporate image	1 (updated) logo Official documents template Official presentation template
Social media presence	Social media will be the means to access a wider community, build consistent interaction and stimulate its engagement.	> 500 overall followers (M48) from different platforms
Promotional material	Digital and printed promotional material will be produced to present the project, its objectives, and its results. This material will also position impacts of the project	4 posters 1 rollup 4 project brochures
Newsletters	Newsletters will be sent every 6 months starting in M6. Concise and accessible information about the project will be provided. The newsletter will target stakeholders and the general public	8 newsletters
Video	Information video about the project and the demonstrator and pilot cases in action	2 videos

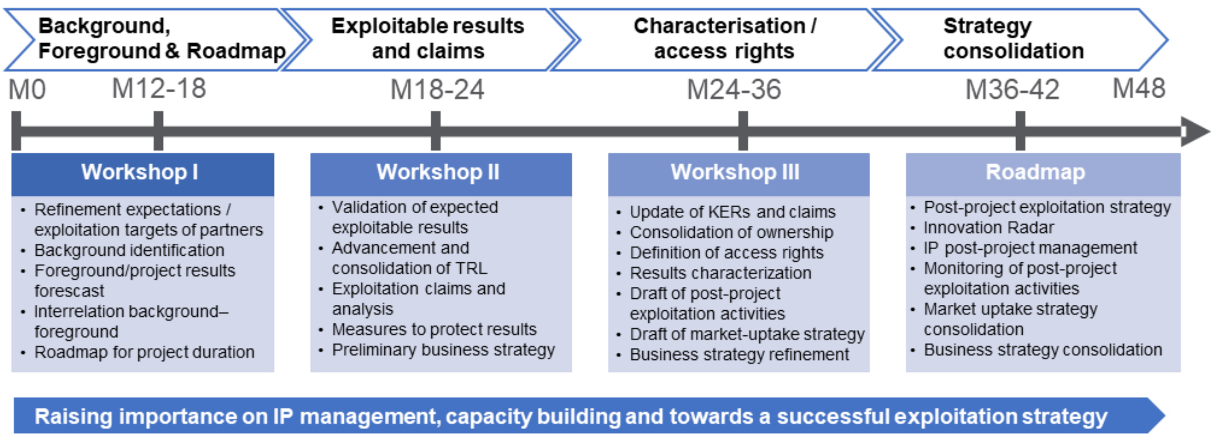
2.2.2. Dissemination and strategic engagement of MAGICIAN

Dissemination activities in MAGICIAN will be undertaken in T7.1 and target five objectives: **Dissemination Objective 1** (**DO1**) is to engage with the target users of the MAGICIAN-innovations and pilot cases, e.g automotive companies, labour unions, employers' associations, and policy makers, to promote early adoption and market uptake. DO1 considers a campaign based on face-to-face meetings, organisation of workshops, and activities to demonstrate prototypes and results. The demo infrastructure is fully modular and transportable between industrial sites not only to increase potential exploitation but also dissemination-potential. **DO2** aims to generate interest by robotics practitioners and researchers across different application areas. DO2 will be achieved by working closely and involving stakeholders identified in T7.2 into MAGICIAN-activities and -progress. **DO3** will focus on using the lessons learnt in MAGICIAN to train the next generation of civil and robotics engineers and supply chain actors. This will be led by LU and will closely interlink with the SSH and human-centred activities related to the project. **DO4** refers to making accessible the scientific and technical output produced during the project, including scientific and technical papers and tutorials in conferences, workshops, journals, web sites, etc., and showcase these innovations to companies involved in mechanical production segments as well as trade fairs. **DO5** focuses on facilitating the access to SMEs / start-ups and guaranteeing success of the Open Calls. These activities will be prefaced by an ecosystem mapping in each of the partners ecosystems, as well as at European level (T7.2). This mapping will identify strategic research and industry institutions, standardisation bodies, policy makers, and other initiatives and structures (DIHs/EDIHs) within the area of industrial automation and robotics.

Dissemination and co-creation measures		
Measure	Expected impact	KPI
Workshops	Discuss and disseminate the project user-centred design results for industrial applications with manufacturing companies, system integrators, robotic manufacturers, academic venues, etc.	2 demonstration workshops 2 educational workshops
Web seminars	Sharing the results from research, development and pilot activities. Moreover, preparation for potential applicants for the Open Calls	6 web seminars (1 seminar on human-centred approach, 2 demonstrator seminars, 1 market uptake seminar, 2 Open Calls seminars)
Activities with other projects and initiatives	Knowledge exchange, project clustering, creating and exploiting synergies (e.g. Made in Europe, EFFRA, DIHs / EDIHs activities, etc.). Foster dissemination of the Open Calls. in HORIZON-CL4-2021-HUMAN-01-02 activities	At least one (1) joint activities with related projects and initiatives at national, European, international level. Participation in the CSA activities upon request
Participation in events and presentations	Raise awareness, exchange knowledge, identify collaboration opportunities (e.g. AI4EU, RobMoSys, ROSIN, Big Data Europe, etc.). Dissemination of the Open Calls	> 30 active participations in exhibitions, conferences, workshops, industrial events
Scientific publications	Share the project results with the scientific community to foster knowledge exchange in the specific research fields	> 10 conferences/workshops papers > 5 peer reviewed scientific publications in journals. All papers will be open access
Industry and EU publications	Share the project results with the industry stakeholders to foster knowledge exchange	> 2 articles in industrial magazines or EU publications
Contributions in policies / standardisation	Policy recommendations and standards for future research and deployment in the industrial field of human-robot collaboration and interaction.	Policy brief developed jointly (if possible) with projects under HORIZON-CL4-2022-DIGITAL-EMERGING-02,CSA*-HUMAN-01-02 and topic groups at euRobotics, I-RIM and the AI4EU, Data and Robotics

2.2.3. Exploitation strategy, and IP and knowledge protection strategy

The exploitation strategy of MAGICIAN aims at fostering and promoting the uptake of the innovations developed throughout the project, including its approach towards human-centre design. This includes refining, developing, and implementing roadmaps for the KERs through four internal exploitation workshops aimed at producing a clear understanding of market trends, environment competitiveness, market entry barriers, IPR strategy, etc.



The preliminary exploitation strategy of MAGICIAN can be observed in the following table.

KER	Type*	Description	Preliminary exploitation strategy	Partners

K1	C / K	A learning framework to capture human-knowledge / experience on identification and rework of defects of semi-finished products	Licensing selected components of the framework. Development of patents. Commercial agreements with early adopters. Data production/exploitation. Further development of methods and algorithms.	FORTH, IIT, PIP, UNITN
K2	C / S	Specialised end-effector interfaces	R&D, engagement of investors, further use case validation, sales through the IIT Technology transfer office and licensing. Potential customers: robotics hardware integrators, robot manufacturers, robot application developers and research organisations	IIT, ALT, TOFAS, CRF
K3	C	A robotic module for visual and tactile quality control of semi-finished products	Early adopters of the technology. Licensing components of the module. Development of patents Commercial agreements with early adopters. Design protection. Scientific publications.	FORTH, TOFAS, PIP, IIT
K4	C	A robotic module for reworking defects from semi-finished products	Early adopters of the technology. Licensing components of the module. Development of patents. Commercial agreements with early adopters. Design protection	FORTH, IIT,TOFAS, ALT
K5	C / S	A robotic platform able to integrate 2. and 3. in an industrial setting	Early adopters of the technology. Licensing components of the module. Development of patents. Commercial agreements with early adopters. Design protection	TOFAS, UNTIN, ALT, PIP
K6	C / K / S	A SW toolkit for rapid reconfiguration for new industrial scenarios	Licensing and/copyright the software. Development of patents. Commercial agreements with early adopters. Design protection	ALT, PIP
K7	K / P	Set of human-robot interfaces and methodologies to involve end-users and improve their well-being	Deepening the understanding of human-robot interaction in industrial settings. Testing research SSH methods and methodologies in real use cases. Extend the potential for additional research opportunities and/or areas to implement your existing research	LU, UNITN
K8	K / C	MAGICIAN exploitation roadmaps and business models	Further development of methods and methodologies. Expand the portfolio of expertise and possible operative approaches for SMEs in novation funding. Strengthen experience in accelerating SMEs/start-ups and for innovation portfolio management. Expand impact assessment expertise, tailoring approaches. Publish in peer-reviewed journals with focus on innovation, management and business modelling.	SEZ, ZAB, ALT
K9	K / C	MAGICIAN closed-loop welding process defect identification/ optimization	Early adopters of the technology. Licensing components of the module. Development of patents. Commercial agreements with early adopters.	HWH, TOFAS, ALT

*K = new Knowledge as the basis for further R&D and education, scientific results; C = Commercial relevant results (development of new products/processes/services/solutions/business models); S = results/expertise contributing to new Standards; P = results/expertise supporting Policy.

In addition to these, other exploitation activities include spin-off initiatives between project partners (FORTH, SIG), extraction of lessons learnt and best practices to be replicated in other industrial settings (TOFAS to the Stellantis Group). Further activities consider the exploitation of knowledge gathered in MAGICIAN to strengthen institutional positioning in the EU-AI and -manufacturing landscape, explore further opportunities for R&I projects and business consulting, and fostering networking and collaboration opportunities (ZAB, SIG).

2.2.3.1 Knowledge management and IPR protection.

The strategy of IP/knowledge protection and management will be guided by SIG for which an IP methodology tailored to the general framework conditions of Horizon Europe has been developed. This methodology incorporates the Innovation Radar (https://www.innoradar.eu/) to monitor and manage the most promising results. The Exploitation Strategy of MAGICIAN considers the IP management in a series of exploitation workshops and organically integrates it in the exploitation roadmaps to be developed for the most promising KERs. IP-related provisions will be specified in the Consortium Agreement (CA), including a) Foreground Knowledge, comprising information generated as a result the project activities and IPR, e.g. copyrights, patents, and pending application for patents; b) Background Knowledge, comprising information and property rights owned by the parties before the CA is signed; c) Use, direct or indirect utilisation of knowledge for developing, creating and marketing a product or process, or creating and providing services. Protection will follow two overall approaches to be further refined: Software will be copyright protected, e.g. through licence codes, to avoid unauthorised duplication; Hardware developments will aim for protection through patents, when possible. Activities considered in the exploitation workshops with regard to IP management aim at: a) making the partners aware of the IPR management issues and their rights, b) identifying and avoiding potential conflicts of interest, c) developing and implementing contingency plans for possible conflicts. Moreover, a set of rules will be consensuated for results that may only be jointly exploited. All partners will be able to specify in the CA background knowledge to be excluded from the access rights. Access rights will be defined for the execution of the project, affiliates, third parties, and partners joining or leaving the consortium. Specific regulations will also be foreseen for software (e.g. for the defect detection sensors, but also for machine control). These rules will deal with licensing, sub-licensing, modifications of software and access to source code. Planned publications will be approved by the Project Management before submission.

2.2.3.2. Preliminary business strategy and business case opportunities.

During its exploitation activities, MAGICIAN will explore several business cases and strategies for the most promising results. These strategies aim directly at facilitating the market penetration and uptake of the innovations produced by the project in different fields of manufacturing, AI, robotics, and human-machine collaboration and set the foundations of the long-term impacts of the project, beyond its runtime.

BCS1 – Robotic module quality control of semi-finished products (visual and tactile sensing)

KERs Involved

K3, K1, K6, K7

Distribution & Operations

- Solution developed by MAGICIAN-technical partners
- Solution distributed by early adopters/AE-beneficiaries
- Business opportunities defined at exploitation workshops (SIG, ZAB, CRF)
- Cybersecurity implementation
- Ethics compliance and use acceptance (LU)

End Users

- Shop floors with defect detection tasks
- Quality control workers
- Manufacturers of assembly lines
- Semi-finished products producers
- System integrators

Key Enabling Structures/Organizations

Partnership for Robotics in Europe (SPARC), AI, Data and Robotics Association (Adra), European Robotics Association (euRobotics), European Automobile Manufacturers' Association (ACEA), AI, Data and Robotics Partnership, EDIHs in manufacturing and AI

Target Market

- Global robotics market was valued at USD 27.73 billion in 2020. Expected to reach USD 74.1 billion by 2026 (CAGR: 17.45%)*
- Defect detection market estimated to grow from USD 3.5 billions in 2021 to USD 5.0 billion in 2026 (CAGR: 7,5%) ***
- Vision inspection for manufacturing: 70% of the $2.6 trillion aerospace services market is dedicated to quality and maintenance****
- Automobile manufacturing industry

*https://www.mordorintelligence.com/ ***https://www.marketsandmarkets.com *****https://www.statista.com/

BCS2 – Robotic module for defect removal from semi-finished products (grinding task)

KERs Involved

K4, K1, K6, K7

Distribution & Operations

- Solution developed by MAGICIAN-technical partners
- Solution distributed by early adopters/AE-beneficiaries
- Business opportunities defined at exploitation workshops (SIG, ZAB, CRF)
- Cybersecurity implementation
- Ethics compliance and use acceptance (LU)

End Users

- Shop floors with defect removal tasks
- Defects treatment operators
- Manufacturers of assembly lines
- Semi-finished products producers
- System integrators

Key Enabling Structures/Organizations

European Automobile Manufacturers' Association (ACEA), European Association of Aerospace Industries (AECMA), EDIHs in manufacturing and AI, AI, Data and Robotics Association (Adra), Big Data Value Association (BDVA), European Robotics Association

Target Market

- Global robotics market was valued at USD 27.73 billion in 2020. Expected to reach USD 74.1 billion by 2026 (CAGR: 17.45%)*
- Grinding machines: In 2020, the grinders market size was estimated at 6.14 billion U.S. dollars worldwide. By 2027, this market is forecasted to exceed 8.7 billion U.S. dollars*****
- Defect detection market estimated to grow from USD 3.5 billions in 2021 to USD 5.0 billion in 2026 (CAGR: 7,5%) ***
- Vision inspection for manufacturing: 70% of the $2.6 trillion aerospace services market is dedicated to quality and maintenance****
- Automobile manufacturing industry

*https://www.mordorintelligence.com/ *****https://www.statista.com/ ***https://www.marketsandmarkets.com ****https://www.airbus.com/

BCS3 – Learning framework to capture / transfer human-knowledge on identification and removal of defects

KERs Involved

K1, K3, K6, K7, K8, K9

Distribution & Operations

- Learning algorithm implementation (FORTH, IIT, PIPPLE)
- Cybersecurity implementation
- Ethics compliance and use acceptance (LU)
- Business opportunities defined at exploitation workshops (SIG, ZAB, CRF)
- Solution developed by MAGICIAN-technical partners
- Solution distributed by early adopters/AE-beneficiaries

End Users

- Shop floors with defect detection and remotion tasks
- Quality control companies
- System integrators
- Industry 4.0/5.0 solution providers
- Industries with automated production lines

Key Enabling Structures/Organizations

The AI Association, European Association for Artificial Intelligence (eurai), AI, Data and Robotics Association (Adra), Partnership for Robotics in Europe, EIT Digital, EFFRA, AI, DATA and Robotics Partnerhsip, EDIHs in manufacturing and AI, DTA

Target Market

- **Global market size for AI in manufacturing: USD 2.3 billion in 2022 expected to grow to USD 16.3 billion by 2027 (CAGR: 47.9%). Main applications: Predictive maintenance and machinery inspection, production and planning, field service, quality control****
- Defect detection market estimated to grow from USD 3.5 billions in 2021 to USD 5.0 billion in 2026 (CAGR: 7,5%) ***
- **Vision inspection for manufacturing: 70% of the $2.6 trillion aerospace services market is dedicated to quality and maintenance******

**https://www.researchandmarkets.com/ ***https://www.marketsandmarkets.com ****https://www.airbus.com/

BCS4 – Integrated solution for automatic defect detection (visual / tactile sensing) and removal

KERs Involved

K1, K2, K3, K4, K5, K6, K7, K8, K9

Distribution & Operations

- Solution developed by MAGICIAN-technical partners and AE-beneficiaries
- Solution distributed by early adopters/AE-beneficiaries
- Open Calls winners' development
- Open Calls winners' development
- Business opportunities defined at exploitation workshops (SIG, ZAB, CRF)
- Closed-loop manufacturing processes and optimization

End Users

- Automated shop floors production lines
- Production machines producers
- Semi-finished products producers
- Industry 5.0 integrators
- Automotive, shipbuilding, aerospace industry
- Human-machine interaction and collaboration companies

Key Enabling Structures/Organizations

European Automobile Manufacturers' Association (ACEA), European Association of Aerospace Industries (AECMA), EDIHs in manufacturing and AI, AI, Data and Robotics Association (Adra), Big Data Value Association (BDVA), European Robotics Association

Target Market

- Global robotics market was valued at USD 27.73 billion in 2020. Expected to reach USD 74.1 billion by 2026 (CAGR: 17.45%)*
- Global market size for AI in manufacturing: USD 2.3 billion in 2022 expected to grow to USD 16.3 billion by 2027 (CAGR: 47.9%). Main applications: Predictive maintenance and machinery inspection, production and planning, field service, quality control**
- Automobile manufacturing industry
- Grinding machines: In 2020, the grinders market size was estimated at 6.14 billion U.S. dollars worldwide. By 2027, this market is forecasted to exceed 8.7 billion U.S. dollars*****
- Defect detection market estimated to grow from USD 3.5 billions in 2021 to USD 5.0 billion in 2026 (CAGR: 7,5%) ***
- Vision inspection for manufacturing: 70% of the $2.6 trillion aerospace services market is dedicated to quality and maintenance****

*https://www.mordorintelligence.com/ **https://www.researchandmarkets.com/ ***https://www.marketsandmarkets.com ****https://www.airbus.com/
*****https://www.statista.com/

2.3. Summary

SPECIFIC NEEDS	EXPECTED RESULTS	D & E & C MEASURES
Grinding operations are physically demanding and **hazardous** for human workers. **Defect detection** involves repetitive and **low added-value** operations. This may be avoided by: - **End-to-end quality monitoring** and assurance - **Flexible**, efficient, and reconfigurable **systems** - **Human-centricity** coupled with enabling technologies (AI, robotics, etc.) - Improving **time and resource efficiency** in manufacturing	- **Novel algorithms** for learning and replicating human operators' defect detection and removal process and a new set of human-robot interfaces. - **Robotic module** for **visual and tactile quality control** of semi-finished products, **robotic module for defects removal** from semi-finished products, and **SW toolkit** for their rapid integration and reconfiguration - **Closed-loop welding process** defect identification/ optimization - **Exploitation roadmaps** and business models - **Five PhD students** trained on industrial application of robotics	**Exploitation**: Patenting algorithmic models and robotic systems. Commercial agreements. Licensing software. Design protection. Human-robot interaction modelling testing. Further R&D. **Dissemination**: Demonstration workshops in different plants for targeted groups (human operators in manufacturing, industry automation, AI and ML, science and research, incl. SSH and HR-interaction). Participation in application, industrial, and scientific conferences, trade fairs, events, etc. Publications in scientific / industrial journals / magazines. Data accessibility following the guidelines of the DMP. **Communication**: Tailored messages of outcomes and impact to the public and specific groups through website, newsletter, social media, audiovisual material, and open access online events.

TARGET GROUPS	OUTCOMES	IMPACTS

End-users / Customers in automation of manufacturing, grinding robotics companies, quality control, production of semi-finished products. **Developers' community** and system integrators in flexible and autonomous systems, and industrial human-robot interaction. **Scientific community** in computer vision, defect detection, realisation of the cobot paradigm. **Wider society**, users, and workers unions. **Policy makers**	**Performance vs humans**: False positives in defect detection success rate ≤ 120%. Undetected defects ≤ 110%. Scanning time of a full vehicle ≤ 80%. Defects removed ≥ 98%). Defect removal time ≤ 110%. **Closed-loop process**: Target n° of cycles for inline defect identification and classification < One single cycle. Success rate of closed-loop optimization ≥ 90%. **Overall performance and safety**: Probability of missing major defects during the scanning phase ≤5%. Probability to have an accident (evaluated in simulation) ≤ 10-6. Defect detection target ≤ 0.3mm. Misclassification rate ≤ 10%. Probability of faulty classification ≤8%.	**Economic**: Improved productivity in the production area; enlarged market size for cobots and components; reduced turnover for physically intensive working activities and reduced health costs on health related to grinding and defect removal in manufacturing. **Technological**: New robotics components executing mechanical working operations and transformation; immediate and easy to use human-robot interfaces **Scientific**: New algorithms and techniques on multimodal perception and learning systems in the industrial domain. New SSH and human-robot interaction models. **Societal**: paradigm shift in manufacturing towards a class of skilled workforce; improved ergonomics, safety and health conditions at the worksite; improved labour relations.

3. Quality and efficiency of the implementation

3.1. Work plan and resources

The complexity of the challenges behind MAGICIAN requires a work plan organised in 7 WPs; an outline of their content and of the flow of information between them is captured in the PERT diagram in Figure 7.

WP1 - *Project Management* - sets up all the instruments necessary for the correct execution of the project, defining, among others, the Data Management plan and the Risk and Quality plans and it underlies the development of the entire project . WP2 - *Use case definition and platform design* - defines the use case in detail, develops the user-centred design and identifies the tools for its correct assessment and identifies the robotic platform requirements and architecture. Clearly, it provides input to the technical development and is directly linked to the test and validation activities, and in particular to the evaluation of user acceptance and satisfaction.The detection and learning phases for both the defect classification and the grinding operations execution are at the core of WP3 - *Data acquisition and skills learning* - together with the perception and sensing components necessary for the robotic platform. WP4 - *Robotic platform and interfaces* - is entirely devoted to the definition and implementation of the robotic platform and its interfaces, developing the control, planning and scheduling algorithms for the grinding operations and the defect detection station. The entire set of solutions and algorithms are then integrated in WP5 - *Integration and performance analysis* - where the demonstrator is built-up and tested. Finally, WP6 will be devoted to the management of the cascade funding scheme.

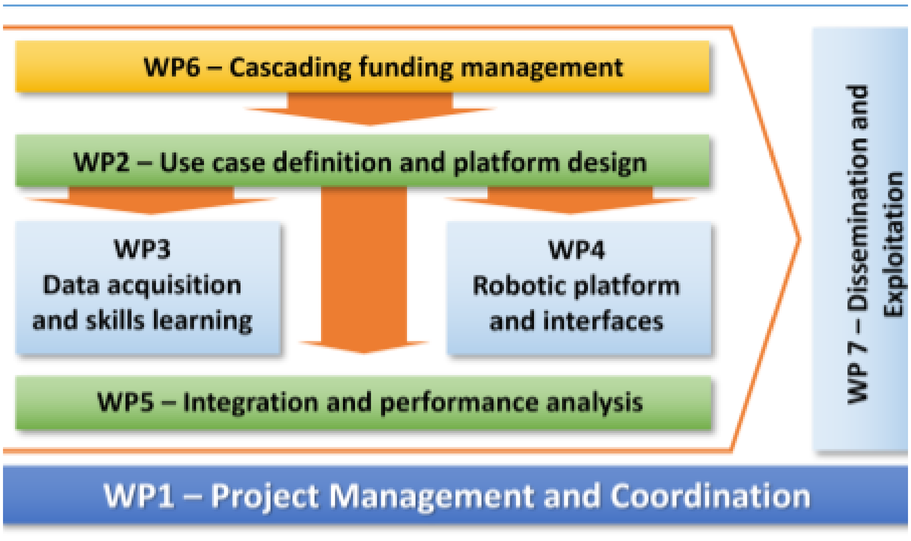


Figure 7. Pert diagram of the MAGICIAN project

Following the best practices of project management, the MAGICIAN workflow will have an iterative structure. The project duration will be 48 months. After the initial kick-off, we will have a first milestone at M6 (MS1), which will include the start up of management and dissemination activities, the definition of the use case. At M3 a first iteration of the technical activities will start, which will produce a first version of the project's components at M12 (MS2). At M18 (MS3), we will release an initial version of the user-requirements and we will release the user centred design of the robotic platform, along with the definition of the interfaces. At M21 (MS4), we will release an integrated version of all the software components, will launch the first open call (OC1) for cascaded funding for additional technical contribution to the system and will begin the first experimentation round on the use-case. At M24 (M5), we will release a first working version of the prototype and will sign the contracts for OC1. At M30 (M6), we will make a midterm review for the winners of OC1. At M33 (M7), we will have a second release of the different components and will launch the second call (OC2) for additional use-cases. At M36 (M8) we will release a second version of the prototype, integrating also the components coming from OC1. We will also collect the results of the first experimentation on the use-case, launch a second experimentation round on the TOFAS use-case and sign the contract for OC2 (additional use-cases from third parties). At M42 (MS9), we will make a review round of the new use-cases recruited through OC2. At M45 (MS10) we will make a personalised release of the components for the new use-cases. The last months will be devoted to the evaluation of the data collected during the validation, to an intense communication and dissemination activity and to the definition of business plans for all the MAGICIAN outcomes (MS11).

3.1.1. GANTT Chart

Trimester	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	Deliverables
Milestones		1		2		3	4	5		5	6	7		8	9	10	
WP1 - Project Management																	6
T1.1: Management and coordination of the project				D				D				D				D	4
T1.2: Data Management		D														D	2
T1.3: Risk and quality management																	
WP2 - Use case definition and platform design																	6
T2.1: Use case definition		D											D				2
T2.2: User centered design						D										D	2
T2.3: Interface definition and robotic platform design						D								D			2
WP3 - Data acquisition and skills learning																	4
T3.1: Perception system, data acquisition and processing																	
T3.2: Learning defect classification skills from humans				D			D				D				D		4
T3.3: Learning defect working skills from humans																	
WP4 - Robotic platform and interfaces																	4
T4.1: Human-Robot Interfaces																	
T4.2: End-effector design and interaction control co-design																	
T4.3: Planning and scheduling																	
T4.4: Motion control and active sensing				D			D				D				D		4
T4.5: Closed-loop defect analysis																	
T4.6: Configuration optimization tool																	
WP5 - Integration and performance analysis																	5
T5.1: Platform integration								D				D			D		3
T5.2: Demonstrator set-up																	
T5.3: Performance analysis												D				D	2
WP6 - Cascaded funding management																	5
T6.1: Open Calls launch, management and selection process								D				D					2
T6.2: OC implementation and monitoring												D					2
T6.3: Innovation management, impact assessment and lesson learned																D	
T6.4: Development and technical assistance for FSTP															D		1
WP7 - Dissemination and exploitation																	4
T7.1: Dissemination and Communication		D														D	2
T7.2: Ecosystem Mapping and Development																D	1
T7.3: Path toward Exploitation																D	1
TOTAL																	34

3.1.2. List of work packages

WP No	Work Package Title	Lead Partic.No	Lead Partic. Short Name	Person Months	Start Month	End month
WP1	Project management	1	UNITN	68	1	48
WP2	Use case definition and platform design	3	LU	122	1	48
WP3	Data acquisition and skills learning	4	FORTH	199	4	45
WP4	Robotic platform and interfaces	2	IIT	222	4	45
WP5	Integration and performance analysis	7	ALT	173	16	48
WP6	Cascaded funding management	9	ZAB	101	13	48
WP7	Dissemination and exploitation	8	SIG	92	1	48
			Total PM	**977**		

3.1.3. Work package descriptions

Work package number	1	**Lead Beneficiary**	UNITN
Work package title	Project Management		

Objectives

1. To keep the project on track in terms of results, time and budget. 2. To maintain the research data coming from the project

Task 1.1 Management and coordination of the project (Lead: UNITN; Part: All; M1-M48)
Coordination of the project will be done by UNITN. This includes management of the consortium, preparation of meetings and the periodic reports, submission of deliverables and all other consortium level matters. Each partner will appoint a project manager who will deal with the local management. Internal reporting is planned every 6 months and will be done by all partners using templates provided by the coordinator. General meetings are planned every 6 months and prior to the review meetings and will be attended physically by all partners. Web meetings are planned every 2-6 weeks. *Innovation management* will be done in close cooperation with WP7 (exploitation task) input from the market, from potential users of the technologies and future cooperation partners will be acquired and considered when fine-tuning the developments planned in the project. This process will run in parallel to project management and new findings will be discussed by the partners during the regular general meetings. *Cohesion and coordination activities* with the European Partnership on AI, Data and Robotics and similar EU initiatives (e.g. HORIZON-CL4-2022-TWIN-TRANSITION-01) will also be addressed here. In particular, coordination actions with the AI4EU Foundation, RobMoSys and ROSIN are foreseen to increase the impact of this innovation action and, in case, to adopt the developed open-source frameworks.

Task 1.2 Data Management (Lead: UNITN; Part: All; M1-M48)
The Data Management will be defined in the Data Management Plan and implemented in this task throughout the whole duration of the project. All data will be made available via a file sharing server set up by UNITN (for consortium-internal use) and public data will be stored in the MAGICIAN repository. All partners will make their data available in a suitably structured format, including meta-data where needed following the specification and the structures defined in the Big Data Europe and similar open-source initiatives. Data used in scientific publications will follow the open access rules and will be made available in a permanent repository.

Task 1.3 Risk and quality management (Lead: SIG; Part: All; M1-M48)
A Quality Plan (QP) will be delivered at project start to define the organisation of the working team, set the quality standards for the consortium, and to specify a clear definition of policies and operational procedures for the management of the collected data. In this task, the correct analysis of the risks detailed in Section 3.1.6 and the implementation of the planned mitigation strategies will be also monitored and updated in due course. We will also lay the blueprint for the policy adopted by the Consortium for open access policy, together with the data management activities carried out in Task 1.2 (T1.2).

Work package number	2	**Lead Beneficiary**	LU
Work package title	Use case definition and platform design		

Objectives
1. Deploying user-centred design **(O6),** 2. Involvement of workers, managers and union representatives **(O6, O7),** 3. Facilitating multidisciplinary team work **(O6),** 4. Formulating ethical and social requirements and conditions, including gender dimensions **(O6),** 5. Supporting mutual learning and skills development **(O7)**, 6. Conducting Social and psychological impact-evaluation **(O7)**, 7. Defining the user interfaces **(O6, O7),** 8. Designing of the robotic platform and the components of the solution **(O3, O6, O7)**

Task 2.1 Use case definition (Lead: CRF; Part: All, except SIG; M1-M39)
This task will define a comprehensive description of the use case to extract requirements and operative scenarios for the project developments. Starting from the automatic brushing/polishing operation, and considering the existing reference use-case performed in line, the task will describe the project use-case with its relations to the real reference UC, its operative scenarios, draft layout, task analysis and main KPIs for description, characterisation and final validation in relation to the project objectives and the KSO.

Task 2.2 User-centred design (Lead: LU; Part: UNITN, IIT, CRF, TOFAS, ALT, HWH; M1-M48)
This task concerns the user-centred design. The four basic principles for this task are: an appropriate allocation of functions between workers and robots; active involvement of workers (end-users) and union representatives; iterative design solutions and multidisciplinary design teams. The human user is the starting point in human centred design and the human is the main focus in all steps of the design and development process. This is done through analysis and examination but also through validation tests in real environments and situations where the workers (end-user) are involved. The task is divided into 3 activities:
Baseline analysis of ethical and social conditions concerning human-robot interaction in manufacturing (M1-M12): The baseline analysis will rely on desktop research and field studies: (1) desktop research involves a review and analysis of existing research and resources that studied how human-robot interaction in manufacturing have impacted the satisfaction, trust/comfort, privacy, equality and skills development of

workers; (2) field studies/baseline observations of the workers practices at the manufacturer (TOFAS) and participatory interviews to understand their current ways of working: their challenges and incentives. The baseline study will also include a gender analysis of the fieldsite. The insights gained from the desktop research and the field studies will be distilled in an initial requirements report aimed at technical partners.
Iterative refinements of requirements through a series of workshops with researchers, developers, union representatives and workers (M12-M30): The iterative refinements of user requirements will be conducted through a series of workshops. We will involve all stakeholders in this work (e.g researchers, developers, manufacturing managers, union representatives and workers). In the workshops user scenarios and prototypes will be refined according to the findings of the former workshop and built on each other. The outcomes of the workshops will formulate a series of ethical and social requirements and conditions, including gender dimensions. They will be used to enable technical partners to answer the question "what are the ethical and social conditions and requirements that must be taken into account when developing the MAGICIAN solution"?
Social and psychological impact-evaluation of the system at large (M24-48): The goal of this task is to evaluate robotic solutions in real environments i.e. in workers' everyday working life at manufacturers. This task includes iterative interviews/observations at manufactures, in special areas, in which the robotic solutions are deployed (to explore how user acceptance changes over time). The task also includes ethnographic enquiry to increase the understanding on how the robotic solutions impact the workers' perspective on quality of working life, trust/comfort, safety, privacy, and ethics, as well as what kind of skills development is needed. The ethnographic enquiry will include a gender analysis. This task relates to the socio-technical environment in which the robotic solutions can exist within and evaluates the situated usage and ecological validity of the proposed solutions.
Task 2.3 Interface definition and robotic platform design (Lead: UNITN; Part: IIT, LU, FORTH, CRF, TOFAS, ALT, PIP, HWH; M1-M42)
Two mobile robotic platforms will be developed: one for defect perception and one for defect reworking; commercial cobots will be employed, having to share the workspace with humans. Preliminary analysis accounting for workers' requirements (T2.1, T2.2), cost, max payload and DoFs will be carried out on specific collaborative robotic arms: versatility and interchangeability of the platforms will be pursued. In platform i), the robot will be equipped with sensors to scan and identify defects on the chassis (T3.1), and to reconstruct the scene. In platform ii), a robot with high-payload will be equipped with a commercial grinding tool attached through a compliant hardware interface specifically designed to dampen the vibrations generated by the contact of the tool with the chassis (T4.2). For monitoring both the learning and autonomous operations, external cameras will be employed. Moreover, robots will be able to autonomously move within the physical cell to carry out the assigned tasks. ALT, coordinating with TOFAS and Stellantis group, will be directly involved in the design phase through the organisation of specific workshops.

Work package number	3	**Lead Beneficiary**	FORTH
Work package title	Data acquisition and skills learning		

Objectives
1. Selecting the appropriate sensing solution for the detection of defects **(O1),** 2. Defining the algorithms for low level perception for tactile and visual channels **(O1),** 3. Developing a classification framework to analyse and classify the severity of defects **(O1),** 4. Selecting a sensing solution to record the human motion and the applied forces **(O1, O2),** 5. Discovering models and strategies for defect reworking **(O2),** 6. Learning strategies and parameters correlated with a specific defect reworking scenario **(O2),** 7. Produce containerized software modules and documentation that can be reused in different manufacturing pipelines **(O3)**

Task 3.1: Perception system, data acquisition and processing (Lead: FORTH; Part: UNITN, IIT, LU, CRF, TOFAS, ALT, PIP, HWH; M4-M45)
This task will consider the perception and the data acquisition phases for both the visual and tactile solutions. In most of the cases, extended defects will undergo vision-based detection processes, while small and dubious defects will significantly rely on tactile-based processes. The multi-modal perception software module for MAGICIAN implemented in this task will be exploited in two phases of the production process: a) Defects detection during inspection b) Post-reworking verification. Active sensing techniques will serve the acquisition of data from a channel on the basis of the data acquired by other channels. These techniques, which rely on real-time processing of the acquired data, will mimic the multi-modal workers' perception strategies. Tools based on Fast Fourier Transform will be implemented to detect high-frequency harmonic content related to roughness due to defects. The fusion of signals (e.g., via particle filtering, Extended Kalman Filter) coming from

different sources (force, motion, and visual data) will provide a richer characterisation of the defects, later exploited in T3.2. We will also cover human perception and modelling to help the robot generate motions that are safe and ergonomic for the human coworker integrating the findings of WP2. Indeed, the request that cobots, work side by side with humans implies the knowledge of the person's motion to guarantee safety and ergonomics. In this task, we will use the visual perception to build upon human motion and biomechanical models developed in the literature and set-up a tailored solution to reconstruct the human skeleton and predict their motion along the working operations. Finally as part of the data acquisition, a number of validation and testing datasets will be collected and annotated. These datasets will be used in order to verify the technical robustness of the methods developed in this work package.

Task 3.2: Learning defect classification skills from humans (Lead: FORTH; Part: UNITN, IIT, LU, CRF, TOFAS, ALT, PIP, HWH; M4-M45)

The goal of this task is to categorise the imperfections and create the best possible strategy for their identification. The different imperfections will be identified and initially categorised based on their visual properties. The best identification strategy for each type will be selected using three criteria: a) accuracy, b) identification speed, and c) minimum implementation cost. Different methodologies for fast visual identification will be evaluated. Multispectral cameras will be used to identify oxide depositions on the car body surface. High resolution depth sensors will be used to identify surface anomalies. These technologies will enable fast and accurate identification of specific imperfections. Additionally, an image dataset of the imperfections will be created. The dataset images will be captured with different camera sensors (i.e optical, multispectral, depth sensors) to enable the training of AI systems that can ultimately identify the imperfections using regular visible light cameras. Using visible light camera sensors for most vision tasks will help reduce the overall complexity of the final system. Besides visual data, tactile information will be acquired in parallel with visual data by exploring the chassis surface with a proper end-effector (T4.2), and acquiring static (force-based) and dynamic (acceleration-based) signals. An expert operator will label the acquired data according to the severity of the defect (remarkable, medium, little) and the type of process needed to remove it. After having collected a sufficiently extended human-labelled, multi-modal dataset, semi-supervised learning techniques (possibly using the results of the AI4EU Foundation) will be followed for data acquisition, and a life-long, annotated dataset will be created and exploited by a neural network-based classifier. Immunity from overfitting and robustness of the AI solution, evaluated with the target success rate considering a data set different from the one used for training, will also be addressed.

Task 3.3: Learning defect working skills from humans (Lead: IIT; Part: UNITN, FORTH, CRF, TOFAS, ALT; M4-M45)

This task aims to transfer two skills from the worker to the robot: i) motions for defect inspection, ii) motions for grinding. We will rely on the Learning from Demonstrations (LfD) approach to represent by means of motion primitives the involved movements. The learning process will rely on data acquired by the human interacting with the chassis through the wearable interface (T4.1) and through a sensor-equipped grinding tool (T4.1) and on visual data from the camera. Defect inspection will mainly rely on a dynamic comparison between signals coming from the investigated part and from a previously acquired non-damaged part (baseline). Motion primitives for tactile defects exploration and for grinding will be retrieved by exploiting a multi-modal learning approach (e.g., based on Generative Adversarial Networks) integrating information from different sources (pose of the tool, interaction forces/acceleration, and visual data). Raw pose and force data related to the human grinding motion will be acquired by recording the actions of an expert user equipped with a properly sensorised grinder tool or in robot kinesthetic teaching mode. Explicit mathematical constraints based on the defect tomography (T3.1) will be injected into the learning problem formulation to avoid the damage of areas surrounding the defect. Similar to T3.2 the modules developed within this task will be implemented to be generalizable to multiple use cases as they may arise from the cascade actions.

Work package number	4	**Lead Beneficiary**	IIT
Work package title	Robotic platform and interfaces		

Objectives

1. Interfaces from and to the user, 2. Designing an end-effector and a wrist interface able to quickly mount grinding tools (**O2**), 3. Developing impedance and force control methodologies for enhanced adaptation, safety and vibration suppression during the grinding operations (**O2**), 4. Synthesising task planning and motion strategies to optimise the sequence of sensing and grinding operations (**O3**), 5. Transfer the knowledge learnt

from the human to the robotic platform through planning and control (**O3**), 6. Closed-loop control for welding process optimization (**O4**), 7. Development of software architecture and configuration tools (**O3**)

Task 4.1 Human-Robot Interfaces (Lead: IIT; Part: UNITN, LU, CRF, TOFAS, ALT; M4-M45)
To acquire the tactile dataset (T3.2), the worker's hand will be equipped with a wearable interface (glove) designed to render as realistically as possible the interaction forces experienced by the worker during the inspection phase. The interface wearability will be studied and optimised in order to satisfy the different requirements (T2.2) as well as the requirements of the potential use-cases received through the cascade funded projects, without compromising the operator's ability to detect and classify defects. Different prototypes (e.g., an instrumented finger to be coupled with the operator's bare finger, a device attached to the palm) will be evaluated. The multi-modal sensing functionality of the haptic interface will be designed through an incremental process, starting with a simple set of sensing principles (e.g. an accelerometer and a force sensor) and possibly enhanced with additional sensors (e.g., piezoelectric polyvinylidene fluoride film sensors, strain gauges) until the acquired data will be sufficiently descriptive for classifying (sub)millimetric defects. Arrays of tractors will be exploited for static, force-based measurements. The final wearable interface will be designed to be a general-purpose device so that it can easily adapt to different use cases that will come through cascaded funding (T6.4). The grinder tool will be equipped with IMU and force/torque sensors. Both the interfaces for defects detection and grinding tasks will be equipped with a fiducial marker for trajectory tracking. After the system roll-out, a haptic ring will provide the operator working side-by-side to the robot with a discrete haptic cutaneous feedback concerning the outcomes of the post-reworking inspection and verification phases.

Task 4.2 End-effector design and interaction control co-design (Lead: IIT; Part: UNITN, LU, FORTH, CRF, TOFAS, ALT; M4-M45)
Grinding operations require careful control of the forces applied by the grinder on the surface. The goal of this task is to implement control strategies that allow the robots to safely grind surface imperfections, exploiting a properly designed end-effector. The robot controller will have to track the desired motion, impedance and force trajectories (learned in T3.3). To this aim, impedance control and hybrid motion-force control will be investigated. To collect data for learning, control tools permitting the workers to directly operate the cleaning robotic arm in kinesthetic teaching mode will be developed: this operation modality will be used as a fall-back-solution and tio collect a preliminary dataset used in the early stages of the project together with visual data (T3.2). In this case, the controller will only guarantee transparency to human guidance motion while ensuring safety and that excessive forces are not applied. As concerns the end-effector design, our approach will be to develop specialised end-effector interfaces that permit the direct and robust mounting of grinding tools while providing intrinsic features that accommodate the adaptation of tool to the car surface, while reducing at the same time the amount of chattering that affects the performance of the robotic system. To this aim, visco-elastic components will be explored and integrated in the structure of the specialised end-effector interface. Additional integrations will be implemented to adapt the end-effector in order to meet the requirements of the different tools that will be used in the use cases of the cascaded funding (T6.4). In the definition of the end-effector and of the control strategies, we will build upon outcomes from other EU initiatives, such as RobMoSys.

Task 4.3 Planning and scheduling (Lead: UNITN; Part: CRF, TOFAS, ALT; M4-M45)
The operations to be carried out on both the visual-tactile inspection and defects reworking should be scheduled properly in order to optimise the effectiveness and the time to carry out the operations. The sequence of the analysis/reworking activities will be decided based on the statistical information coming from the past executions and on a preliminary scan and on the feedforward information coming from the welding station. The development of the task scheduler will also consider the possibility of parallel execution by multiple robots. For the implementation of the module, we will develop two competing solutions, the first based on POMDP and using Storm, the second based on deterministic modelling in an Optimisation Modulo Theory framework. We will adopt the solution with the best level of generality and performance allowing us to accommodate diverse tasks (including those from cascade funding calls). The motion planner component will be composed of two modules: the first will be executed offline and produce a PRM of all possible manoeuvres, the second will be executed in real--time and will associate different weights and costs to the nodes and to the transition of the PRM. These parameters will be decided based on the time and on the energy spent to execute the transition, on the prediction of the human motion (see T3.1) and on the probability of collecting a rich amount of information during the viewpoint schedule. The motion plan will be generated as the result of a graph optimisation problem with the probability of having accidents treated as a cost, and with execution time treated as a reward.

Task 4.4 Motion control and active sensing (Lead: UNITN; Part: IIT, FORTH, CRF, ALT, HWH; M4-M45)
In this task the motion controller strategy is defined and designed based on the planned path (T4.3). In particular, we will implement motion control routines to both determine the robot motions to guarantee human worker safety and ergonomics (using the models developed T3.1) and execute active sensing algorithms for optimal defect perception (T3.1).

Task 4.5 Closed-loop defect analysis (Lead: HWH; Part: UNITN; M4-M45)
This task aims on the inline defect detection of welding processes and on the automatic adjustment of the respective process execution parameters in an optimal way**.** To do so, the welding control unit will be equipped with the required interfaces for process data acquisition and for robot interaction. Data preprocessing algorithms such as FFT or PCA will be used for realtime feature extraction. For the identification of defects, their severity and their root causes, statistical and physical process models of the welding process will be developed. The models will be trained and validated by using already existing process data as well as data of the TOFAS laboratory. To do so, deep learning methods such as ANN and learning Bayesian Networks (BNs) will be applied. For the easy detection of defects on the car body surface, data of the welding control unit (defect classification and severity) and the robot (defect location) will be combined and provided for further processing. For the closed-loop control of the welding process, strategies for the adoption of the process parameters will be developed and implemented: DNN methods will be a) used to analyse historical data for deriving the best fitting welding control strategy, and b) combined with the workers skills and experience (e.g., by learning BNs).

Task 4.6 Configuration optimization tool (Lead: PIP; Part: UNITN, IIT, FORTH, ALT, HWH; M4-M45)
Goal: Determine optimal configuration settings for new use-cases to speed up successful deployment of MAGICIAN. In order to do this, we need to gather and store data (e.g., performance, configuration settings, characteristics) from various use-cases, analyse this data to find patterns, and create a model to find the optimal settings. This demands to define data requirements for new use cases, such that the data can be well analysed. We envisage input monitoring data from robotic behaviour (SR & CR) and classification model (both visual and tactile data based model). The generated models shall allow to i) find use-case characteristics that show significant differences in performance of robots and models; ii) group use cases in use-case groups with similar characteristics and performance; iii) find patterns for optimal behaviour for each use case group; find optimal settings for each use case group. The output will consist of optimal use case settings for different use case groups with different characteristics. The main challenges will be i) to define requirements for new use-cases in order to add new data from use cases to our database, and use these requirements for selected experimentations in WP6; ii) gather data coming from selected organisations (from WP6) and use it for optimising the model.

Work package number	5	**Lead Beneficiary**	ALT
Work package title	Integration and performance analysis		

Objectives
1. To define in detail the procedures that will be used during the validation process **(O6),** 2. To integrate the different hardware and software components according to designs done in other WP's **(O7),** 3. To prepare all materials needed for the pilot demonstration **(O9)**, 4. To perform the validation in the pilot demonstration and and do performance analysis **(O9)**

Task 5.1 Platform integration (Lead: ALT; Part: UNITN, IIT, FORTH, CRF, TOFAS, PIP, HWH; M16-M45)
Tactile and vision systems (sensing equipment), the grinding tool (revision equipment), collaborative robots and computational components and interfaces of the system will be integrated, possibly carried out along the lines and the outcomes of the EU project ROSIN. In this task, the performance of the developed system will be tested to reach an acceptable level with the limited number of test parts. The integration work with the existing production area software will be also addressed and, if possible, fully integrated.

Task 5.2 Demonstrator set-up (Lead: ALT; Part: UNITN, CRF, TOFAS, PIP, HWH; M16-M45)
After integration of the system, a pilot demonstration area will be set up in ALT's production technology laboratory. Two stations with realistic process conditions will be designed, manufactured and set up in the laboratory. The first station will be for the sensing and the second one will be for the revision operation. Car bodies and similar parts supplied by TOFAS will be located in these stations. The necessary process design and virtual analysis will be done for the collaborative robots and sliding mechanisms in relation with the two process stations and the physical sensing and revision tools. All of these equipment will be mounted in the process area.

Necessary electric and pneumatic connections will be realised. The hardware and software which were integrated preliminary in the T5.1 will also be integrated in the realistic process environment. The safety and process requirements will be fulfilled. The collaborative robot programs will be prepared according to the control plans and virtual analysis done before. After preliminary testing efforts, complete setup will be transferred to TOFAS laboratory to perform testing with real manufacturing operators in a real manufacturing area and also to guarantee the modularity and transferability of the working system between different sites. The demonstrator will be developed to be as much as possible transferable to increase exploitation (T6.2).

Task 5.3 Performance analysis (Lead: TOFAS; Part: UNITN, IIT, LU, CRF, ALT, PIP, HWH; M16-M48)
After the collaborative robot programs preparation, the first trials will be done on the first car bodies. The performance of the system will be analysed in the realistic process conditions. The basic problems will be reported to the technology provider partners. The necessary improvements will be carried out either on the physical equipment and or on the software programs. An iterative cycle will be executed till achieving the basic conditions from the system. After this stage, successive car bodies will be tested with the developed system and performance levels will be compared with the manual ones. Quantitative evaluation metrics and measurement methods for individual core technology modules/components and for the full system will be reported, such as accuracy and timing of sensing (the SR will successfully pass a number of test cases for the sensing operations identified during the use case definition, and will successfully interact with a human operator for the cleaning phase) or accuracy and timing of cleaning (the CR will successfully pass a number of test cases for the cleaning operations identified during the use case definition, with the defect being identified by a human operator).

Work package number	6	Lead Beneficiary	ZAB
Work package title	Cascaded funding management		

Objectives
The overarching goal of the WP is to launch and manage two pen Calls (OC) for proposals aimed respectively at a) deepening and expanding the functionalities implemented in the project core pilots, b) extending the applications of the intelligences embedded in the systems (AI) towards new use cases. Specific goals are
1. to launch OC1 and OC2, including definition of relevant documentation, promotion of the calls in coordination with WP7 and continuative support to potential applicants (e.g. helpdesk). 1. Selection of Beneficiaries, including definition and implementation of the selection process, involvement of external evaluators, notification to selected beneficiaries; 3 Implementation of OC1 and OC2, including contractualization process, provision of the financial support, monitoring of the implementation, innovation management and impact assessment. 4. Development and technical assistance to partners joining as FSTP.

Task 6.1 – Open Calls launch, management and selection process (Lead: ZAB; Part: All; M13-M36)
This task targets the efficient call selection and management and of the applicants' solutions, and its implementation will start with the call set-up and distribution: the set-up of a call will result in an information kit composed of flyers in PDF format, the OC presentation, and any other information for distribution via website and digital channels, the OC proposal template, the submission guidelines for applicant, and the evaluation criteria for each call. Document templates are provided by the EC and will be adapted for the priorities of each call. OC selection: The first step of the review and selection process consists of the consolidation of the external expert pools. Then, for each open call, both an offline and an online review will be organised. The offline review will be performed by independent experts for ranking the proposals based on previously defined criteria (excellence, impact, quality of implementation). This offline review will be consolidated by an online review together by the MAGICIAN evaluation committee to cross-check strategic alignment with the MAGICIAN project. As a final step, the results will be communicated to the project officer for approval and eventually communicated to the AE applicants. Each of the awarded applicants will receive up to € 200k for an implementation no longer than 12 months. 5 solutions will be funded in the first OC, and 5 in the second one. Any remaining FSTP budget will be considered for a potential extra solution funded in the OC2.

Task 6.2 OC implementation and monitoring (Lead: ZAB; Part: UNITN, IIT, TOFAS, ALT; M25 – M36)
This task targets the monitoring of the AEs with the purpose to deliver the selected start-ups and SMEs an appropriate administrative, business and technology support, and to enable a steering of the targeted 10 implemented solutions and consists of: Processes and templates: Set-up of processes and templates for monitoring and coaching. For the engagement part, guidance and information for the solution owners will be provided during implementation. The contractual aspects will be managed by WP1. For the operation part including technical and financial reporting, appropriate templates will be provided, and eventually gathered for

the interim (Y3) and final project reviews (Y4). The third and last aspect is the process and the templates to regularly report solutions' advances toward the MAGICIAN management for steering (identification of possible issues and success stories). Monitoring during execution: Execution of monitoring and coaching will be provided on the principle of providing a single point of contact for each SME/start-up, further routing internally to the required competence / service. The portfolio of services encompass support for administrative issues (e.g., reporting), provision of technology support, and finally services around business innovation management.

Task 6.3 Innovation management, impact assessment and lesson learned (Lead: ZAB; Part: UNITN, IIT, CRF, TOFAS, ALT, PIP, HWH; M19-M48)

This task will be dedicated to support selected companies to accelerate their development process with relevant innovation management support with a focus on their access to the market. It includes guidance to conjointly mature the business view and the technical development toward any potential intended customer. In this task, support for further market access will be provided in monitoring the market evolution with the technical development as well as the company internal resources and competencies. Secondly, support for marketing material such as the preparation of success stories will be provided by the communication leading partner. This material shall support the start-up/SME to increase its solution's visibility at EU level. Finally, the last activity of this task is the creation of lessons-learnt for the different stakeholders within MAGICIAN, in order to adapt EU projects services toward SMEs and business needs as well as the EC's initiatives (e.g. EDIHs). Under this activity, companies will be supported to introduce their investment plan to private investors including both banks and business angels, VCs, corporate investors and/or institutional stakeholder (e.g. EDIHs). In parallel, dedicated impact assessment approaches and related tools will be implemented in order to estimate the impact of the project on the potential business and growth perspectives of involved SMEs/start ups, following the methodologies provided by EC for EDIHs, and other relevant literature references (to be reviewed by M24). An interview will be planned 6 months after the end of each solution implementation to monitor the impact.

Task 6.4 Development and technical assistance for FSTP (Lead: UNITN; Part: IIT, FORTH, TOFAS, ALT, PIP, HWH; M25-M45)

This task will be dedicated to the adaptation and further development of the MAGICIAN technological solutions to the additional technological providers and use cases joining the project along the execution. This task is dedicated to the interaction with the new partners and the analysis of the new requirements.

Work package number	7	**Lead Beneficiary**	SIG
Work package title	Dissemination and exploitation		

Objectives

1. Create a communication channel with industrial/consumers associations/single players, regulatory bodies and the general public, 2. Promote results among the industrial and the scientific communities and regulators, 3. Develop new business models & exploitation strategies with the appropriate IPR management, 4. Create a long-term market deployment plan beyond the project period

Task 7.1 Dissemination and Communication (Lead: SIG; Part: All; M1-M48)

This task will develop the communication and dissemination strategy by refining target audiences and setting up proper communication channels to reach them. Attendance to conferences, exhibitions, EU events, organisation of workshops, demos and training sessions will be planned to involve all consortium members. Publications in scientific, industrial, and commercial resources are highly fostered among all consortium partners. Social media will be analysed and activated to support dissemination among relevant communities. These activities will be supported by a clear visual identity that will be defined from the beginning of the project and shared with all the partners, including: logo and templates supporting both inter-project activities (deliverables, reports, presentations) and activities outside the consortium (publishable reports, presentations, leaflets, infographics, eNewsletter, etc.). Promotional material will be designed and created according to both project and partners needs in terms of outreaching target audience. A project website will be developed, maintained, and updated with public material on progress of the project, demonstrator, activities, publications, etc.. The website will be the gateway for stakeholders, partners and industrial and scientific communities, and will be linked to the created social media profiles, boosting ratings. Planned and performed activities will be tracked and assessed by the dissemination manager, backed by a set of KPIs (See Section 2.2) that will be defined from project outset to monitor status and effectiveness of such activities. A first detailed strategy is outlined under section 2.2. in the proposal and will be updated by M06 in D7.1. A final update on the deliverable will be provided in M48.

T7.2 Ecosystem Mapping and Development (Lead: SIG; Part: All; M1-M48)

To guarantee and stimulate a wide uptake of project results through dissemination as well as exploitation this task will focus on the mapping and development of MAGICIAN's partners' ecosystems, as well as at European level. This mapping will identify strategic research and industry institutions, standardisation bodies, policy makers, and other initiatives and structures (DIHs/EDIHs) within the area of industrial automation and robotics. Structures such as EFFRA, DTA, EDIHs, WMF, Made in Europe, PPP on AI, Data and Robotics, etc., will be of special strategic interest. Following the mapping, results will be analysed and cross-examined to foster synergies between ecosystems and further develop MAGICIAN's reach through and in combination with ongoing dissemination activities during the project runtime. Results will be presented in D7.2 and regularly updated.

Task 7.3 Path toward Exploitation (Lead: SIG; Part: All; M1-M48)

This task will mainly focus on the management of IPR inside the consortium during and after the project period. SIG will organise a series of *Exploitation and IPR workshops* in conjunction with partner meetings to foster discussions on IPR and exploitation. Aspects such as identification of background and foreground IP, refinement of exploitable results, identification of protection mechanisms, owners, and exploitation claims, and clarification on access will be approached during these workshops. This will support the refinement of exploitation and business model and strategies development. These strategies will also consider the contribution of the FTSP to the overall concept and demonstrators. Results of the workshops, and the corresponding exploitation strategies and business models will be summarised by SIG in D7.3.

3.1.4. List of deliverables

No	Deliverable name	Short Description	WP No	Short name of lead participant	Type	Diss. level	Month
D1.1	Data and quality Management Plan	Description of the quality management plan and of the project data collection plan	1	SIG	R, DMP	SEN	6
D1.2	First coordination report	Periodic report on the project work progress and activities performed	1	UNITN		PU	12
D1.3	Second coordination report	Periodic report on the project work progress and activities performed	1	UNITN		PU	24
D1.4	Third coordination report	Periodic report on the project work progress and activities performed	1	UNITN		PU	36
D1.5	Final coordination report	Periodic report on the project work progress and activities performed	1	UNITN		PU	48
D1.6	Final data and quality plan	MAGICIAN data set repository and final quality management result	1	UNITN	R, DATA	PU	48
D2.1	Use case definition	Description of the use case, benchmarks and KPIs	2	CRF	R, DEM	SEN	6
D2.2	Initial user requirements report	Definition of the user requirements for the first use case	2	LU	R	PU	18
D2.3	Robotic platform design	Specification of the robotic platform with interfaces definition	2	UNITN	R	SEN	18
D2.4	Additional use case definition	Description of the additional use cases, benchmarks and KPIs	2	LU	R, DEM	SEN	39
D2.5	Final robotic platform design	Specification of the robotic platform with interfaces definition	2	UNITN	R	PU	42
D2.6	White paper on recommendations for collaborative systems	Final report on ethics, privacy, user acceptance, trust/comfort aspects and skills development	2	LU	R, ETHICS	PU	48
D3.1	First delivery of perception systems	Preliminary version of target analysis and dataset acquisition and annotation, visual perception module for imperfections detection, tactile sensing system and human motion detection and tracking	3	FORTH	R, OTHER	PU	12

D3.2	Second delivery of perception systems	First release of the algorithms for human classification and reworking skills learning integrated with the perception system	3	FORTH	R, OTHER	PU	21
D3.3	Third delivery of perception systems	Third release of the perception module with additional technology integrated and first release of the MAGICIAN perception and learning modules, including s/w containers and documentation	3	IIT	R, OTHER	PU	33
D3.4	Perception and learning module	Final version of the modules for perception and learning of defects and human motion skills, including s/w containers and documentation	3	FORTH	R, OTHER	PU	45
D4.1	Human-Robot interfaces and intelligence	First release of the algorithms for planning, active sensing and control of the robot activities	4	IIT	R, OTHER	PU	18
D4.2	Grinding robot solution	First release of the developed robot	4	UNITN	R, DEM	PU	21
D4.3	First integrated robot solution	First release of the integrated robot hardware and control components	4	PIP	R, DEM	PU	33
D4.4	Final integrated robot solution	Final version of the integrated robot hardware and control components	4	IIT	R, DEM	PU	45
D5.1	MAGICIAN First demonstrator	First integrated platform and first set-up of the demonstrator	5	ALT	R, DEM	SEN	24
D5.2	First performance assessment	Test of the first version of the components	5	ALT	R	PU	36
D5.3	MAGICIAN second demonstrator	Second integrated platform and second set-up of the demonstrator	5	TOFAS	DEM	SEN	36
D5.4	MAGICIAN Final demonstrator	Final MAGICIAN platform with adaptation to new use cases	5	TOFAS	R, DEM	SEN	45
D5.5	MAGICIAN Performance analysis and assessment	Final performance analysis of the MAGICIAN platform applied to different use cases	5	TOFAS	R	PU	48
D6.1	Report on OCs launch and selection of beneficiaries	Activities for OC set-up, management and assessment	6	ZAB	R	PU	24
D6.2	Final report on OCs	Description of all the OC activities	6	ZAB	R	PU	36
D6.3	Implementation and impact assessment report	Document collecting the activities and the outcomes of the OC management	6	ZAB	R	PU	36
D6.4	Technical assistance	Report on the development activities for OC beneficiaries integration in MAGICIAN	6	UNITN	R	SEN	45
D6.5	Impact assessment report and lessons learnt	Impact and assessment of the integration of the OC partners in MAGICIAN	6	ZAB	R	PU	48
D7.1	D&C and exploitation plan	Dissemination, exploitation, and communication plan and WEB communication	7	SIG	R, DEC	SEN	6
D7.2	Report on Ecosystem Mapping and Development	Report on the identification of the strategic players for a successful MAGICIAN exploitation	7	SIG	R	PU	48

D7.3	Final D&C report	Final report on dissemination and communication activities	7	SIG	R	PU	48
D7.4	Exploitation plan	Path toward Exploitation, standardisation and IPR management	7	SIG	R	SEN	36

3.1.5. List of milestones

Milestone number	Milestone name	Related work package(s)	Due date (in month)	Means of verification
MS1	Project start-up	WP1, WP2, WP7	M6	Deliverables, DMP, D&C and Exploitation plans
MS2	First Release of the robot components	WP3, WP4	M12	Deliverables: first release of the different components for robot perception and action
MS3	User-centred requirements and platform design	WP1, WP3, WP4	M18	Deliverable: User requirements, definition of the interfaces, design of the robotic hardware platform
MS4	First software integration	WP3, WP4, WP6	M21	Deliverable: Release of the first integrated version of the software. Launch call of OC1.
MS5	First complete working prototype	WP2, WP5, WP6	M24	Deliverables, signed contracts for OC1
MS6	Midterm review for OC1	WP6	M30	Review of OC1
MS7	Second Release of the components, launch of OC2	WP3, WP4, WP6	M33	Deliverables: second version of the components. Launch call for OC2
MS8	Second version of the prototype	WP5, WP6	M36	Deliverables: second integrated prototype, assessment of the first experimentation on TOFAS use case. Contracts signed for OC2
MS9	Midterm review for OC2	WP6	M42	Review of OC2
MS10	Personalised prototype for new use cases	WP3, WP4	M45	Deliverables: Release of personalised components for OC2 use cases
MS11	Final results	WP1, WP6, WP7	M48	Deliverables: final assessment of the system, and user experience. Business plans, roadmaps toward exploitation of the different components

3.1.6. Critical risks for implementation

(i) Likelihood: L = low, M = Medium, H = High; (ii) Severity: L = low, M = Medium, H = High

#	(i)	Description of risk	(ii)	WPs	Proposed risk-mitigation measures
1	M	The tactile interface data is not sufficient for classifying displaying micrometric defects.	M	WP4	Alternative sensing technologies providing higher resolution would be explored and/or a subset of defects of larger dimensions will be considered.
2	L	The quality of the motion-force controller is not sufficient to properly grind the vehicle surfaces.	H	WP4	The quality of the force control could be improved by integrating high-quality force-torque sensors on the robot, or increasing the control frequency. Visco-elastic elements could be included at the robot-grinder interface to damp vibrations that negatively affect the control performance.
3	M	The AI-based perception and defect classification systems are not able to reliably and robustly identify all defects.	M	WP3	The consortium has developed high TRL components that will form the basis of the development. We use hybrid model-based and AI-based approaches to robustify the solution. As a fall-back, we envisage the

					use of highly accurate and expensive sensors and human supervision to confirm the classification of the algorithm before the defects are treated by the robot.
4	L	The motions for defect inspection can not be learned well.	M	WP3	The learning process could be eased by the use of parametric motion primitives collected from worker motions: only a few parameters need to be learned.
5	M	The motion-force trajectories for grinding can not be learned well.	M	WP3	The learning problem could be simplified by splitting it into simpler sub-problems. E.g. a different strategy could be learned for each defect type and severity. A fall-back solution will be to define heuristics to carry out the cleaning operations based on the direct observations of the workers' task execution.
6	L	Integration Failure	H	WP5	The project follows a step by step approach to integrate all the different components and data streams into final demonstrators, with a previous step addressed to conduct a test campaign with a preliminary version of the developments, aimed to detect errors on modules developments and gaps in the integration process. Iterative integration of the modules during the development is conducted.
7	L	Limited number of applicants in OCs	M	WP6	Creation of a database of target organisations (associations, initiatives, chambers of commerce, universities) to distribute information about OCs. Launch of preparatory promotional activities 2 months before the actual launch of OCs. Leveraging on EDIHs/DIHs outreaching capability to attract SMEs/startups. Weekly opening of an online help desk to address questions/doubt of prospective applicants.
8	L	Changes of existing Standards and/or Regulations during project execution	M	WP4, WP5, WP6	A continuous surveillance to know of changes on standards/regulations will be performed and, when possible, provide access to new coming standards/regulations drafts to the consortium members. Necessary changes to reach the market will be analysed into the final evaluation phase so that they can be considered before the project follow up.
9	L	Poor participation and engagement of workers, managers and union representatives in the user-centred design activities	H	WP2	TOFAS and CRF are project members and have direct contact with workers, managers and union representatives. Furthermore, relevant stakeholders for user activities will also be recruited in the north of Europe (Sweden) to engage even more participants and to get a cultural perspective on cobots between the north and south of Europe.

3.1.7. Summary of staff effort

	WP 1	WP 2	WP 3	WP 4	WP 5	WP 6	WP 7	Total PM / Partner
01 - UNITN	**34**	16	39	77	28	20	6	220
02 - IIT	2	16	49	**65**	12	6	2	152
03 - LU	2	**29**	2	4	3	1	2	43
04 - FORTH	3	2	**61**	7	8	4	3	88
05 - CRF	3	19	12	13	11	3	10	71
06 - TOFAS	2	13	10	5	30	6	4	70
07 - ALT	2	12	3	5	**50**	12	4	88
08 - SIG	6	0	0	0	0	1	**45**	52

09 - ZAB	8	2	0	0	0	**40**	8	58
10 - PIP	4	4	19	22	7	4	3	63
11 - HWH	2	9	4	24	24	4	5	72
Total PM	68	122	199	222	173	101	92	**977**

3.1.8. Cost items and other costs

Purchase costs item (travel and subsistence, equipment and other goods, works and services)

Participant Number/Short Name: 1 / UNITN		
	Cost (€)	**Justification**
Travel	60000	Project meetings, conferences and workshops
Remaining purchase costs (<15% of pers.)	88846	
TOTAL	148845	

Participant Number/Short Name: 2 / IIT		
	Cost (€)	**Justification**
Other goods, works and services	39500	Consumables for prototype, Open Access publications, audit certificate
Remaining purchase costs (<15% of pers.)	65200	
TOTAL	104700	

Participant Number/Short Name: 3 / LU		
	Cost (€)	**Justification**
Travel	60000	Conferences, project meetings, field studies at TOFAS and ALT
Remaining purchase costs (<15% of pers.)	41100	
TOTAL	101100	

Participant Number/Short Name: 4 / FORTH		
	Cost (€)	**Justification**
Equipment	50000	Camera sensors (conventional , multispectral), computing platforms
Remaining purchase costs (<15% of pers.)	59140	
TOTAL	109140	

Participant Number/Short Name: 5 / CRF		
	Cost (€)	**Justification**
Other goods, works and services	46500	Conference fees, audit certificate, consumables (sensors and devices for the CRF preliminary demonstrators and local testing mockup)
Remaining purchase costs (<15% of pers.)	20000	
TOTAL	66500	

Participant Number/Short Name: 6 / TOFAS		
	Cost (€)	**Justification**
Other goods, works and services	33000	Sensors, tools, fixtures and scraps for the demonstrator and logistic costs
Equipment	22500	Cobot and Camera depreciation costs
Remaining purchase costs (<15% of pers.)	16000	
TOTAL	71500	

Participant Number/Short Name: 7 / ALT		
	Cost (€)	**Justification**
Equipment	122000	2 Robotic arms, Sensors, Haptic Tool, Computing unit, slider, control unit
Remaining purchase costs (<15% of pers.)	30500	
TOTAL	152500	

Participant Number/Short Name: 8 / SIG		
	Cost (€)	**Justification**
Other goods, works and services	51000	Website, logo, corporate image, communication and dissemination material and videos, exhibition workshops, audit certificate
Remaining purchase costs (<15% of pers.)	22000	
TOTAL	73000	

Other costs categories items (e.g. internally invoiced goods and services, LRIs)

Participant Number/Short Name: 6 / TOFAS		
	Cost (€)	**Justification**
Internally invoiced goods and services	10000	Scraps of the car body parts, demonstration consumables, material costs for process equipment manufacturing that will be used from internal stocks

3.2. Capacity of participants and consortium as a whole

3.2.1. Consortium as a whole

The consortium of MAGICIAN was configured with the aim to combine all necessary competences and expertise in order to carry out the technology developments, ensure successful dissemination and exploitation of project results, and facilitate a successful transfer of the innovative technologies to the market. The MAGICIAN consortium brings together a multi-disciplinary team of experts in robotics, vision and tactile systems, machine learning, scheduling and planning, system integration, as well as major players in the automotive industry worldwide. The strategy for building the project consortium has been founded on the following three criteria: a) the scientific and technological competences of the partners, b) the role each partner plays in the innovation process, c) the record of successful joint work experiences. The competences and the expertise of each of the partners are well summarised in the following table in relation to the project objectives.

Areas of Expertise	UNITN	IIT	LU	FORTH	CRF	TOFAS	ALT	SIG	ZAB	PIP	HWH
Application domain and potential market					X	X	X	X	X		X
User-centred design			X		X	X					X
Sensing and perception	X	X		X							
Learning algorithms and classification	X	X		X						X	X
Robotic platform	X	X									
Planning and scheduling	X									X	
System integration and platforms	X	X		X			X			X	
Setup of instrumented testing sites					X	X	X				X
Open Call mechanism	X								X		

An innovation project like MAGICIAN has the natural ambition of producing results that can be immediately applied on the market, hence the role of CRF and TOFAS key players of the EU automotive industry, and ALT being an international integrator designing and manufacturing lines and equipment for the automotive industry is mandatory. Given the collaborative nature of the robotic platform with humans, we need a combination of academic competences and of industrial competences to analyse the human robot interactions/collaborations from different competing perspectives (e.g. academic, social, industrial,...). Moreover, in this field we have envisaged experts in social sciences and humanities, which will cover the analysis of any possible gender aspects related to the innovations MAGICIAN will develop, role that is mainly covered by LU for the scientific competences, and by CRF and TOFAS for the domain knowledge. Also, LU will be responsible for the Ethics approval and management along the lines depicted in Form A of this proposal. The robotic platform needs to recognise objects, defects and humans in the robotic cell, hence the partners (i.e., UNITN, IIT and FORTH) will have to cover this requirement by using multi-modal information sources (e.g., visual sensors, tactile) and translate this understanding into the needed information for defect reworking. IIT and FORTH will also lead learning for the defects classification and human grinding abilities, at the heart of the MAGICIAN solution. PIP will use its recognised expertise in the area of machine learning to help with the development of the data analysis components and of the configuration tool. HWH will give a substantial contribution in the integration of feedback loops into the production process between the welding workstations and the SR.

We will develop a TRL7 working prototype able to move autonomously and operate according to the project

paradigm. The partners (chiefly, UNITN, IIT, and ALT) have a wide expertise in the area of robotic platforms and on the developments of mechanical components to be integrated into the robot components and end-effector. Furthermore, UNITN has a long record of research and innovation in the field of planning and scheduling, which are used to both determine the correct execution of the different tasks to minimise the operations time and to plan the correct robot actions for an effective execution of the perception (active sensing) and grinding operations.
Given the centrality of the robotic platform in the project and its complexity, we need a combination of academic competences (UNITN, IIT and FORTH) and of industrial competences (CRF, TOFAS, ALT, POPPLE, and HWH) to integrate the different components and deliver an effective demonstrator.
Finally, the industrial partners of the project will be actively involved toward the exploitation of the project's results mentioned in WP7. In particular, CRF develops innovative solutions for Stellantis plants in all manufacturing field: Human Robot Collaboration ergonomics and flexible manufacturing including robotics and flexible tools, are among the main field of research; as such CRF is highly motivated to disseminate the MAGICIAN innovation into EMEA Stellantis plants. Instead, TOFAS as a joint venture of Stellantis and Koç Holding (the biggest enterprise in Turkey) will also exploit the Koç Holding innovation platform for the other industrial holding companies. ALT, being a well known system integrator of automotive and general industrial robotic manufacturing lines is also highly motivated to disseminate the results of this project in their applications. Finally, SIG and ZAB will give essential contributions in the area of dissemination and exploitation and in managing the complexity of the open call mechanism.

3.2.2. Consortium completeness and Value Chain: Project Contributions, Roles and Resources

The first criterion for the selection of the partners was to accommodate the multidisciplinary nature of some of the project activities, as previously specified in Section 3.2.1. The second one was to strike a good trade off between two conflicting needs: a) complementarity of the expertise and of the approaches, b) redundancy in the most critical activities to decrease the technical risk that could arise by potential problems with some of the partners. The positioning of the partners along the value chain is well exemplified in Figure 8. In depicting the value chain[72], we have leveraged the balance between benefits and resources. In particular, we have defined which of the needs will be addressed and formalised the commitment to deliver them with respect to the scope statement of the project reported in Section 1. The objectives have been defined and specified to be measurable through KPIs in Section 1.1 by performing the functional analysis. The value chain defines the role of each MAGICIAN partner towards the project objectives. Notice that all the areas needed for a successful project have been identified and covered by the partners: in particular, a certain level of redundancy and complementarity has been foreseen for the application developers, which is the main point of failure of the project, as detailed in the risks of Section 3.1.6. UNITN and IIT have some common knowledge about robot control and mechatronic components, while UNITN and FORTH have experts in the project about perception and modelling. Similarly, IIT, FORTH and HWH have common grounds on human robot interfaces and interactions, while PIP has a converging expertise with FORTH and IIT in the area of machine learning and data science. This level of redundancy on the most critical technological innovations allows a certain degree of robustness towards the MAGICIAN's objectives. As reported in previously, each partner has an adequate level of allocated resources to fulfil the foreseen activities.

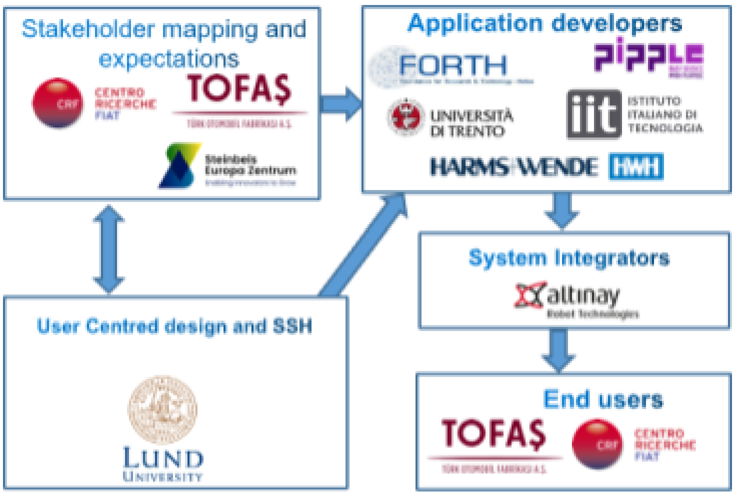


Figure 8: MAGICIAN's Value Chain

As regards the commercial exploitation of the results (see Section 2.2), the main actors will be ALT and other system integrators linked to TOFAS and to the Stellantis group. They will be involved in the system development from the early phases and they will help us steer the most important development choices towards economically sustainable solutions. Some of the research partners will be also an actor of the commercialisation process for the aspects related to the protection of the IP they will contribute to. We will consider as a collaboration scheme the creation of joint venture enterprises with the direct participation of system integrators and the project partners.

[72] Lazar, O. "The Project Driven Strategic Chain." PMI Global Congress 2010, USA, October 2010.