Ref. Ares(2024)2354014 - 29/03/2024

D6.1 – Industrial Equipment Repair-Reuse-Recycle Suite v1

WP6 – BUILD: AIDEAS 4 Industrial Equipment Repair-Reuse-Recycle

Co-funded by the European Union

Document Information

GRANT AGREEMENT NUMBER	101057294	ACRONYM		AIDEAS
FULL TITLE	AI Driven Industrial Equipment Product Life Cycle Boosting Agility, Sustainability and Resilience			
START DATE	01-10-2022	DURATION		36 months
PROJECT URL	https://aideas-project.eu/			
DELIVERABLE	D6.1 – Industrial Equipment Repair-Reuse-Recycle Suite v1			
WORK PACKAGE	WP6 – BUILD: AIDEAS 4 Industrial Equipment Repair Reuse Recycle			
DATE OF DELIVERY	CONTRACTUAL	31-Mar-2024	ACTUAL	29-Mar-2024
NATURE	Other	DISSEMINATION LEVEL		Public
LEAD BENEFICIARY	UNIVPM			
RESPONSIBLE AUTHOR	Pietrangeli Ilaria and Ciarapica Filippo Emanuele			
CONTRIBUTIONS FROM	1-CERTH, 4-IKERLAN, 6-UNIVPM			
TARGET AUDIENCE	1) AIDEAS Project partners; 2) industrial sector; 3) other European projects (H2020/HORIZON EU); 4) scientific stakeholders.			
DELIVERABLE CONTEXT/ DEPENDENCIES	This document is the first release of solutions proposed in WP6. The second version of these solutions will be presented in deliverable D6.2 – Industrial Equipment Repair-Reuse-Recycle Suite v2 (M24), while the final version will be presented in deliverable D6.3 - Industrial Equipment Repair-Reuse-Recycle Suite v3 (M36)			
EXTERNAL ANNEXES/ SUPPORTING DOCUMENTS	None			
READING NOTES	None			
ABSTRACT	This deliverable aims at presenting the features, the technical specifications, and the implementation status of the toolkits developed in the Industrial Equipment Repair-Reuse-Recycle Suite. There are four toolkits developed in this suite: Prescriptive Maintenance (AI^{PM}), Smart Retrofitter (AI^{SR}), LCC/LCA/S-LCA (AI^{LC}) and Disassembler (AI^{DIS}).			

Document History

VERSION	ISSUE DATE	STAGE	DESCRIPTION	CONTRIBUTOR
0.1	09-Feb-2024	ToC	Table of Contents	UNIVPM
0.2	04-Mar-2024	Draft draft	1st draft of the deliverable	UNIVPM, IKERLAN, CERTH
0.3	12-Mar-2024	Review	Conduction of Internal Reviews and Plagiarism check	TAU, UPV, CERTH
0.4	20-Mar-2024	Draft	2nd Draft addressing the comments by the reviewers	UNIVPM
1.0	29-Mar-2024	Final Doc	Quality check and issue of final document	CERTH

Disclaimer

Any dissemination of results reflects only the author's view and the European Commission is not responsible for any use that may be made of the information it contains.

Copyright message

© AIDEAS Consortium, 2024
This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both. Reproduction is authorised provided the source is acknowledged.

TABLE OF CONTENTS

ABBREVIATIONS/ACRONYMS

AI	Artificial Intelligence
API	Application Programming Interface
CSV	Comma-Separated Values
CNN	Convolutional Neural Network
DIS	Disassembler
DSS	Decision Support System
EoL	End of Life
GUI	Graphical User Interface
LC	Life Cycle
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LoRaWAN	Long Range Wide Area Network
LSTM	Long Short Term Memory
MP	Machine Passport
MQTT	Message Queuing Telemetry Transport
PC	Personal Computer
PLC	Programmable Logic Controller
PM	Prescriptive Maintenance
REST	Representational State Transfer
RUL	Remaining Useful Life
S-LCA	Social Life Cycle Assessment
SQL	Structured Query Language
SR	Smart Retrofitter
UI	User Interface

Executive summary

This deliverable aims at presenting the features, the technical specifications, and the implementation status of the toolkits developed in the Industrial Equipment Repair-Reuse-Recycle Suite. The toolkits include Prescriptive Maintenance (AI^{PM}), Smart Retrofitter (AI^{SR}), LCC/LCA/S-LCA (AI^{LC}), and Disassembler (AI^{DIS}). In addition, the AIDEAS Machine Passport (AI^{MP}) is also presented as its data acquisition and data sharing across the entire suite.

These toolkits aim at providing AI solutions for extending the useful life of machines through prescriptive maintenance (repair), building a second life for machines through Smart retrofitting (reuse), and activating a machine recycle program combining AI techniques and Life Cycle methodologies (LCC, LCA, S-LCA).

For every toolkit, an overview of the solution is presented; from the point of view of an end-user who is not familiar with complex terminology. Afterwards, all the features and functionalities of the solution are presented. In addition, the problems that can be addressed by using the solution are listed. A general description of the solution from a technical point of view is provided, including the technologies used for the implementation of the solution. Finally, the implementation status of the toolkits in terms of current implementation (state of solution development at M18 - March 2024) and next developments (the future development plans) are presented. Further information on the solution can be found on the AIDEAS website: https://viewpoints.aideas-srv.cigip.upv.es/

Document structure

Each section of the document contains the information of one of the solutions, with a final section for conclusions, namely:

Section 1: Prescriptive Maintenance.

Section 2: Smart Retrofitter.

Section 3: LCC/LCA/S-LCA.

Section 4: Disassembler.

Section 5: Machine Passport.

Section 6: Conclusion.

1. Prescriptive Maintenance

1.1 Overview

The AIDEAS Prescriptive Maintenance is a toolkit for predicting the Remaining Useful Life (RUL) and identifying maintenance requirements with the target of extending the overall machine remaining life. Predicting component remaining life allows early detection of component degradation on industrial processes. This allows to schedule maintenance to avoid system failure when it is necessary and to define the specific set of actions for that specific potential failure instead of preventive maintenance, which is scheduled regularly, thereby incurring greater costs. The primary goal of the AI^{PM} solution is to provide an accurate information regarding the degradation of a system or component, along with the remaining useful lifetime. This is to support the decision-making process aimed at extending the overall machine lifespan.

The utilization of signal monitoring (physical or data models) or maintenance records constitutes the foundation for estimating the RUL of equipment or its critical components. Leveraging this input data, the Prescriptive Maintenance solution will deploy various techniques and algorithms—such as regression, artificial intelligence, and statistical methods—to develop an accurate degradation model tailored to the available data type. Each algorithmic approach offers a distinct insight: one provides a more specific estimation value of the remaining lifetime, while the other offers a more generalized assessment of the risk of failure. Both measures consider a range of uncertainty. This information will be crucial for the decision-making process of a prescriptive maintenance or second life modernization strategy. Prescriptive maintenance strategies will repair or replace damaged components within an optimal period of time, avoiding unplanned downtime, minimizing preventive costs and ensuring optimal performance levels of equipment during usage phases. With significant degradation impacting an entire assembly or a piece of equipment, decision-making will pivot towards strategies involving modernization or end-of-life considerations, including options for reuse or recycling to optimize the residual value of materials.

1.2 Features

The main features and functionalities offered by the AI^{PM} are the following:

- **Import Data**: The user can select data from different sources (MONGO databases, CSV, or EXCEL files).
- **Data Validation and Preprocessing:** This validates the training data and ensures that the input data is in the correct format before feeding it into the model.
- **Machine Configurator**: This allows the definition of the current machine configuration, to identify the different components and its associated variables.
- **Create and Export Models**: This provides different algorithms, which train on the available preprocessed data to determine if there is an anomaly, or if the system is not behaving as expected.
- **Obtain RUL and Failure Risk Estimation and Display Results**: Using trained models and new data, this allows to predict a RUL estimation and a failure risk at system component level in both machine and component.

- **Export Data**: This sends the data to the AIDEAS Machine Passport and allows the user to export it directly if needed.

The main problem that can be solved using this solution is the prediction of the remaining useful life of a machine or any of its components. For this, two different approaches can be used:

- The first approach is based on signal monitoring, where the behaviour of a set of signals is analyzed periodically and the RUL is predicted based on the current value of the monitored signals and their trend over a time window.
- The second approach is based on maintenance records, analyzing the time between the failure and the operating context in which the operation was performed.

1.3 Technical specifications

The AI^{PM} backend has been developed from scratch, based on new concepts, using previous knowledge and expertise in the field, and considering the current state of the art from existing literature. The solution's frontend has been developed using the AIDEAS project's UI template. No previous developments have been integrated into the solution.

In the first approach for the prediction of the RUL, the solution works with a fault observation database, which records the evolution of a set of signals in a period prior to a specific failure. For this purpose, the solution offers the user the possibility to select a set of signals associated with the fault. From this data, the solution initiates a learning process using a Long Short-Term Memory (LSTM) neural network from the Pytorch library. This model can capture long-term dependencies and patterns in the sensor data and can make a more accurate prediction of the RUL of the machinery, enabling proactive maintenance and minimizing downtime. In addition to selecting the fault and the signals to be monitored, the user can also adjust some network parameters. However, the network must be trained separately for each pilot's application.

In the second RUL prediction approach, the solution will attempt to assess the risk of failure of a component based on the cumulative time (or other significant driver) in operation and the impact of operational context parameters. Based on maintenance records and operating information, Survival analysis is performed using the Cox regression model (proportional hazards model) from Lifelines and pycox libraries.

The backend of the AI^{PM} is developed using python and FLASK as the framework for the API server. The backend provides the API endpoints through which the frontend communicates, sends requests, and obtains the results. The frontend of the solution is developed in REACT, using the AIDEAS's UI template.

For deployment, docker is used since it is the most widely used containerization solution. Docker also makes it easy to deploy the packaged application into the runtime environment and is widely supported by deployment tools and technologies. For internal storage, a MinIO server is used. MinIO is a High-Performance Object Storage.

1.4 Implementation status

1.4.1 Current implementation

Currently, the solution includes the following features:

- Creation or upload of the machine configuration file.
- Loading of reliability files (in the first approach, different observations of signal evolution before the failure, and in the second approach, a historical failure database with operational context data).
- Development of a RUL prediction model and a survival model for RUL prediction and risk assessment based on historical data.
- RUL prediction with an uncertainty range based on real data (simulated with data loaded from a file).
- The trained RUL model can be stored in a repository and re-loaded prior to a prediction.
- The AI^{PM} solution has been developed in Python environment.

Link to the GITLAB repository of the solution: https://gitlab-cigip.alc.upv.es/aideas/industrial-equipment-repair-reuse-recycle/pm-prescriptive-maintenance/pm

1.4.2 Next developments

Future development will include:

- Connection to different external data sources to ensure data reliability (monitoring signals or maintenance records).
- Adaptation of models (learning process) to data provided by AIDEAS pilots and improvement of prediction accuracy. Introduction of additional algorithms to choose from during training phase.
- Possibility to modify or employ new algorithms and models to enhance forecasting.
- Obtain results in real time or based on a predefined time interval (from real monitored data).
- Enhancement of the user interface to meet the needs of the pilots.
- Communication with the AIDEAS Machine Passport (i.e., sending the calculated failure risk and RUL results).
- Integration of keycloak for user management and access rights. The users will be integrated under MinIO, so each user can access certain information.

2. Smart Retrofitter

2.1 Overview

The AIDEAS Smart Retrofit (AI^{SR}) solution is a toolkit to retrofit old machines and bring them closer to the Industry 4.0 world. Since the old machines in most cases do not have the possibility to collect, analyze and share real machine data, the idea of the Smart Retrofit solution is to implement a hardware part and a software part. The first part can "sensorize" the machine and enable the connection with other systems. Then, these systems can collect and send the information to an industrial PC to carry out analysis with an AI algorithm, the software part of the Smart Retrofit solution. This tool allows companies to exploit the information and data obtained to understand the behaviour of an outdated machine/system and reprocess it to obtain value-added information. The structure of the Smart Retrofit solution is modular and generic for each application and features a set of devices that allow analogue and/or digital data to be acquired from a generic sensor and then shared with an industrial PC and possibly with the company's cloud system. The new sensors required to connect the machine are chosen following an assessment of the machine's AS-IS status. Once the hardware part of the Smart Retrofit solution has been installed, it is possible to exploit the artificial intelligence algorithm calibrated appropriately for the company's needs. The solution works mainly locally but can share information externally (e.g. cloud, business management systems, AIDEAS Machine Passport). As the solution is rather generic, it is also possible to integrate different solutions from the AIDEAS project into the software part of this Smart Retrofit tool, eventually installing new sensors that acquire data and information of interest to be processed with the different AI solutions.

2.2 Features

The main features and functionalities offered by the AI^{SR} are the following:

- **Data Acquisition**: This is achieved by the hardware pairing of the solution through the installation of new devices and sensors (where required).
- **Import Data**: The data acquired by the machine is automatically sent to the industrial PC where the AI algorithm works.
- **Data Validation and Preprocessing:** This validates the data and prepares the input data in the correct format before being entered into the model.
- **Data Analysis:** The input data is processed to obtain useful information for the company regarding the behaviour of the dated machine.
- **Obtain and Display Results:** Once the analysis is complete, results on the machine's behaviour are obtained and displayed on an intuitive user interface.

One of the problems that the Smart Retrofit solution manages to solve is related to the possibility of reusing an old machine making it more integrated in the context of smart factory and industry 4.0.

In particular, the Smart Retrofit solution enables sustainability by:

- Preventing the dumping of an old but functioning machine in the landfill.
- Preventing the purchase of a new machine, controlling the operation of the machine thus avoiding waste and inefficiencies (environmental sustainability).

- Preventing the destruction of internal knowledge related to the machine itself and not altering the assets of work (socially sustainable).
- Preventing facing huge new investments and waste of resources in general.

Thanks to the artificial intelligence algorithm, it is possible to reprocess the data collected by the machine and obtain information useful to the understanding and study of the behaviour of the dated machine. In addition, the genericity of the solution allows the integration of various AIDEAS solutions with an old machine, thus expanding the possibilities of analysis of the machine itself.

2.3 Technical specifications

The hardware part of the AI^{SR} solution has a generic configuration that includes several devices such as: PLC and related analog/digital input/output modules; a Wi-Fi module and/or LoRa antenna and gateway, an industrial PC and possibly a display. Depending on the needs it is possible to develop one of the following three configurations:

- SR-Box installed on the machine and industrial PC placed externally, where it receives data (through internet/intranet/LoRa), processes it, and displays it on a monitor.
- Industrial PC inside the SR-Box and installed on board machine. The sensors collect data via the PLC and sends it to the PC. The PC processes them and sends the results to the cloud/ AI^{MP} system.
- Use of Smart Sensors that send data to the Smart Retrofit solution located in a separate location from the machine. This solution is the least preferred due to the features of smart sensors and their higher cost than normal ones.

Each configuration uses the same devices (except for sensors) and has a similar structure for data exchange. Despite this, it is evident that they are well suited to different needs. In configuration 1, the PLC must be connected to the Wi-Fi antenna and the LoRaWAN antenna to communicate with both. In configuration 2 and configuration 3, the Wi-Fi connection module (or alternatively the LoRaWAN connection module and gateway) can be inserted to allow data to be sent to a central information management system. For communication via intranet and MQTT communication protocol, the industrial PC must also be connected to the intranet or a local network.

The software side of the AI^{SR} always works the same way. The data sent and saved in a database is automatically retrieved, pre-processed, and analysed by the artificial intelligence algorithm. A data request is made once the data analysis process starts. This request resumes after a certain amount of time. The data is pre-processed and used by the model extracted from the previous algorithm training. The results of the analysis will be displayed on an intuitive user interface through a screen/monitor, and simultaneously stored locally and/or sent to a cloud collection system.

2.4 Implementation status

2.4.1 Current implementation

The AI^{SR} is utilized only in the D2TECH pilot. The Smart Retrofit solution continues to undergo further development. In relation to the hardware part, an analysis and a selection of devices was conducted for the implementation of a tool capable of bringing an old machine closer to the world of Industry 4.0. Some devices ensure the development of a generic solution, modular and easy to integrate on a dated machinery. Following the selection of the specific devices, they were purchased, connected, and tested in such a manner that ensures the effective operation of each part. Therefore, it can be said that the hardware part is almost definitive.

Regarding the communication part, the possibility of integrating the communication via Internet/intranet, MQTT, and the communication protocol LoRa, as requested by D2TECH was studied. The main problem with using LoRaWAN lies in the speed, frequency, and latency in the transmission, possible collisions with other devices that transmit on the same band at the same time and the duty cycle. In particular, the regulation of this technology varies depending on the country in which it is used (no single standard in Europe), but in general, it is unsuitable for real-time or near real-time communication. However, LoRaWAN is a technology that is widely used in corporate contexts, and for this reason, it could be useful and advantageous to integrate it, to cross-check with information obtained via Wi-Fi, to send data to other systems already existing in the corporate context, and to develop a control phase with a certain delay that can be considered acceptable in the context of the machine.

As for the development of the AI algorithm, it is still under development, as D2T has encountered several obstacles in finding a dated machine on which to install the solution. In order to try to develop an AI algorithm that can be integrated into the Smart Retrofit solution, the PAMA pilot provided us with a data set concerning the energy consumption of one of their machines.

The dataset is currently being studied in order to improve as much as possible the AI algorithm most suitable for achieving the PAMA objective. Then the same algorithm will be re-trained on the data that D2T will provide us or that can be acquired on the old machine.

The algorithms identified as the best candidates for predicting the energy consumption parameters are artificial intelligence algorithms such as Decision Tree (regressive type) and Support Vector Machine (regressive type). The main libraries used for developing these algorithms in Python are *sklearn* for algorithms and *numpy*, *pandas* and *joblib* for the data pre-processing and for saving the model. Using these algorithms, it will be possible to take several input variables to return the prediction of the value of the energy variable. The input variables could be either binary values of type 0 and 1 or discrete values. The output will be the discrete value predicted consistently with what was learnt in the train-test phase and the values passed as input. From these outputs, it will be possible to tell whether the machine is consuming energy resources in a normal manner with respect to the activity it is performing or whether, due to a malfunction, problem or overload, it is consuming more/less energy than it should.

As for the user interface, a first prototype of the interface has been created, following the Figma mockups developed in AIDEAS D2.1 – Reference Architecture & Viewpoints.

Link to the GITLAB repository of the solution: https://gitlab-cigip.alc.upv.es/aideas/industrial-equipment-repair-reuse-recycle/sr-smart-retrofitter/sr

2.4.2 Next developments

- Complete the development of the AI algorithm for the Smart Retrofit Solution.
- Adjust and retrain the algorithm for the D2TECH pilot.
- Complete the development of the UI, connecting frontend and backend.
- Connect to cloud systems for data sharing (Communication with the AI^{MP}, sending the obtained results etc.).

3. LCC/LCA/S-LCA

3.1 Overview

The AIDEAS LCC/LCA/S-LCA (AI^{LC}) is a toolkit that combines AI and Life Cycle methodologies (LCC, LCA, S-LCA) for identifying the best machine end-of-life (EoL) by devising a multi-objective optimization strategy to strike a balance between economic, social, and environmental benefits.

The first step of this toolkit involves the analysis of end-of-life scenarios for machines. The company has different EoL scenarios to choose from once it decides to dismantle the machine. For instance, the company could carry out a destructive disassembly or a non-destructive disassembly or could grind the product to be able to deal with individual parts of the initial product. The individual parts of the product (called components) in turn can be subjected to disassembly, shredding, recycling, reuse if functional, valorization, or disposal in landfills. By proceeding iteratively according to this logic, the user will be able to create a tree representing all possible EoL processes.

The next step involves the impact analysis of different machinery EoL scenarios, from a cost (LCC), environmental (LCA) and social (S-LCA) point of view. The toolkit aims to model the disassembly/recycle process and predict the outcome of each disassembly/recycle action by examining the probabilistic relationships between the different aspects of the disassembly, sort, separate and recycle process. Considering the results obtained from LCC, LCA and SLCA, a Swarm Intelligence algorithm devises a multi-objective optimization strategy to identify the best EoL processes, to strike a balance between economic, social, and environmental benefits.

3.2 Features

The main features and functionalities offered by the AI^{LC} are the following:

- **Import Data**: The user can insert data through the UI (typically by opening a new project).
- **Data Validation and Preprocessing**: This validates the training data and ensures that the input data is in the correct format before feeding it into the model.
- **LCC/LCA/S-LCA Configurator**: This allows the definition of EoL scenarios by developing an EoL tree to identify the different EoL processes and their associated variables. It also allows the company to define the economic, environmental and social impact connected to each EoL processes. The EoL tree is an AND/OR tree in which layers with "component" nodes and layers with "process" nodes alternate. As output of each component/material node of the EoL tree, different deconstruction methods processes m (m=1,...,Mj) can be defined, e.g., Reuse/Repair/Recycle/Dismantling (landfill). For each "component" node, the user has to define the constituent materials, the weights of those materials, and the commercial value. For each "process" node m, the user has to insert the operational cost required to achieve that process, the inputs (resources) and outputs (emissions). As an output of each "process" node, the user defines which components/raw materials are obtained.
- **Create and Export Models**: This provides different algorithms. One algorithm calculates the optimal end-of-life path through an AND/OR search tree optimization algorithm. Moreover, a Swarm Intelligence algorithm has been developed in order to find the best

weights among economic, environmental and social parameters. When we go down one level in the EoL tree, the algorithm will add up all the costs of the levels above.

- **Obtain Predictions and Display Results**: This determines the best EoL path that minimizes the economic, environmental, and social impacts.

Export Data: This sends the data to the AIDEAS Machine Passport and allows the user to export it directly if needed.

The main **problem that can be solved** by using this solution is the optimization of the End-of-Life strategy for machine and components. This will increase the competitiveness and reputation of the company. Moreover, this tool will enhance reusability and recyclability of machine components, allowing the company relevant cost savings. The **main problem** for the user that relates to this solution is the identification of EoL processes and their impacts. An inappropriate End of Life strategy could result in inefficient exploitation of available resources. Other issues include the data gathering, which is time-consuming.

3.3 Technical specifications

To use the AI^{LC} solution, the user (a company employee) logs into the AIDEAS platform and enters the username and password. The user data could be collected via interactive prompts or GUI elements, allowing for a flexible and user-driven data input process. The user initiates the action of establishing a database connection or uploads data files. The Frontend sends a request to the Backend to process a connection to the database or to process the file upload. The Backend requests the storage layer (data/files) to authorize the connection or to prepare to receive the file. The Backend informs the Frontend about the success or failure of the connection or file upload operation.

The AI^{LC} is fed with different information, which the company provides through a UI. This information relates to the possible processes for their product EoL. The user can model a new EoL tree or upload an existing one. The Frontend sends a request to the Backend to model or upload a saved graph and perform the analysis. Following the creation of the EoL tree; for every EoL process, the company user has to insert some information regarding the process cost, the process environmental impact and the process social impact. During this stage, the AI^{LC} tool supports the user by proposing a list of characterization factors (for environmental assessment) and medium risk hours (for social assessment) for the most common processes.

One algorithm calculates the optimal end-of-life path through an AND/OR search tree optimization algorithm. Moreover, a Swarm Intelligence maximization algorithm has been developed to determine the best EoL path that minimizes the economic, environmental, and social impacts. For the algorithm development, different Python libraries have been used (such as pandas, matplotlib, sklearn, and numpy). The solution stores data and processes it locally and then sends it together with the results to a data collection cloud. Synchronous/Asynchronous Interfaces have been developed using RESTful APIs, while MySQL has been used for data repository. The Frontend of the solution is developed using Yes, Bootstrap and CodeIgniter (for the UIs).

For deployment, docker is used since it is the most widely used containerization solution. Docker also makes it easy to deploy the packaged application into the runtime environment and is widely supported by deployment tools and technologies. The AI[LC] toolkit is new and was developed using only open libraries that do not require licenses.

3.4 Implementation status

3.4.1 Current implementation

Currently, the solution includes the following features:

- Creation or upload of the configuration file for developing the EoL tree. The file can be saved too.
- Creation or upload of the configuration file for developing the LCC, LCA and S-LCA impact analysis.
- Data visualization from csv or excel files. Data can be visualized in both tables and graphs.
- MySQL connection and data visualization. The solution can be connected to an external SQL database to visualize its data in both tables and graphs.
- The Swarm Intelligence algorithm has been designed in Python environment. Models can be created choosing the input data, the set of variables to use, the algorithm and its parameters. Training results can be visualized as a report or in graphs, showing the current machine condition. The model can be saved too.
- Obtaining EoL best path and LCC, LCA and S-LCA values given a model and a new dataset. The results can be visualized as report, table, and graphs.

Link to the GITLAB repository of the solution: https://gitlab-cigip.alc.upv.es/aideas/industrial-equipment-repair-reuse-recycle/lc-lcc-lca-slca/lc

3.4.2 Next developments

Future developments will include:

- Communication with the AIDEAS Machine Passport i.e., to send the obtained results.
- Integration of keycloak for user management and access rights.
- Fine tuning the Swarm Intelligence algorithms.
- Creation of a far less customizable (with predefined parametrizations) version of the tool for unexperienced users.
- Enhancement of plots when huge datasets are loaded.
- Keeping a history of the results, saved under an internal database, for example MySQL.
- Tool implementation in the pilot company.

4. Disassembler

4.1 Overview

The AIDEAS Disassembler (AI^{DIS}) is a toolkit that allows the user to assess the wear status of a component or piece of equipment. This analysis is the first step before making the choice to keep the component in operation or to disassembly and dispose of it. The AIDEAS Disassembler allows users to analyze the status of an equipment disassembly with all the related information through image acquisition. Afterwards, the AIDEAS Disassembler will process the image through an artificial intelligence algorithm to understand the component status in terms of damage and possibility to keep it for the next operations.

This solution helps disassembly operators to effectively understand the state of wear and tear of the product to disassemble. Many times, machine components (for instance the cutting tool of milling machine) are disposed periodically, after a pre-determined number of working hours, without analysing the actual status of the component. Thus, the AI^{DIS} solution allows the state of the objects to be disassembled to be analysed using smart cameras. In fact, an artificial intelligence algorithm capable of detecting the defective areas of the analysed product is implemented and loaded on the latter devices. To achieve this, it is necessary to use machine learning techniques. In particular, Convolutional Neural Networks (CNNs) were chosen to work with the images. The development of reliable and trustworthy algorithms enables operators to make informed decisions based on real-time cues, simplifying the disassembly process, and ensuring high-quality results.

4.2 Features

The main features and functionalities offered by the AI^{DIS} are the following:

- **Import Data**: The user can insert data through a UI by opening a new acquisition. The purpose of this GUI is to allow the user to choose between starting the training or the testing phase of a program.
- **Data Validation and Preprocessing**: This validates the training data and ensures that the input data is in the correct format before feeding it into the model. Image augmentation techniques are available to enhance the training dataset. The tool allows users to adjust various camera settings such as brightness, contrast, exposure, saturation, white balance, and gain. It also provides functionality to save the captured images in a dataset.
- **Disassembler Configurator**: Users can select the specific disassembly program they want to execute. The application supports capturing images using smart cameras for analysis. The machine learning model is trained using the selected dataset.
- **Create and Export Models**: Users can test the trained model on new images to detect defective areas.
- **Obtain Predictions and Display Results**: This supports real-time camera analysis to aid the disassembly.
- **Export Data**: This sends the data to the AIDEAS Machine Passport and allows the user to export it directly if needed.

The main **problem that can be solved** by using this solution is to enhance reusability of machining components by avoiding the disposal of good components of the machine. Time and money can be saved by the company by analyzing the actual status of a component (e.g., a cutting tool in the PAMA pilot). Disassembling a component that could still work requires operator time for disassembly. In addition, replacing a component that is still good also constitutes environmental damage. The **main problem** for the user that relates to this solution is the identification of component status. Wear cutting tools/inserts result in poor surface machining quality and/or uncomplete machining. Inappropriate disassembly strategy could result in inefficient exploitation of available resources. Moreover, the training phase of the algorithm is time consuming.

4.3 Technical specifications

To use the AI^DIS solution, the user (a company employee) logs into the AIDEAS platform and enters the username and password. The user data could be collected via interactive prompts or GUI elements, allowing for a flexible and user-driven data input process. The user initiates the action of establishing a database connection or uploads data files. The Frontend sends a request to the Backend to process a connection to the database or to process the file upload. The Backend requests the storage layer (data/files) to authorize the connection or to prepare to receive the file. The Backend informs the Frontend about the success or failure of the connection or file upload operation.

The AI^DIS is fed with different information, which the company provides through a UI. The purpose of this GUI is to allow the user to choose between starting the training or the testing phase of a program. The user can evaluate a new image or upload an existing one. The Frontend allows users to adjust various camera settings such as brightness, contrast, exposure, saturation, white balance, and gain. It also provides functionality to save the captured images in a dataset. In particular, the ImageAugmentor class represents a Graphical User Interface (GUI) application for data augmentation of images using the Keras library. The application allows the user to apply various data augmentation techniques to create artificial images from existing ones.

The AI^DIS is made up of other applications as provided below:

- TrainingApp class represents an application that allows the user to train a data augmentation algorithm for generating artificial photos based on the images taken.
- The TestApp class represents an application that allows the user to run a data augmentation algorithm for generating artificial photos based on the images taken.
- The CameraAnalysis represents a GUI application for camera analysis using the Tkinter library for the GUI and OpenCV (cv2) for capturing and processing camera frames. The GUI allows the user to adjust various camera parameters such as brightness, contrast, exposure, saturation, white balance, and gain. Additionally, it provides functionality to save the captured images and navigate to the next and previous frames.
- The GlobalParamiters Class is a README that provides an explanation of the GlobalParamiters class, which is a utility class that contains all the initial variables used in the AI^DIS _Application. This class is responsible for managing and storing various global parameters that are shared between different parts of the application.

For the frontend and algorithms development, different Python libraries have been used (pandas, matplotlib, sklearn, numpy). The solution stores data and processes it locally and then sends it together with the results to a data collection cloud. Synchronous/Asynchronous interfaces have been developed using RESTful APIs while MySQL for Data Repository.

For deployment, docker is used since it is the most widely used containerization solution. Docker also makes it easy to deploy the packaged application into the runtime environment and is widely supported by deployment tools and technologies.

4.4 Implementation status

4.4.1 Current implementation

Currently, the solution includes the following features:

- Creation or upload of the configuration file for developing the analysis. The file can be saved too.
- Models for training or testing phases.
- Models to run a data augmentation algorithm for generating artificial photos based on the images taken.
- Applications for managing and storing various global parameters that are shared between different parts of the application.

Link to the GITLAB repository of the solution: https://gitlab-cigip.alc.upv.es/aideas/industrial-equipment-repair-reuse-recycle/dis-disassembler/dis

4.4.2 Next developments

Future developments will include:

- Communication with the AIDEAS Machine Passport i.e., to send the obtained results.
- Integration of keycloak for user management and access rights.
- Fine tuning the training and analysis algorithms.
- Creation of a far less customizable (with predefined parametrizations) version of the tool for unexperienced users.
- Enhancement of plots when huge datasets are loaded.
- Keeping a history of the results, saved under an internal database, for example MySQL.
- Tool implementation in the pilot company.

5. Machine Passport

5.1 Overview

The Repair-Reuse-Recycle task within the AIDEAS Machine Passport framework is a pivotal initiative designed to facilitate the efficient exchange of data across the end-of-life stages of industrial equipment. Aimed at consumers, repair shops, and waste management companies, this task simplifies the intricate web of data involved in the latter stages of a product's lifecycle. By integrating disparate sources of information into a coherent stream, the AIDEAS Machine Passport ensures that all parties have access to the data they need to make ecologically and economically sound decisions. More detailed information is available in D5.1 – Industrial Equipment Use Suite v1.

5.2 Features

Key features of the Repair-Reuse-Recycle task include:

- **Sustainable Data Management**: Streamlines the handling of data relevant to end-of-life processes, promoting sustainability.
- **Unified Data Standards**: Establishes common standards for data formats and communication protocols, enhancing interoperability.
- **Service-Oriented Architecture**: Adopts a service modelling approach to guarantee compatibility and quality of data.
- **Transparent Knowledge Sharing**: Ensures that knowledge derived from data is shared transparently amongst stakeholders.
- **AI-Driven Insights**: Utilizes explainable AI to provide clear, understandable insights from complex datasets for strategic decision-making.

5.3 Technical specifications

The technical infrastructure of the Repair-Reuse-Recycle task is designed for robustness and flexibility:

- **Large-Scale Data Acquisition**: Integrates data from multiple sources, ensuring a comprehensive overview of the end-of-life phase.
- **Adaptive Communication Protocols**: Employs flexible protocols to accommodate a diverse range of data interactions.
- **Application of Explainable AI**: Incorporates AI algorithms to demystify data analytics, making outcomes clear and actionable.

5.4 Implementation status

5.4.1 Current implementation

As of the current phase, the Machine Passport's Repair-Reuse-Recycle task has made significant progress in establishing a solid foundation for data exchange and commenced the development of specialized applications in line with WP2 objectives.

Link to the GITLAB repository of the solution: https://gitlab-cigip.alc.upv.es/aideas/machine-passport

5.4.2 Next developments

Planned future developments include:

- Enriching the data exchange framework to support a wider array of end-of-life data scenarios.
- Advancing the use of explainable AI for deeper insight into recycling and repurposing strategies.
- Implementing rigorous data quality and consistency checks to ensure information reliability.
- Designing intuitive interfaces for stakeholders to interact seamlessly with the Machine Passport.
- Strengthening security protocols to safeguard sensitive end-of-life data.

These enhancements will solidify the AIDEAS Machine Passport's role as a vital tool in the end-of-life management of industrial equipment, driving informed decisions that support sustainability and resource conservation in the supply chain.

6. Conclusions

This deliverable presents a technical summary of the solutions included in Work Package 6 of the AIDEAS project. It corresponds to the first release of the solutions in M18. There will be two additional iterations of this deliverable, one in M24 for the final release of the solutions and the other at the end of the project including possible changes derived from the continuous integration and the validation of the solutions inside the Pilots.

The document describes the overall development of innovative artificial intelligence-based toolkits for the Industrial Equipment Repair-Reuse-Recycle suite, focused on improving the life cycle of industrial machines through prescriptive maintenance, smart retrofit, and end-of-life management strategies. The toolkits developed, including Prescriptive Maintenance, Smart Retrofitter, LCC/LCA/S-LCA, Disassembler and Machine Passport, are designed to integrate seamlessly with existing industrial configurations, providing AI solutions to extend the life of machinery, enabling smart retrofit for second-life applications, and ensuring environmentally responsible recycling strategies. In fact:

The AI^{PM} uses advanced techniques, such as AI, to predict the remaining useful life of machines and plan targeted maintenance, reducing costs and downtime. This approach allows optimising machine performance and making informed decisions about modernisation or reuse in the event of significant degradation.
The AI^{SR} solution upgrades older machines for Industry 4.0, installing sensors and software with AI to analyze and reuse data and information. This makes dated machines more efficient and integrated with enterprise or cloud systems, facilitating management and performance evaluation.
The AI^{LC} uses AI to define the best end-of-life strategy for machines, balancing economic, social, and environmental benefits. It analyses various dismantling and recycling scenarios, and through advanced algorithms, identifies the optimal options based on the cost-environmental-societal impact.
Finally, the AI^{MP} is a complete digital repository for industrial data, simplifying data management and providing real-time access to dynamic and static machine information.

To make these advanced solutions accessible to end users without requiring in-depth technical knowledge, each toolkit has been carefully designed with user-friendly interfaces, ensuring that the complex underlying technologies, primarily AI, are transparent to users, enabling them to make informed decisions for maintenance, retrofitting and end-of-life strategies.

This document outlines the current state of implementation and future development plans, highlighting ongoing efforts to refine and enhance toolkit capabilities to meet industry needs. Solution development is proceeding according to plan, with an initial stable version ready to be tested. These initial versions are available through the Gitlab repository, as indicated in the Current Implementations sections. The solutions of this Suite will be tested in pilot projects in different sectors by the companies PAMA, BBM, D2TECH and MULTISCAN.

7. References

AIDEAS D2.1 – Reference Architecture & Viewpoints

AIDEAS D5.1 – Industrial Equipment Use Suite