CEN WORKSHOP AGREEMENT

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English version

Circularity Protocols for extending the useful Life of Large Industrial Equipment

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European foreword

This CEN and CENELEC Workshop Agreement has been developed in accordance with the CEN-CENELEC Guide 29 “CEN/CENELEC Workshop Agreements – A rapid prototyping to standardization” and with the relevant provisions of CEN/CENELEC Internal Regulations - Part 2. It was approved by a Workshop of representatives of interested parties on 2022-12-20, the constitution of which was supported by CEN and CENELEC following the public call for participation made on 2022-03-11. However, this CEN and CENELEC Workshop Agreement does not necessarily include all relevant stakeholders.

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The following organizations and individuals developed and approved this CEN and CENELEC Workshop Agreement:

— ASOCIACION DE INVESTIGACION METALURGICA DEL NOROESTE (AIMEN);

— ATLANTIS ENGINEERING AE (ATLA);

— AUSTRIAN STANDARDS INTERNATIONAL (ASI);

— BIBA - BREMER INSTITUT FUER PRODUKTION UND LOGISTIK GMBH (BIBA);

— CLEOPA GMBH (CLEOPA);

— DEUTSCHE INSTITUT FÜR NORMUNG e. V. (DIN);

— IDEKO RESEARCH CENTER (IDEKO);

— IRISH MANUFACTURING RESEARCH (IMR);

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This CWA has been proposed by the LEVEL-UP European Project (funding from the European Commission’s Horizon 2020 – The Framework Programme for Research and Innovation (2014 - 2020) under Grant Agreement No 869991).

Introduction

The LEVEL-UP project performs research leading to offer a scalable platform covering the overall lifecycle, ranging from the digital twins setup, modernisation actions to diagnose and predict the operation of physical assets, to the refurbishment and remanufacturing activities towards end of life. In-situ repair technologies and the redesign for new upgraded components will be facilitated through virtual simulations for increased performance and lifetime.

In 1976, Stahel and Reday have introduced features of the circular economy with a focus on the industrial economy. They defined a circular economy to describe industrial strategies for waste prevention, regional job creation, resource efficiency and dematerialisation of the industrial economy [11]. Since then, one common approach is that in a circular economy, waste can be minimised by sharing, leasing, reusing, repairing, refurbishing, and recycling existing materials and products for as long as possible. This extends the life cycle of products and minimises waste. A product can also be a machine in a production environment, which is the focus of this CWA. The circular economy is a regenerative system that minimises resource use, waste production, emissions and energy waste by slowing down, reducing and closing energy and material cycles.

In parallel, the development of technologies within the framework of Industry 4.0 enables flexible and adaptable production processes. Thus, the potential of circular principles in the context of digital transformation is undeniable. The challenge is that there is a lack of an efficient, systemic, multi-level approach that enables a recursive, cost-effective, holistic and integrated application of circular principles for the digital upgrading of Factory 4.0 investments. There is no single approach that addresses issues at the product, process, system and whole value chain levels and integrating best practices from emerging enabling digital technologies. The Protocols Specifications Document (PSD) fills this gap.

This document is the first version of the Protocols Specifications Document (PSD). It gives firstly a holistic overview about the ten protocols and their interactions flowchart. Depending on the actual scenarios in industrial companies, they can follow the flowchart to reach the goal of extending the useful Life of major capital investments and Large Industrial Equipment. In order to enable companies understanding the details of each protocol, this document provides guidelines for the ten special protocols. Each protocol guideline provides protocol definition and detail description of protocol, including purposes, conditions, as well as list of detailed actions and steps. For each protocol, this document gives a flowchart to visualize the process and interaction of different actions and steps. The kind of guidelines and flowchart will accelerate industrial companies to understand and adopt the LEVEL-UP protocols.

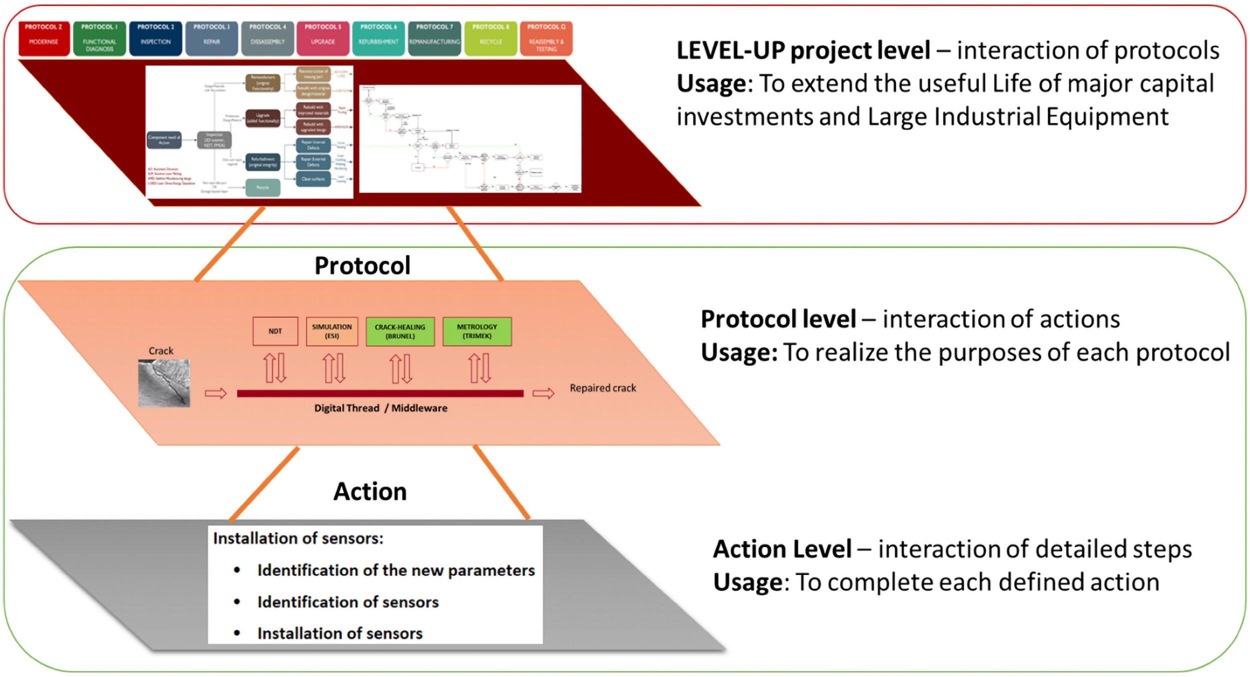

Figure 1 — LEVEL-UP Protocol Abstraction Levels

This section describes the approach to develop the formal LEVEL-UP Protocols Specifications Document. As illustrated in Fig. 1, we can organize the LEVEL-UP protocols in different abstract levels. At the top LEVEL-UP project level, we propose the ten Circularity protocols. These ten protocols interact with each other to extend the useful Life of major capital investments and Large Industrial Equipment in industrial companies. It provides a holistic view about the protocols, as well as synergies and interactions between the ten LEVEL-UP protocols. Afterwards, we can then come to the world of each protocol. At the protocol level, it describes each protocol about, for instance, their purposes, applicable conditions and list of actions. Interaction of these actions is to realize the specified protocol purposes. While, in order to complete defined actions, users may need to follow detailed steps in detail level. For example, in the action of "installation of sensors", users need to first identify new parameters, understand what kind of sensors are required, and then carry out the physical activity of sensor installation.

This deliverable gives protocol guidelines at top LEVEL-UP project level in Chapter 2. It covers a holistic view about the protocols, synergies and interactions between protocols, linkage between LEVEL-UP protocols and LEVEL-UP architecture, as well as short description of the application of protocols in pilots. Based on the understanding of LEVEL-UP protocols at high level, Chapter 3 provides protocols guidelines for each protocol at the protocol and action level. In order to develop protocol guidelines at the protocol and action level, the following main steps are carried out:

— Step 1: Define protocol. This step is to provide definition and description for each protocol. It gives summary description about protocol from various aspects, for instance, protocol scope, protocol purposes, applicable conditions, triggers, input, output etc. Within this step, protocol developers can work together with pilots to understand the problems or questions that the industrial companies currently have and want to solve. This kind of problem understanding activity will lead protocol developers to define protocol clearly to solve the industrial problems. Fig. 2 shows a sample list of questions, outcome from the problem understanding activity.

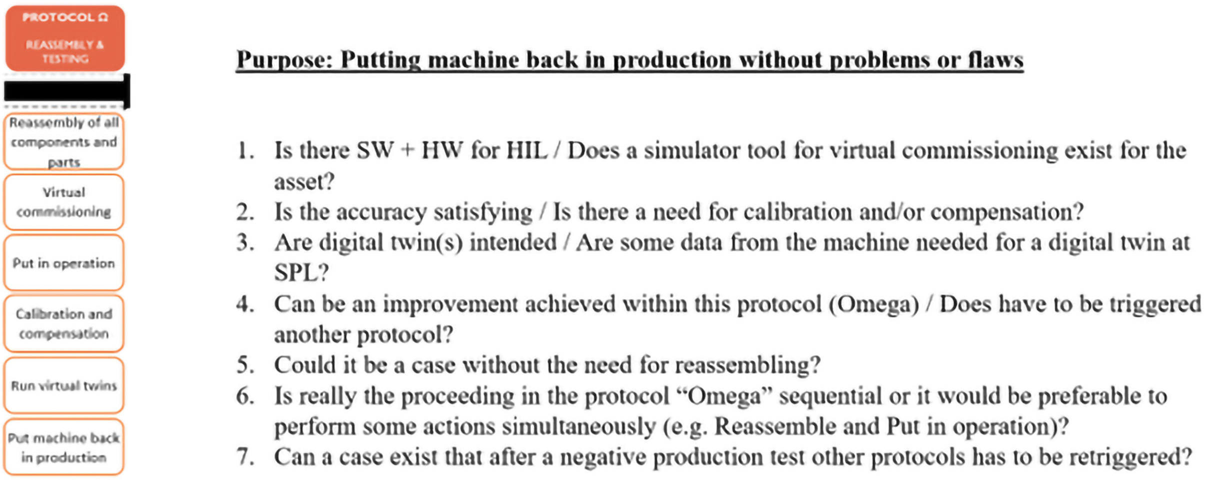

Figure 2 — Example list of questions in the development of Reassembly & Testing Protocol

— Step 2: Provide list of actions for protocols. Following the protocol definition, this step is to provide list of actions to enable the defined protocol. It will update and improve the action schema for each protocol. It defines list of supportive actions, describe relationships and interactions among actions. For each action, it will provide detailed description. In case of necessary, it provides, as well, the detailed description of steps, which are required to complete a given action.

— Step 3: Visualize the protocol guidelines. After clarifying protocol understanding, this step is to visualize the protocol guidelines in the form of flowchart. So that, users in industrial companies can follow the flowchart as guideline to complete the protocol and solve their problems in reality. It takes the outcomes from the last steps as input and provides a flowchart as output. Start point of a flowchart is trigger of the current protocol. The trigger can be, for example, another protocol or some decision making. Endpoint of a flowchart can be further protocols or other conditions.

— Step 4: Develop digital thread for protocol. This step is to define digital thread to link various LEVEL-UP components supporting the defined protocols. It will try to identify and link relevant LEVEL-UP components with the steps and actions defined in the protocol guidelines. While we intend to keep the protocol guidelines generic enough to improve the applicability and to accelerate the adoption in industries. It is clear that LEVEL-UP components cannot cover all the actions and steps in the protocol. Figure 3 shows a sample digital thread in the repair protocol.

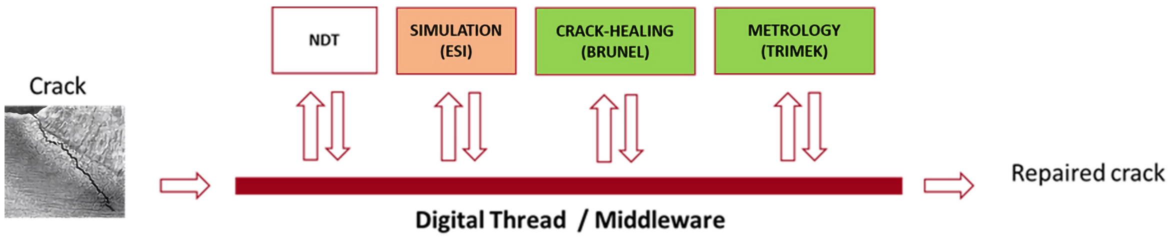

Figure 3 — Example digital thread in the development of Repair protocol

— Step 5: Deploy digital thread in industrial pilots. This step is to deploy digital thread in the industrial pilots to realize the defined protocols. It involves deploying the DT design tool as a service in manufacturing companies. After the service's deployment is ready, manufacturers can stepwise apply and realise protocols activities on their capital items to extend useful life. It allows manufacturers to manage the status of capital items during their life cycle.

This task has two version of deliverable. The first version is mainly about the protocol guidelines. It covers mainly the holistic view about the protocols in chapter 2, as well as the outcomes from the step 1, step 2 and step 3 for each protocol. This document is the final version of the deliverable. It extends the first version to covers the deployment and digital thread part, which is the results from the step 4 and step 5.

1 Scope

This CEN-CENELEC Workshop Agreement (CWA) is the output of "Task 1.5 Horizon 2020 LEVEL-UP Project" and describes ten (10) special Protocols for modernising, diagnosing, inspecting, repairing, disassembling, upgrading, refurbishing, remanufacturing, recycling and reassembly & testing. It provides a formal LEVEL-UP Protocols Specifications Document (PSD), specifying for each protocol unambiguously steps, processes, deployment requirements and conditions, etc. It will provide in total two version of PSD.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

3.1 Definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp/

— IEC Electropedia: available at https://www.electropedia.org/

3.1.1
upgrade
process of enhancing the functionality, performance, capacity or aesthetics of a product

[SOURCE: EN 45554:2020, 3.1.5]

3.1.2
repair
process of restoring a faulty product to a condition where it can fulfil its intended use

[SOURCE: EN 45552:2020, 3.1.3.5]

3.1.3
remanufacturing
industrial process which produces a product from used products or used parts where at least one change is made which influences the safety, original performance, purpose or type of the product

Note 1 to entry: The product created by the remanufacturing process may be considered a new product when placing on the market. Refer to the EU Blue Guide [1] for additional information.

Note 2 to entry: Refurbishing is a similar concept to remanufacturing except that it does not involve changes influencing safety, original performance, purpose or type of the product. It is not covered by this standard.

[SOURCE: EN 45553:2020, 3.1.1]

3.1.4
recycling
recovery operation of any kind, by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes excluding energy recovery

Note 1 to entry: Recycling includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations.

[SOURCE: EN 45555:2019, 3.1.6]

3.1.5
reuse
process by which a product or its parts, having reached the end of their first use, are used for the same purpose for which they were conceived

[SOURCE: EN 45554:2020, 3.1.3]

3.1.6
disassembly
process whereby a product is taken apart in such a way that it could subsequently be reassembled and made operational

[SOURCE: EN 45553:2020, 3.1.3]

4 Protocols overview

4.1 General

The LEVEL-UP Circular Protocols describe what actions and processes should be executed in an structured and formalised manner in order to modernize, upgrade and extend the lifetime of the large industrial equipment, connecting them to the Industry 4.0 paradigm and increasing their competitiveness. The information stored in IT systems, and the data acquired from the different actors in each Protocol will be linked with the Industrial Digital Thread paradigm.

4.2 Protocol description

4.2.1 General

It has in total 10 Circular Protocols which involves a series of actions and processes linked to the different components and solutions offered in the project. In the development of the protocol guidelines, we have updated the action schema for each protocol, as shown in Figure 4. Clause 3 provides detailed guidelines for each protocol.

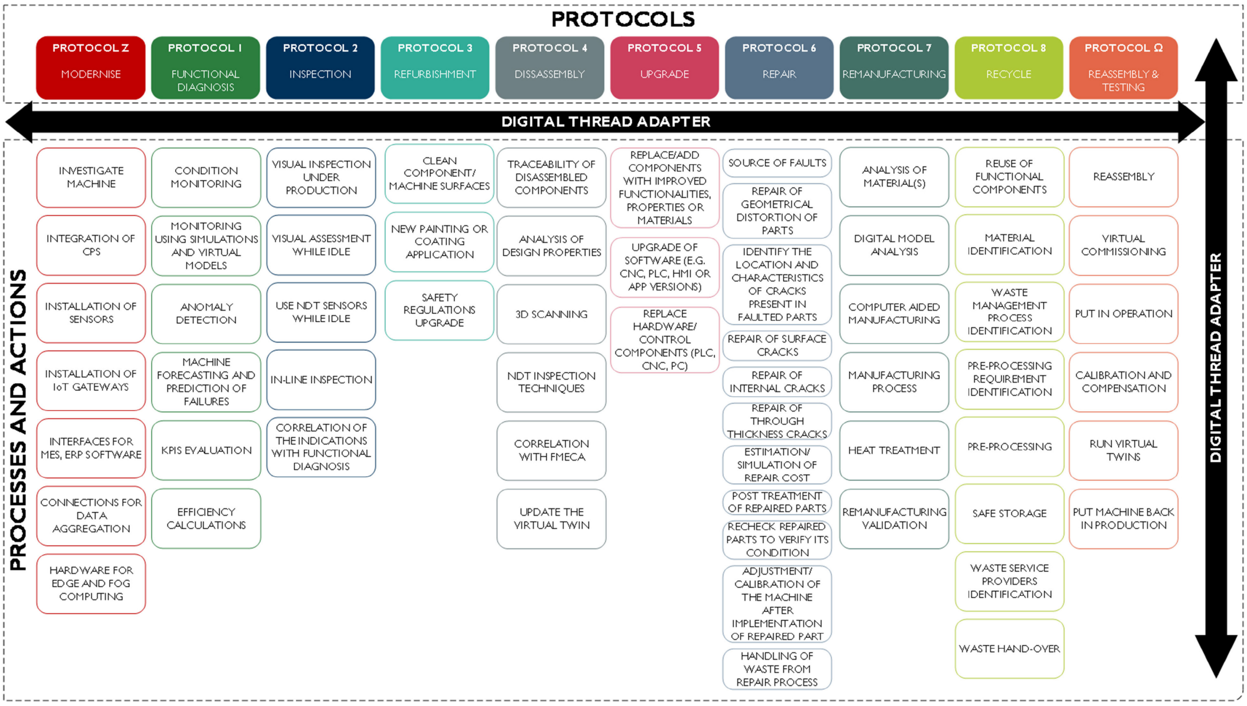

Figure 4 — LEVEL-UP protocols weaved together with an Industrial Digital Thread

4.2.2 PROTOCOL Z – MODERNISE

Protocol Zero involves the actions prior to any of the other protocols being applied. It involves the retrofitting of the old and legacy machinery with Industry 4.0 modules. The goal is to connect the physical with the digital world involving CPS, Sensors, Interfaces and gateways with IoT platforms and ERP, MES, and other IT Transactional data. Upon the finalisation of Protocol Z, the system will be modernised to host the LEVEL-UP strategies and functions.

4.2.3 PROTOCOL 1 – FUNCTIONAL DIAGNOSIS

Protocol 1 Functional Diagnosis involves actions on machines where sensors and CPS are already in place. This can be the status of the machines in an “as is” condition, when Protocols are introduced. Otherwise, if machines are not ready for Functional Diagnosis to be applied, Protocol Zero - Modernise is first implemented. Hence, Protocol 1 is triggered when there is enough data to be analysed, in order to derive a diagnosis on the status of the equipment.

4.2.4 PROTOCOL 2 – INSPECTION

This protocol involves the visual inspection of the machine from the experts while it operates. The use of NDT sensors and their correlation with the findings from the functional diagnosis will provide insights for a focused inspection while the machine is idle. In case of a suspected failure this protocol will trigger the repair or disassembly protocols, based on the degree of degradation or damage.

4.2.5 PROTOCOL 3 – REFURBISHMENT

The Refurbishment protocol is about the light repair and cleaning of the system to bring it to its original status and integrity (as-new status). Old grimy machines, with corroded or rusted surfaces will be cleaned and treated (painting/coating application) in order to bring them to their original status.

4.2.6 PROTOCOL 4 – DISSASEMBLY

Disassembly protocol is a methodology or series of steps to be applied each time a component from a machine is separated or taking apart from it (disassembled). The general purpose is having a deeper knowledge of a specific component that is potentially defective, damaged or needing an improvement by taking the part out of the machine to run some tests and evaluations.

4.2.7 PROTOCOL 5 – UPGRADE

Protocol UPGRADE involves the actions of improving functionalities (incl. also performance, reliability, connectivity, interoperability, durability, security, etc.). So, it means upgrade the materials with improved ones. Old parts will be replaced with improved versions, considering the adoption of advanced materials, built by conventional or new technologies as Additive Manufacturing. Apart from replacement, Upgrade involved the addition of features that were not installed to the original design. Therefore, Upgrade Protocol is about any hardware that provides increased functionalities and properties to the machine.

4.2.8 PROTOCOL 6 – REPAIR

This protocol can be executed both while all components are in place or after disassembly. In the first case, it can either trigger the protocol refurbishment as remedy actions for cleaning and painting, or trigger the protocol Omega for tool adjustments and calibration. In case the components are removed from the machine, the process can also include laser cladding and electropulsing techniques and different pre and post-processing operations. The virtual model of LEVEL-UP will simulate the various scenarios to identify the most suitable repair.

4.2.9 PROTOCOL 7 – REMANUFACTURING

The remanufacturing protocol is intended to restore parts' original functionality. It is mostly suitable for parts that are non-repairable and thus, situations where there are clear advantages for the remanufacturing and not replacement, for several industries. It allows the remanufacturing of one or more missing parts as well as the recovery of the original design and/or material.

4.2.10 PROTOCOL 8 – RECYCLING

The Recycling protocol consists in the recovery and valorisation of materials from components that cannot be repaired. The aim of the protocol is to have a clear set of guidelines to determine how these materials can treated to be reutilised again in the production of products for the same or different industries.

4.2.11 PROTOCOL Ω – REASSEMBLE AND TESTING

The protocol Omega is the last protocol aiming at putting machine back in production without problems or flaws. For example, this can include tool adjustment and/or calibration etc. During this phase, validation of the processes and testing will ensure that the machine will be put back into production with no flaws or problems. The virtual scenarios will increase the efficiency avoiding possible risks during the previous processes.

5 Synergies and interactions between the ten LEVEL-UP protocols

5.1 General

As illustrated in Figure 5, then ten LEVEL-UP protocols are able to work in synergy with each other, to modernize, upgrade and extend the lifetime of the large industrial equipment. Starting from modernisation and functional diagnosis to find components in need of action, it goes then through inspection. Depends on the finding from inspection, further actions (e.g. remanufacture, upgrade, refurbishment and recycle) can be carried out.

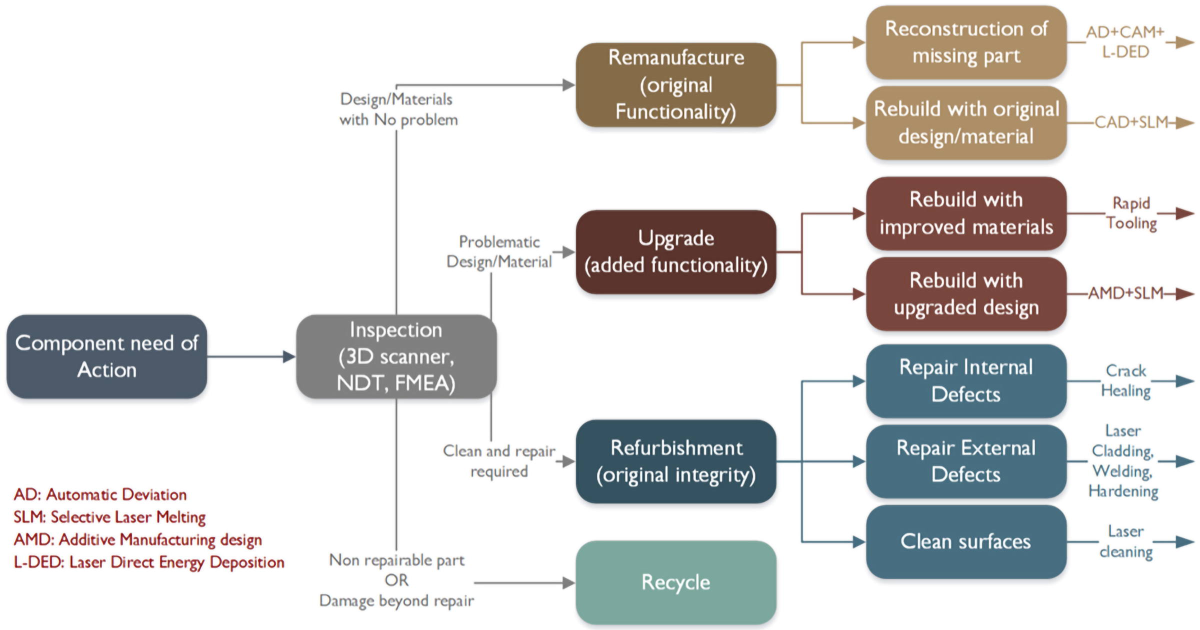

Figure 5 — Synergic interaction between LEVEL-UP protocols

The LEVEL-UP Protocols are actuated based on the findings from the executed processes and actions, and therefore there is no requirement to follow a specific order or sequence. Fig. 6 provides serveral samples of industrial scenarios, in which the protocol can be triggered in different orders.

Figure 6 — Sample industrial scenarios with the application of LEVEL-UP protocols

Figure 7 gives a flowchart to illustrate the synergies and interactions between the ten LEVEL-UP protocols. It guides users to go through the ten protocols, find out which protocols are applicable for problem solving in their current situation. Although we try to make the flowchart as generic and holistic as possible for reference purposes, it cannot cover all industrial scenarios in reality. In special industrial scenarios, users may need to go through the protocol guidelines in detail to find the best set of workflow for their problems.

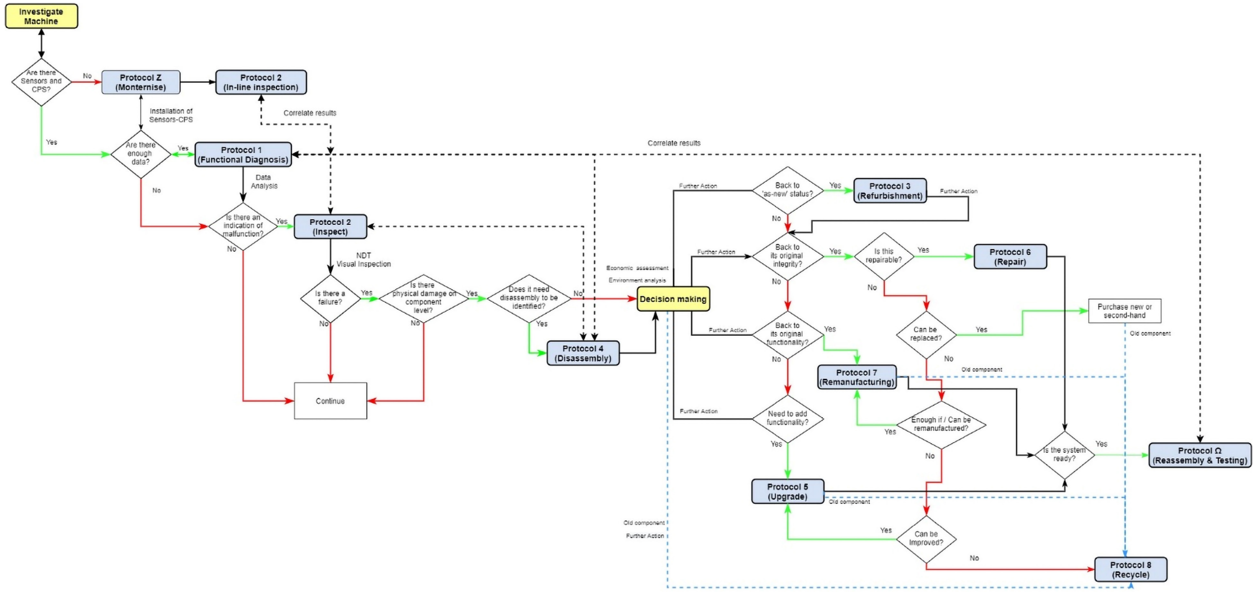

Figure 7 — LEVEL-UP Protocols flowchart

5.2 Realization and application of LEVEL-UP protocols actions in Pilot Lines

Depending on the user-case needs and requirements already defined, not all the protocols will be applied in all the pilot lines. Figure 8 illustrates the current overall protocols deployment in each of the pilot lines.

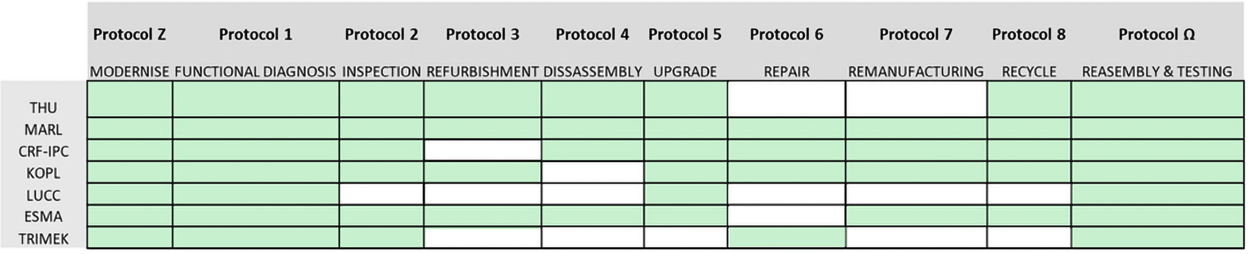

Figure 8 — LEVEL-UP protocols deployment in the pilot lines.

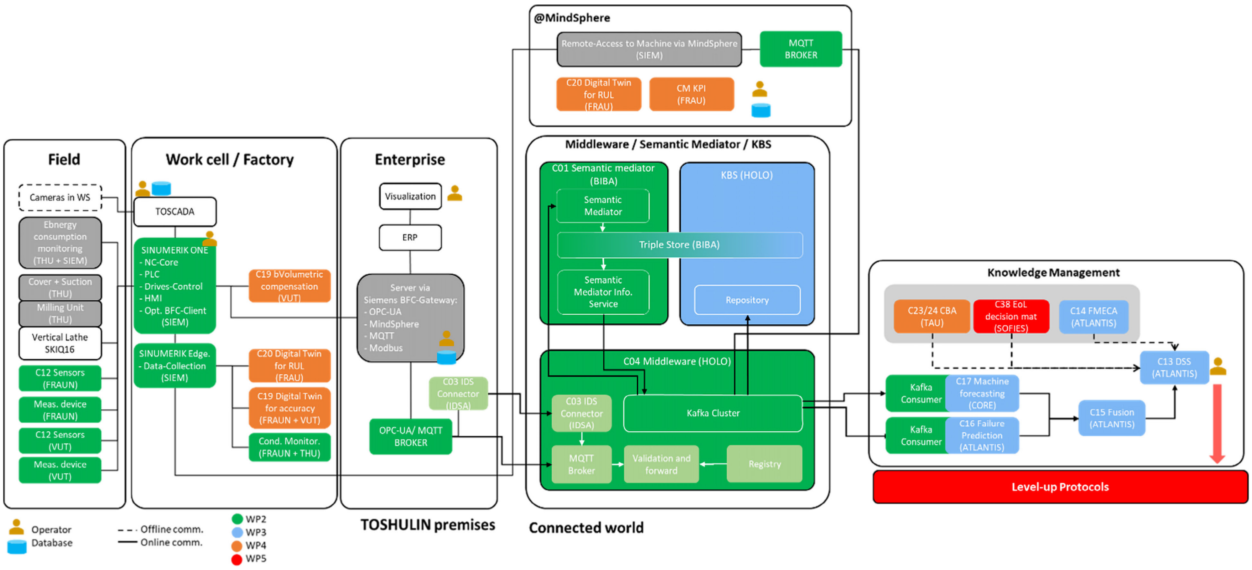

Figure 9 — System architecture in TOSHULIN pilot

6 Specification of LEVEL-UP Protocols

6.1 General

This clause provides protocols guidelines for each protocol at both protocol and action level. It gives a definition and short summary for each protocol. Following the protocol definition, it provides a list of actions to enable the defined protocol. After clarifying protocol definition and protocol actions, reference workflow in the form of flowchart are developed to visualize and guide the execution of protocol actions and steps. Users in industrial companies can follow the flowchart as guideline to complete the protocol and be able to retrofit their equipment in reality.

6.2 PROTOCOL Z – MODERNISE

6.2.1 Protocol definition and summary

Protocol Z MODERNISE involves the actions prior to any of the other protocols being applied. It involves the retrofitting of the old and legacy machinery with Industry 4.0 modules. The goal is to connect the physical with the digital world involving CPS, Sensors, Interfaces and gateways with IoT platforms and

ERP, MES, and other IT Transactional data. Upon the finalisation of Protocol Z, the system will be modernised to host the LEVEL-UP strategies and functions. In short summary:

a) The protocol Z is applied once at every pilot (or use case) and it starts after accomplishing a series of preliminary actions grouped as 'Investigate machine'.

b) It is a prerequisite for other LEVEL-UP protocols and strategies

c) It can be considered as an enabler of the LEVEL-UP architecture. When the Protocol Zero is applied to a pilot, the pilot becomes LEVEL-UP Ready.

d) The Protocol Zero highly depends on the pilots. Each pilot needs different set of actions for the protocol implementation.

    — customized action lists for each pilot. This is mandatory in order to define a common formalization for all pilots.

e) Protocol Zero is a migration methodology (proposed approach) that tends to align a current situation of a pilot line (AS-IS) with the LEVEL-UP architecture (TO-BE)

— "infrastructure" crosscutting function

— data collection – manipulation – management

6.2.2 Protocol actions and reference workflow

Seven main actions are organized to support the protocol application after the machine investigation:

a) Investigate machine.

    1) Machine operational evaluation: identification of current machine failures, components failures, KPIs review [AS-IS scenario]

    2) Machine CPS evaluation: CPSization status, review of sensors installed in the machine, gateways, interfaces, HW/SW for edge, fog, or cloud computing …etc. [AS-IS scenario]

    3) Enterprise IT architecture and systems evaluation: MES, ERP systems, servers, cloud connections…etc. [AS-IS scenario]

    4) Work plan with the objectives to be achieved based on the machine operational evaluation, manufacturer priorities and technical and economical feasibility. (i.e: decrease maintenance down times, process simulation for process optimization, off-spec % reduction, reduction of broken spare-parts and components, extension of key components lifetime…etc.)

b) Integration of CPS.

    1) Support data collection (Manage sensors, how?).

    2) Support LEVEL-UP functions (Reactive) that "run" near to the field (define these functions, i.e., condition monitoring).

    3) Communication capabilities. (communication with the field, with the upper layer, with a human).

    4) I4.0 Standards (AAS -Asset Administration Shell)?

c) Installation of Sensors.

1) Identification of the new parameters -Depicted by LEVEL-UP Components I/O-that needs to be monitored. Can these parameters be measured with the sensors already available?

2) Definition of Sensors (type, mechanical/electrical specs, etc) that needs to be install considering the parameters to measure and the process conditions.

3) Installation of Sensors – Physical work.

4) Sensor Calibration – Metrology.

d) Installation of IoT Gateways.

1) Definition of the network infrastructure- basic. What is the current infrastructure? Any updates/upgrades/improvements needed (i.e., cables, network equipment, etc)?

2) Definition of the network protocols for the inter - communication (among layers). (CPS to IoT, sensor to PLC, etc). Which, if any standards for it?

3) Definition of the IoT gateways specification. (CPU power, storage capabilities, connectivity).

4) Definition of the IoT HW/SW (existing or new).

i. Which LEVEL-UP functions/components should be supported?

e) Interfaces for MES, ERP, Software.

1) Definition of Enterprise software that needs to be interfaced.

2) Which data types will be acquired?

3) Implementation of the Connectors for the enterprise software.

f) Connection for Data aggregation.

1) Data Identification (to be sent to ERP, MES systems, cloud?) and Data evaluation (size, type…etc.)

2) Description of data collection, data processing and data sharing.

3) Specification of operator data interaction.

4) Storage definition and data visibility.

5) Components that produce/consume data.

g) Hardware for Fog and Edge computing.

1) Define the network topology for each pilot.

2) Servers, cloud clusters etc.

3) Adapt current topology to LEVEL-UP architecture.

In addition to the seven main actions, there are five migration steps:

1) Use and update the assessment questionnaire given to pilots.
2) Generate a Migration Matrix for protocol actions.
3) For each use case, AS-IS situation Definition (Step 1- feedback).
4) For each use case, Migration Paths from AS-IS towards TO-BE situation.
5) Definition for each protocol action (based on Step 2 and 3).
6) Migration Paths Implementation.

Stepwise execution of these actions and steps are illustrated in the Modernize protocol flowcharts below:

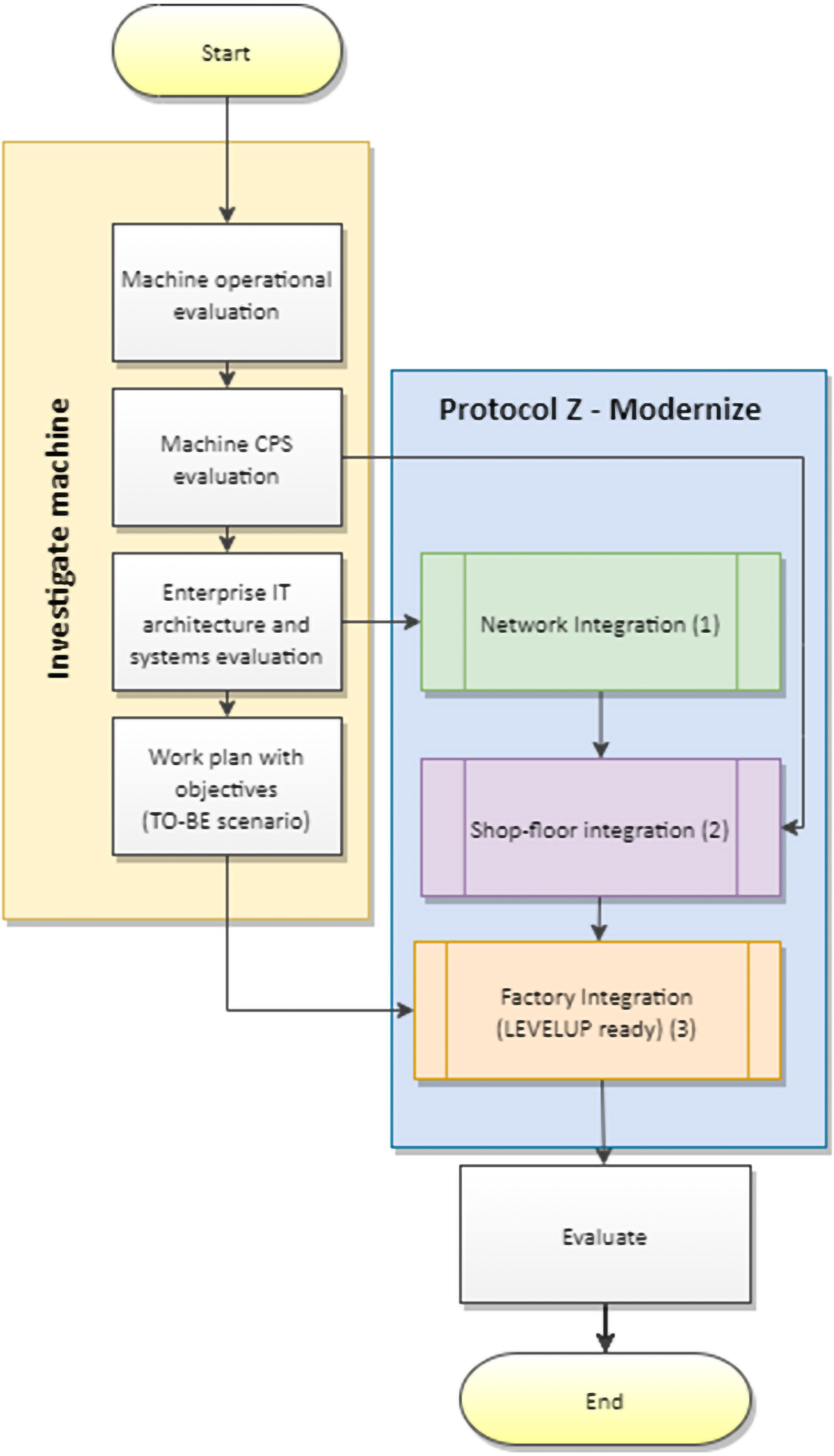

Figure 10 — Protocol Modernize workflow – overview

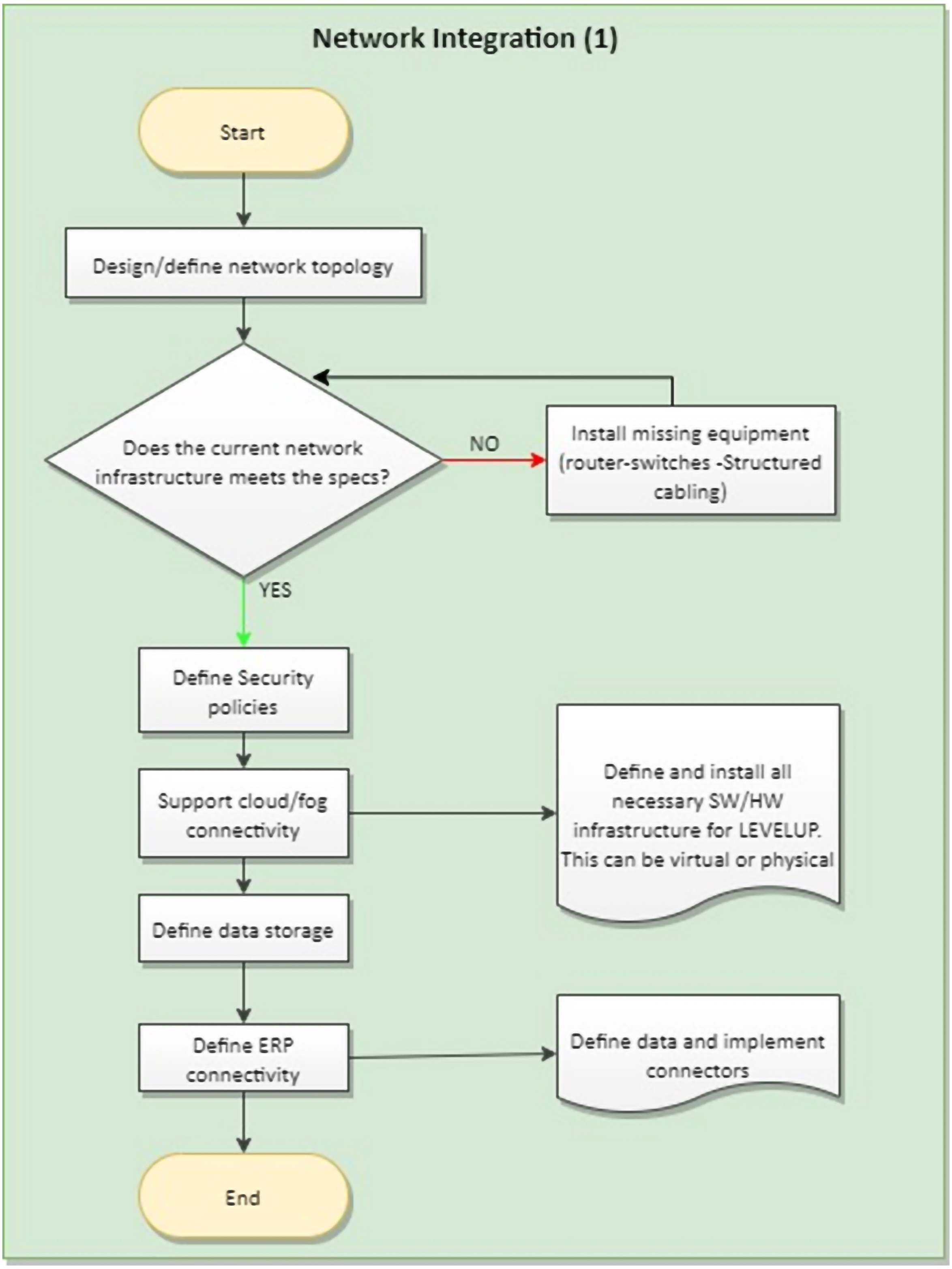

Figure 11 — Protocol Modernize workflow - network integration

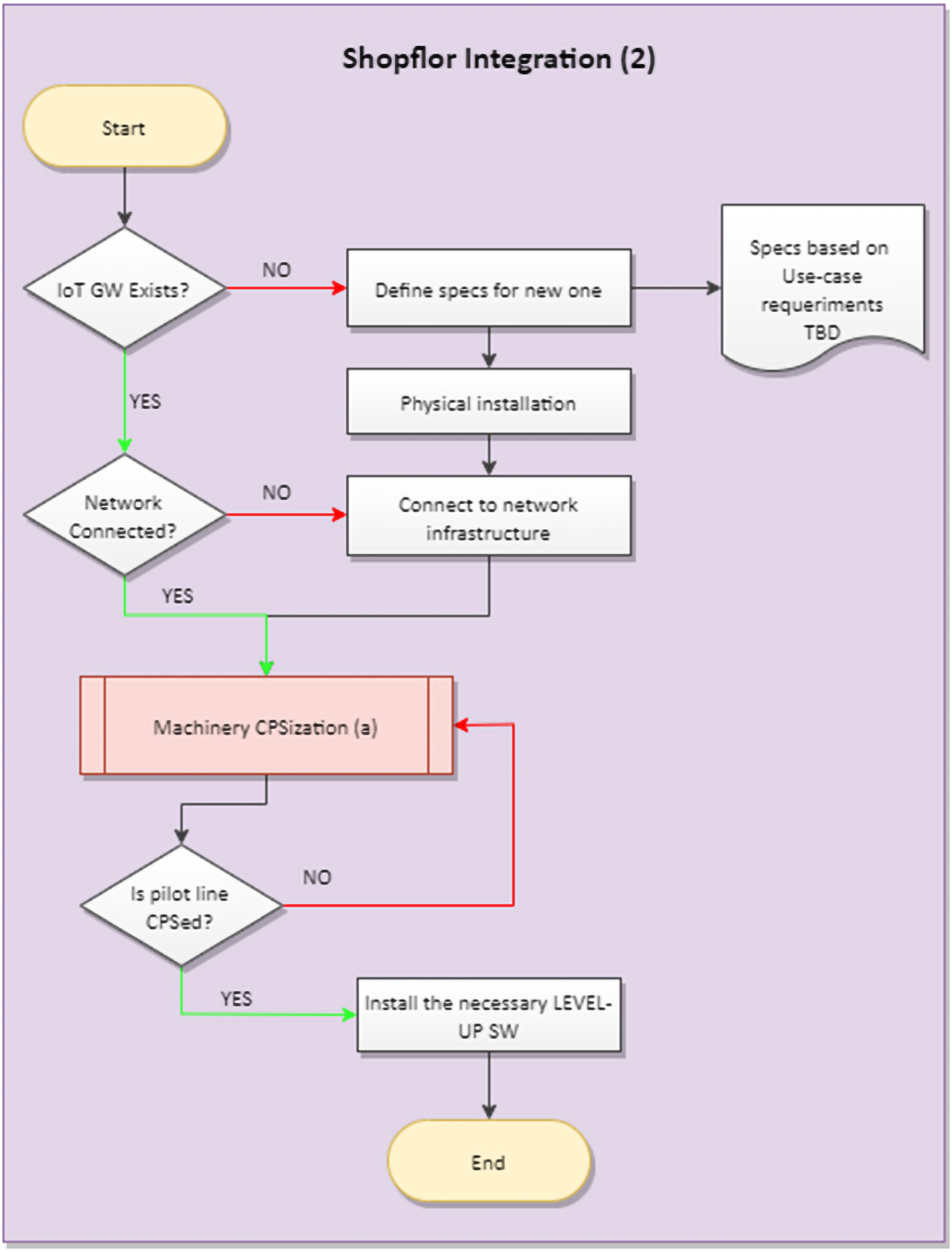

Figure 12 — Protocol Modernize workflow - shop floor integration

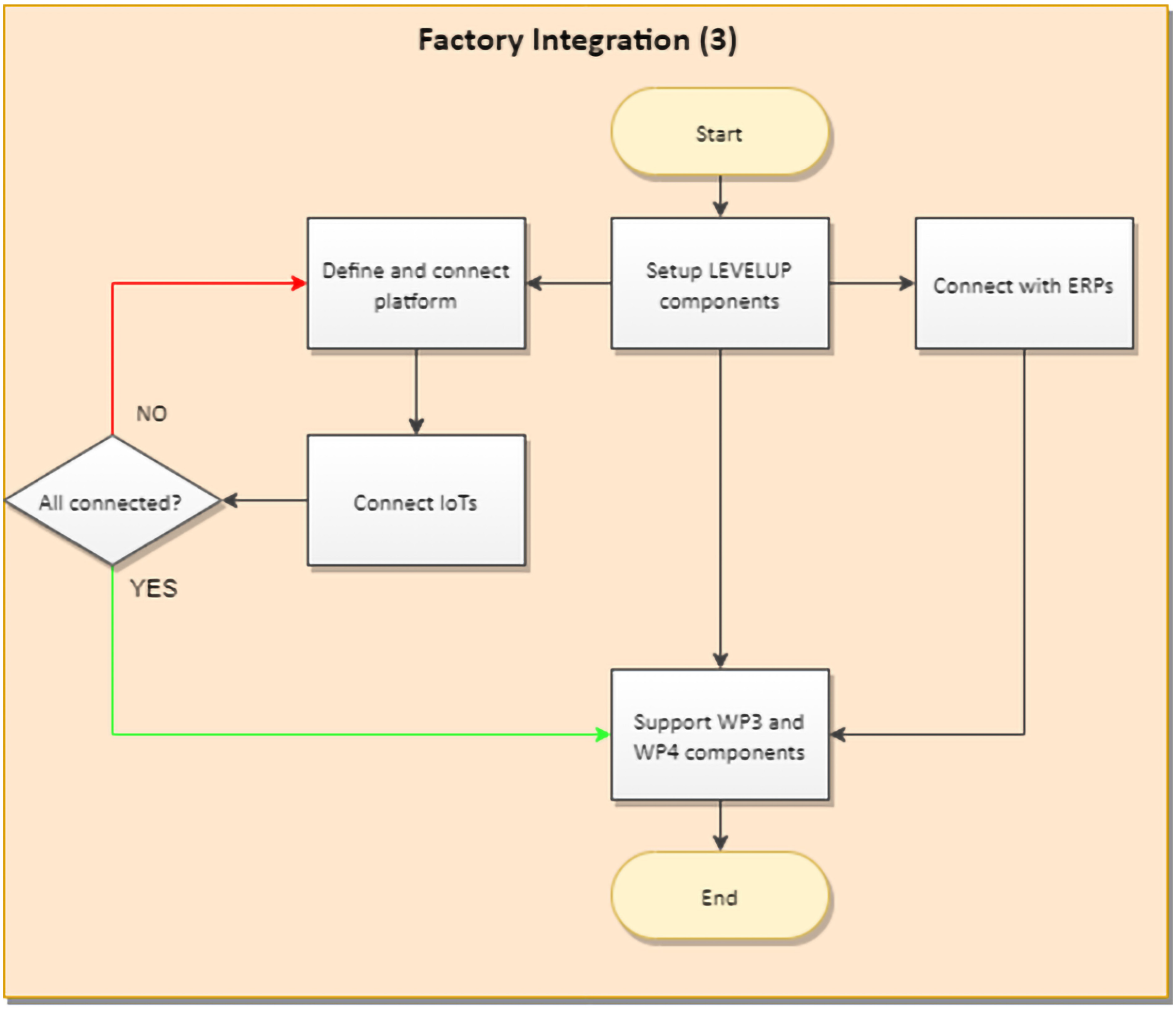

Figure 13 — Protocol Modernize workflow - factory integration

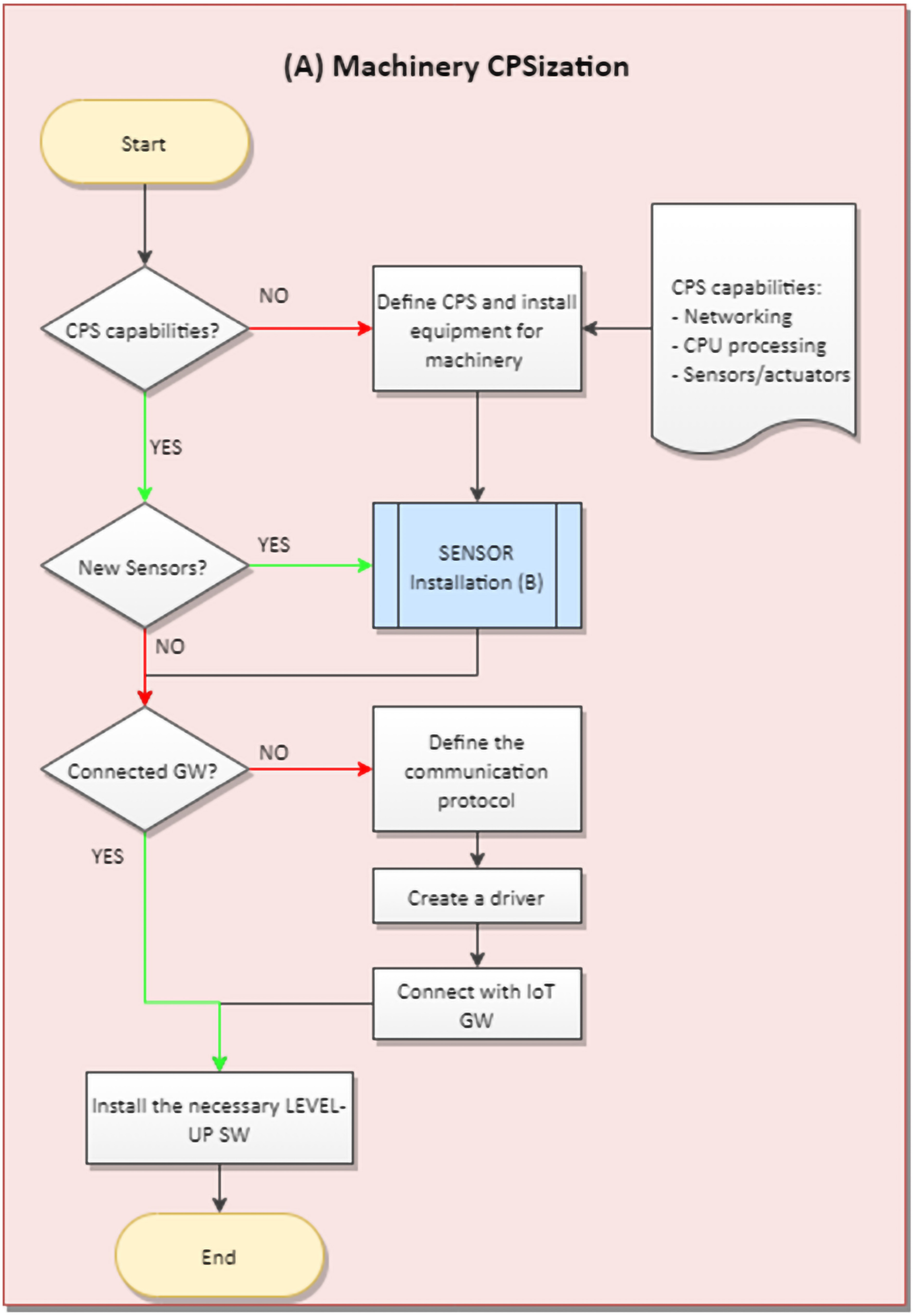

Figure 14 — Protocol Modernize workflow - machinery CPSation

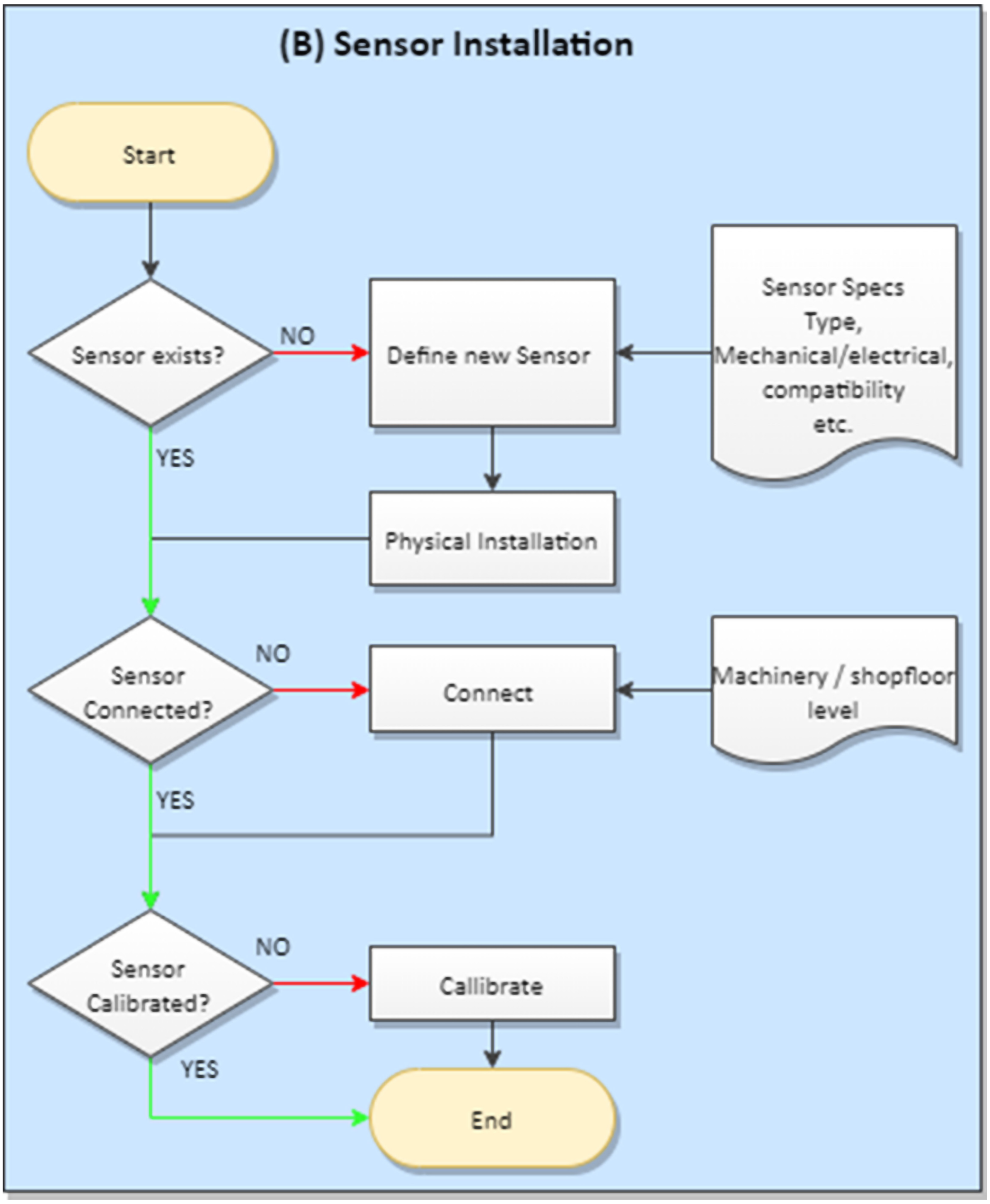

Figure 15 — Protocol Modernize workflow - sensor installation

6.3 PROTOCOL 1 – FUNCTIONAL DIAGNOSIS

6.3.1 Protocol definition and summary

Protocol 1 Functional Diagnosis involves actions on machines where sensors and CPS are already in place. This can be the status of the machines in an "as is" condition, when Protocols are introduced. Otherwise, if machines are not ready for Functional Diagnosis to be applied, Protocol Zero - Modernise is first implemented. Hence, Protocol 1 is triggered when there are enough data to be analysed, in order to derive a diagnosis on the status of the equipment.

The functional diagnosis of the machines will be done based on the experience of the operators, data from Protocol Z, and information from FMEA. It involves condition monitoring, simulations of virtual models, anomaly detection, machine forecasting and prediction of failures. Data from the maintenance logs, repair protocols, PPS, ERP and any other relevant information stored in enterprise systems may be used as reference. The goal is to evaluate Key Performance Indicators (KPIs) and to perform efficiency calculations. Upon finalisation of Protocol 1, the system will deduct and inform if there is an indication of malfunction. If there is, Protocol 2 - Inspection is triggered. The outcomes of Protocol 2 Inspection, Protocol 4 Disassembly and Protocol Ω, Reassembly & Testing may also be correlated to the results of Protocol 1. Protocol 1 is also connected to LEVEL-UP strategies.

6.3.2 Protocol actions and reference workflow

Six main actions are organized to support the protocol application:

1) Condition Monitoring. Monitoring of current condition of machines, monitoring of machine and pilot-defined KPIs [AS-IS and using Protocol Z].

2) Monitoring using simulations and virtual models. Definition and development of virtual models of machines and simulations of use of equipment.

3) Anomaly detection. Use of algorithms for the detection of anomalies in data available from Protocol Z, condition monitoring and simulation results.

4) Machine Forecasting and Prediction of Failures. Application of algorithms and methods for machine forecasting and prediction failures, based on data available from Protocol Z, condition monitoring and simulation results and, if applicable, anomaly detection results. The predictive algorithms will receive as inputs the sensory & metrology data from the data acquisition system/middleware and will return as outputs the machine state forecast (for a specific time window ahead in time that is specific to its pilot/machine process).

5) KPIs evaluation. Calculations of Key Performance Indicators, taking also into account results from Protocol 2 Inspection, when and where applicable.

6) Efficiency calculations. Efficiency calculations based on metrology measurement results, to diagnose the efficiency of machining and feed actions 2, 3 and 4, depending on the needs of specific users.

Stepwise execution of these actions and steps are illustrated in the protocol flowcharts below:

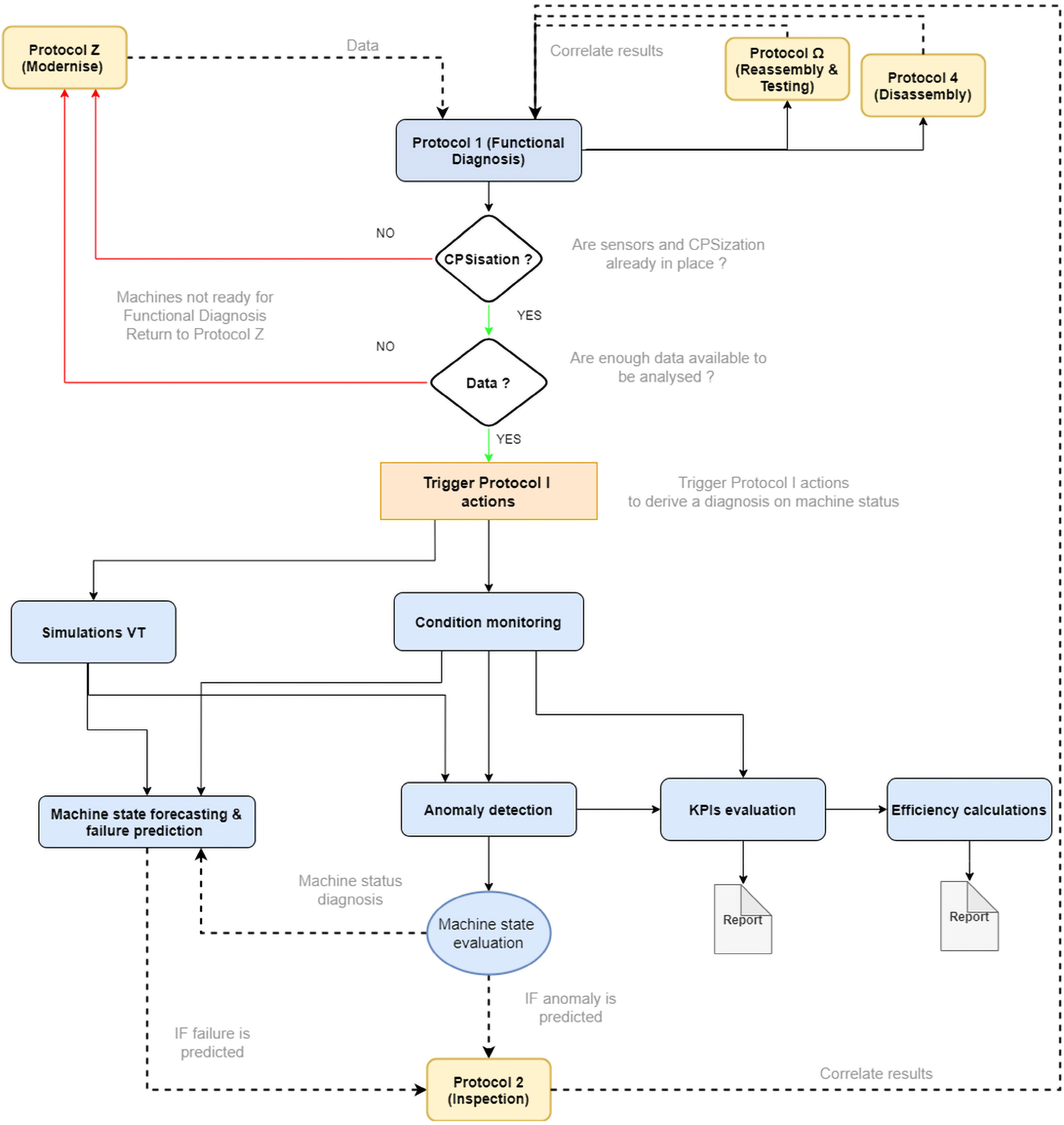

Figure 16 — Protocol Functional Diagnosis workflow

6.4 PROTOCOL 2 – INSPECTION

6.4.1 Protocol definition and purposes

Inspection in manufacturing includes measuring, examining, testing, or gauging one or more characteristics of a product or process and comparing the results with specified requirements to determine whether is the requirements are met for each characteristic. The results are compared to specified requirements and standards for determining whether the item or activity is in line with these targets.

This protocol involves the visual inspection of the machine from the experts while it operates. The use of NDT sensors and their correlation with the findings from the functional diagnosis will provide insights for a focused inspection while the machine is idle. In case of a suspected failure, this protocol will trigger the Refurbishment, Repair, Remanufacturing, or Disassembly protocols, based on the degree of degradation or damage. Inspection will function at three levels relying on three inspections system on the respective levels – Machine Level (ML), Product Level (PL), Shop-floor Plant level (SPL).

6.4.2 Protocol actions and reference workflow

Five main actions are organized to support the protocol application:

a) Visual inspection under production. It will be decided for each of the processes the areas to be inspected, checklist, and the time available for such inspections (Formal procedure for inspection). No reachable areas with damage need Protocol 4 Disassembly.

   1) Definition of checklist.

   2) Perform visual inspection (NDT: castings, forging, machined components and welds. inspection of paint and coatings). Output checklist.

b) Visual assessment while idle.

   1) Definition of checklist.

   2) Perform visual inspection. Output checklist.

c) Use NDT sensors while idle. Use of ultrasounds, eddy current or thermography if some anomaly was found by visual assessment and require further analysis. Output indications (e.g. technology, defect, localization, timestamp). Trigger disassembly if further insights are needed.

d) In-line inspection. Companies can handle the inspection in two levels: product level and machine level.

   1) Product Level:

   In-line monitoring capabilities the quality of parts are correlated with the state of the machines. Provide Product Quality Information (digital representation of the manufactured product – product DT).

      i. Determine Product CAD model, Design, Expected quality.

      ii. In-line metrology inspection. Disparity map evaluaiton. Output: QIF, PLY.

      iii. Vision system. Quality check, localized indications.

      iv. Inner defects: Active Thermography, Terahertz Imaging.

      v. Surface defects: Visible camera, hyperspectral imaging.

2) Machine Level:

At the machine level, the focus in mainly on Structural health monitoring. Structural health monitoring (FOS- based) assesses the state of structural health and, through appropriate data processing and interpretation, may predict the remaining life of the structure Crack detection and localization. Indications: Localized indications.

i. Distributed fiber optical sensor to monitor the overall machine.

ii. FBG installed when an initial crack is detected to monitor the evolution.

e) Correlation of the indications with functional diagnosis. Correlation of indications and product quality information with FMECA to provide suggestions for remedial actions. Correlation of product quality with machine level (ML) and shopfloor level (SPL) status. The goal is to ensure that each product conforms to the pre-defined upper and lower acceptable quality limits, maintaining the production process to the maximum. If the produced quality is low, then the machine parameters will be flagged as indication to poor performance, triggering actions for further investigation. Identify from where the indications or lack of quality/performance is coming from.

Stepwise execution of these actions and steps are illustrated in the protocol flowcharts below:

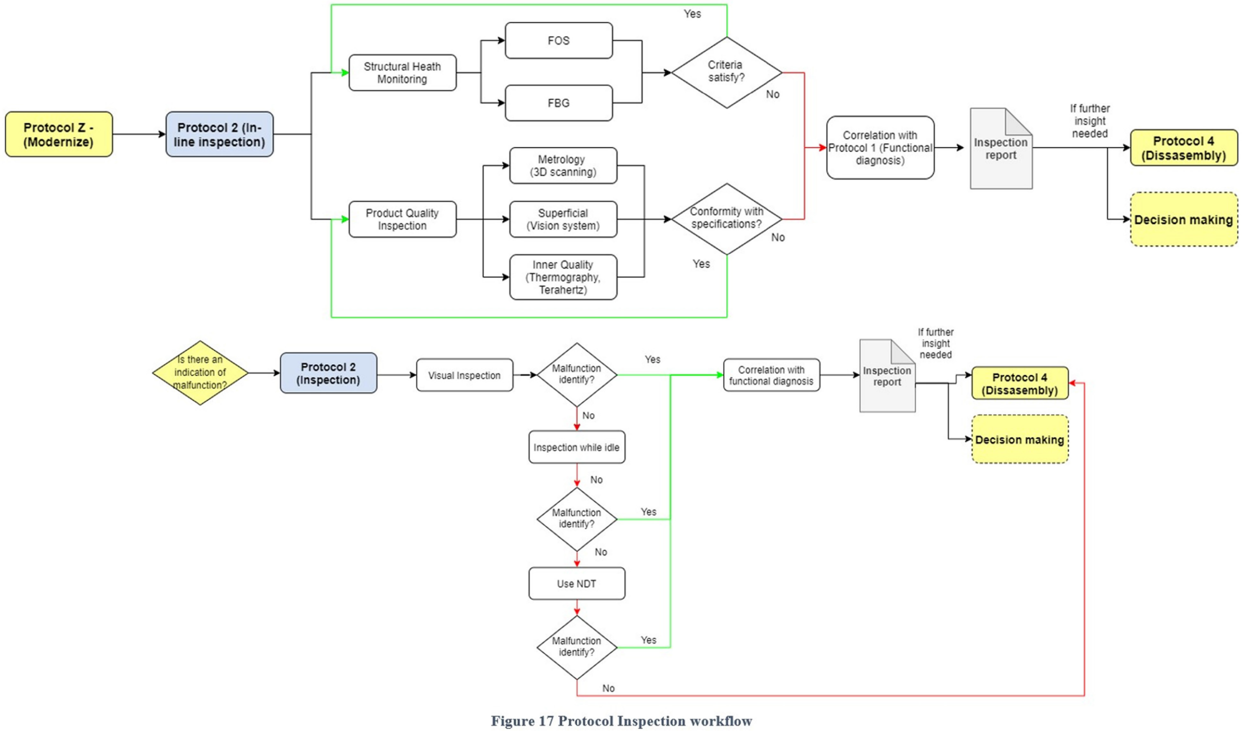

Figure 17 — Protocol Inspection workflow

6.5 PROTOCOL 3 – REFURBISHMENT

6.5.1 Protocol definition and summary

In industrial process facilities, corrosion is the biggest single cause of plant and equipment breakdown, including machinery, vessels, structures, supports and pipelines. While atmospheric corrosion in the form of air (oxygen), and water (moisture, humidity, vapor, etc.) is the main culprit, environmental factors including high temperatures and pressures as well as harsh substances, chemicals and gasses can also accelerate the corrosion of carbon steel and other metals [1].

The Refurbishment protocol is about the light repair and cleaning of the system to bring it to its original status and integrity (as-new status). Old grimy machines, with corroded or rusted surfaces will be cleaned and treated (painting/coating application) in order to bring them to their original status.

The Refurbishment Protocol might trigger the REPAIR one in case a component is found worn out or damaged. In case of non-repairable parts, they will be removed and replaced. In case there are no available substitutes, then the UPGRADE or the REMANUFACTURING protocol is triggered. Within each of these protocols the simulation of the different repair or remanufacturing processes, and the virtual commissioning of the upgraded machine will also serve to guide on the decisions of the best actions to be taken based on the performance, quality, cost, and the minimisation of future risks.

Decision making:

This step is applied after the Protocol 2 Inspection or Protocol 4 Disassembly. The damaged component/part is assessed based on the damage level (type, size, cause...), technical repairability requirements (available technologies), economic impact (cost and benefit analysis) and environmental impact (Life-cycle assessment), so the most suitable protocol (Refurbishment, Repair, Remanufacturing, Upgrade and/or Recycling) will be triggered. The decision making is a previous joint point to all the Protocols above-mentioned.

6.5.2 Protocol actions and reference workflow

Three main actions are organized to support the protocol application:

a) Clean component/machine surfaces. Remove rust and old paint using polished, laser and/or blast cleaning to avoid future problems like corrosion and prepare the surfaces for the new painting and/or coating application.

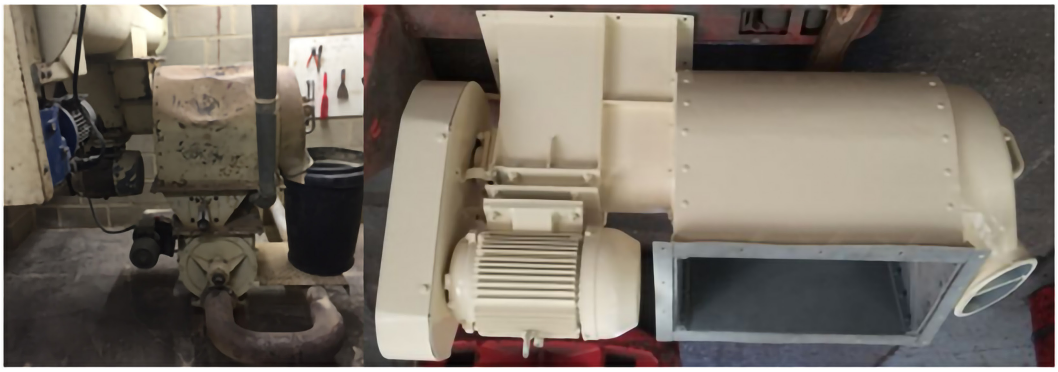

Figure 18 — Cleaning surfaces of a sample machine

b) New painting or coating application. In order to improve the machine/component superficial appearance, new painting will be applied. The application of a protective coating on safety-critical components to extend process equipment durability, enhance easy cleaning or chemical resistance in harsh working environments (i.e. high temperature, CO_2 and H_2S environments, corrosion and wear resistant coatings, coatings for oil sands and other oil and gas exploration and production environments...) will be evaluated and applied if required.

c) Safety regulations upgrade. Upgrade of the machine to meet all appropriate health and safety requirements. It will take the necessary protective measures to eliminate risks, or reduce as far as possible those risks that cannot be eliminated. The protective measures include, for instance, the implementation of additional cover parts of the machinery used specifically to provide protection by means of a physical barrier, and the inclusion of information for machinery users with the residual risks, the protective measures adopted, and the indications about necessity of particular trainings or requirements of personal protective equipment (PPE) considering the Machinery Directive 2006/42/EC regulation. If the machine requires the addition of an upgraded mechatronic component, the Protocol Upgrade will be called.

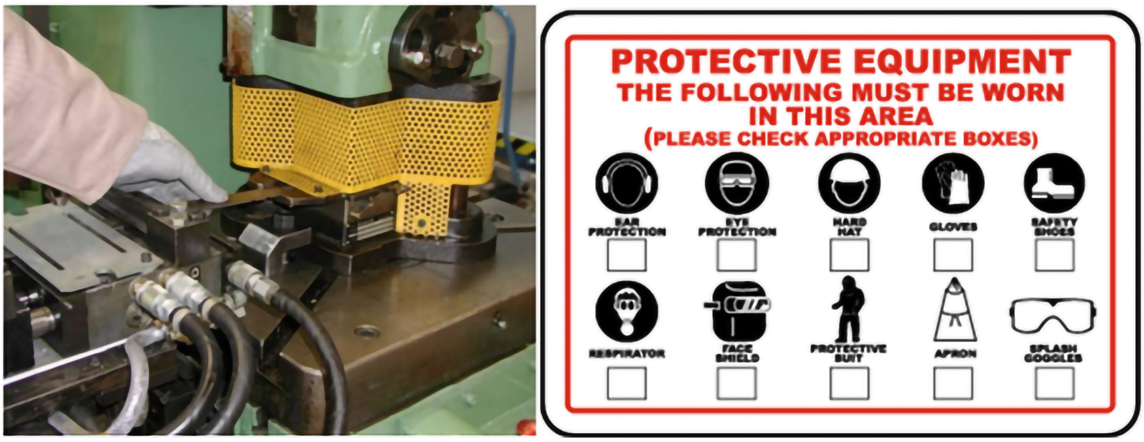

Figure 19 — Safety regulation update of a sample machine

Stepwise execution of these actions and steps are illustrated in the protocol flowcharts below:

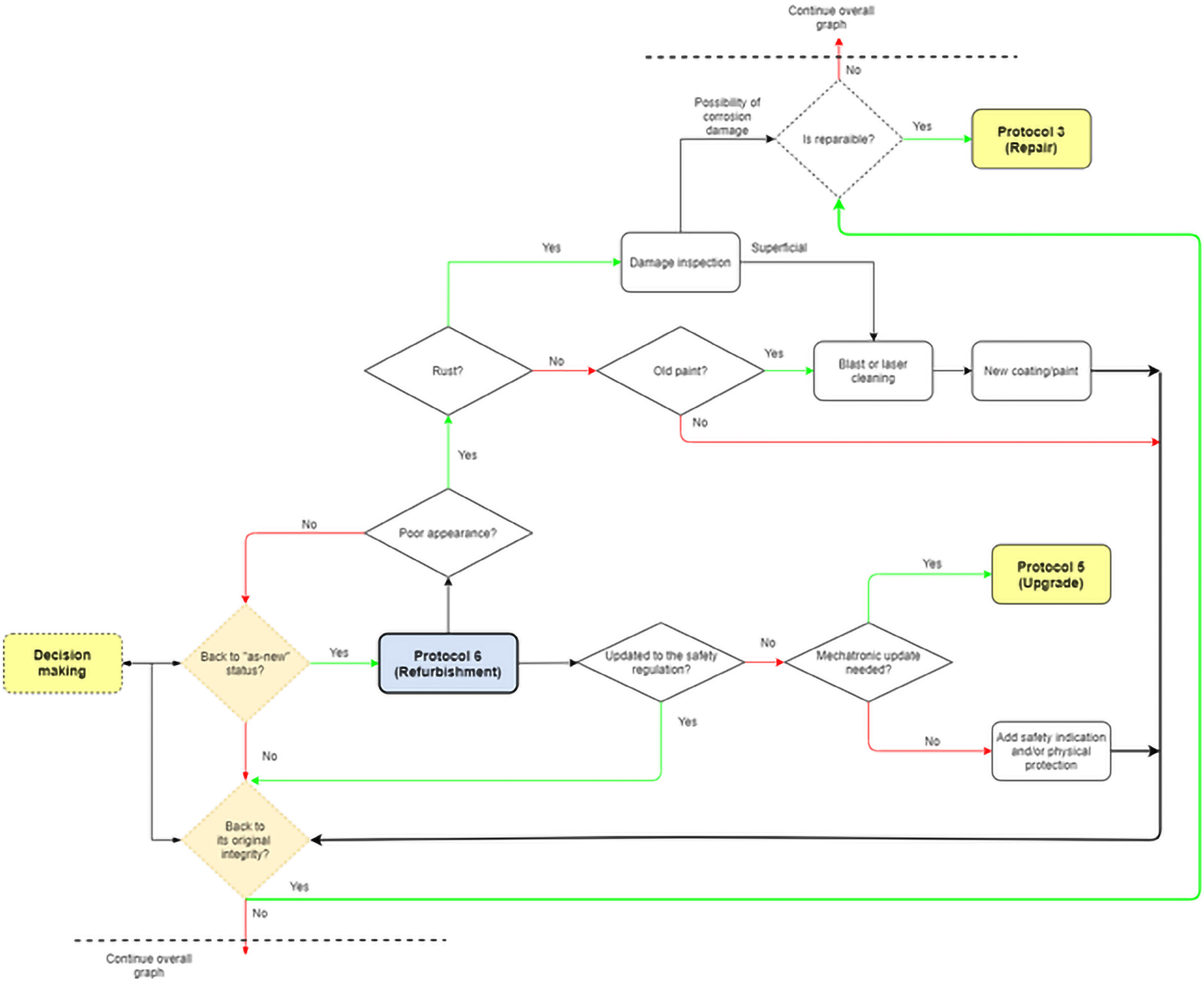

Figure 20 — Protocol Refurbishment workflow

6.6 PROTOCOL 4 – DISSASEMBLY

6.6.1 Protocol definition and summary

Refers to the process of separating a machine or structure into its different parts or taking a component apart from it. This could be done to help determine a problem, to replace a part, or take the parts and use them in another machine/device. The protocol Inspection can trigger this protocol, and this in turn will activate the decision-making process that is the predecessor step to the remedy actions. Finally, after the best suitable option for the component is performed, the Protocol Ω is activated for the reassembly and testing. Having the machine broken down into its pieces allows a more thorough NDT inspection for hidden damages, wear and failures. The identification of failed components and any degradation will lead to a 3D scanning to extract their 3D shape that will be used in the virtual twin system. The design characteristics will also be analysed and stored, such as the material used, its sensitivity against contamination, wear, as well as its tolerances against forces and its reaction to the environment under which it operates. The analysis outcomes will also involve the functional properties that have to serve in order to find the optimal substitute in case they need replacement.

Disassembly protocol is a methodology or series of steps to be applied each time a component from a machine is separated or taking apart from it (disassembled). The general purpose is having a deeper knowledge of a specific component that is potentially defective, damaged or needing an improvement by taking the part out of the machine to run some test and evaluations.

6.6.2 Protocol actions and reference workflow

Six main actions are organized to support the protocol application:

a) Traceability of disassembled components. Assignation of a code, registration of info related to the component, a detailed list issuance of every component that is being disassembled, documentation of the stages of the disassembly process in order to have a useful guideline at the moment of the reassembly and start-up.

b) Analysis of design properties. To evaluate the feasibility of the 3D scanning process and to decide the most suitable NDT inspection techniques to apply:

    1) Data acquisition: component size, weight, material properties and surface finish, ambient conditions, its sensitivity against contamination, STEP file, GD&T, information about the manufacturer of the component.

    2) Testing of mechanical properties, as well as its tolerances against forces and its reaction to the environment under which it operates.

    3) Definition of functional properties.

    4) Storing of information.

c) 3D scanning. Dimensional assessment with 3D scanners

    1) Analysis and import of the design information of the part, e.g. CAD file in STEP format.

    2) 3D scanning of the physical component disassembled.

    3) Obtaining high-density 3D point cloud representing the shapes and design of the component

    4) Analysis and computation of 3D deviation map.

    5) Report of the results of the distances between the actual scanned component and the virtual reference model.

d) NDT inspection techniques. This action would assess the integrity of the part and specific damage characteristics and perform a characterization of failed/worn components

    1) Ultrasonics.

    2) Radiographic imaging (including 3D tomography).

    3) Superficiel techniques: Magnetic particle inspection, Penetrant liquids.

    4) Eddy current testing.

e) Correlation with FMECA. The findings of the inspection and the 3D scanning will be correlated with the FMECA results to provide output to the Multi-DSS.

f) Update the virtual twin. For more detailed simulations, predictions, as well as more accuracy on the remedy actions to implement (e.g. remanufacture, refurbishment). The collected knowledge will be virtually represented as a digital twin of the physical component.

Stepwise execution of these actions and steps are illustrated in the protocol flowcharts below:

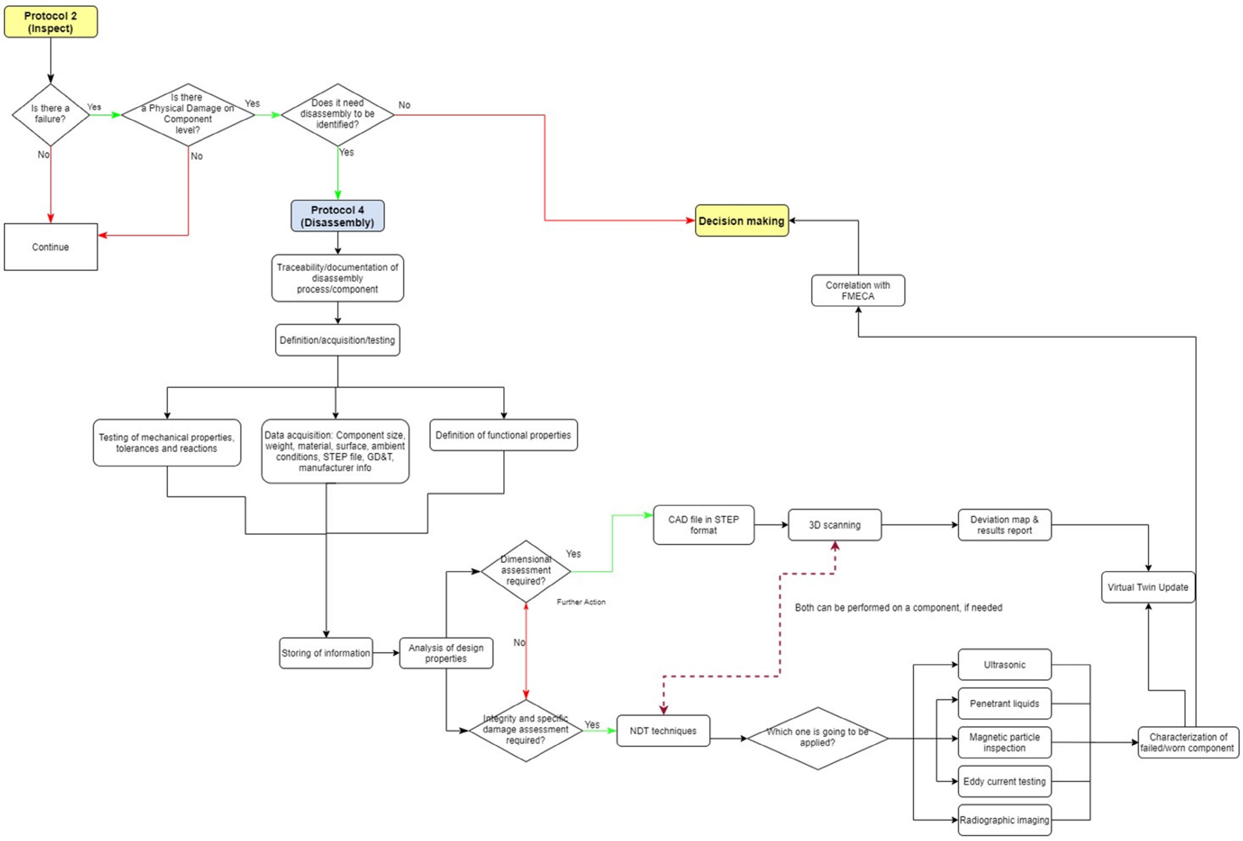

Figure 21 — Protocol Disassembly workflow

6.7 PROTOCOL 5 – UPGRADE

6.7.1 Protocol definition and summary

Protocol UPGRADE involves the actions of improving functionalities (incl. also performance, reliability, connectivity, interoperability, durability, security, etc.). Upgrading is a process where a product is improved by adding, for example, better and more advanced functionalities. Upgrade Protocol is also about any hardware and software that provides increased functionalities and properties to the equipment.

The result is an upgraded product in comparison with the original. An example can be a computer that is upgraded with a new processor. Focusing on a mechanical component, an upgrade could be to build functional surfaces to enhance product properties and functionalities.

Old parts will be replaced with improved versions, considering the adoption of advanced materials, built by conventional or new technologies as Additive Manufacturing. Apart from replacement, Upgrade involves the addition of components and features that were not installed to the original design. The term retrofitting used in equipment and mechatronic systems would be under this protocol and refers to the addition of new technology or features to older systems. Retrofit extends a current system with new functions, which were not available when the machine was produced.

The Upgrade protocol can be applied to equipment, subsystem and down to component level.

6.7.2 Protocol actions and reference workflow

Three main actions are organized to support the protocol application:

a) Replace/add components with improved functionalities, properties or materials. It refers to replacement of components improving the quality and practicality for they were suited to serve a purpose well. It also includes the addition of new parts increasing the ability of equipment to do something or adding new functionalities that were not available in the origin.

b) Upgrade of software (e.g. CNC, PLC, HMI or app versions). Upgrades are used for significant changes and major improvements to current version equipment programs. It could be an overhauled user interface, a set of new features or key structural changes in programs and user applications.

c) Replace hardware/control components (PLC, CNC, PC). In equipment industry, it involves upgrading the control and replacing electronics (e.g. wiring, servos and drives). Upgrading the hardware may involve upgrading the associated software.

This list of actions starts after the evaluation and decision of what is needed to upgrade a particular component.

To carry out any of previously listed action within the upgrade protocol, next tasks must be executed:

a) Analysis and evaluation of the upgrade.

   1) Determine theoretical functions of mechanical/hardware/software to upgrade system/component: High level to low level overview of what the system/component should do. Theoretical functions some of the older functions and upgraded functions.

   2) Evaluate current solution based on the theoretical function of the component: Identify short comings of current design and reasons of failure or poor performance of the components, based on FMECA analysis carried out in previous protocols.

   3) Identify upgrade needs: Mirror current solution to theoretical functions and find out where to improve the system/component, considering it not as a single unit but also the interaction (assembly, communication) with other systems of the equipment.

   4) High level CBA/ROI analysis of possible equipment upgrade alternatives.

b) Definition of Requirements.

   1) Definition of requirements and establishment of specifications for the component. Requirements may differ if the upgrade is focused on a single customer specific need or thinking of upgrading certain system/component of the equipment to fulfill market requirements, due to several reasons: legal regulation, obsolescence, market trend… It includes quality, logistical, technical and financial requirements.

c) Verification of fulfilment of requirements.

d) Design and Design Verification

   1) Mechanical, electrical and/or electronic design.

   2) Use simulation software if upgraded design works as intended or needs changes to better suit its function.

e) Building the component: acquisition, development, manufacture and assembly. This task involves the building of the system, considering the manufacture of the component or development of software code for different control systems and applications. It may also consider the acquisition of components, hardware of softwares from third parties.

  1) Manufacturing: Using classic manufacture technologies or new technologies, involving: a) Define material offset, b) Additive manufacturing of component, c) Post-production of component (e.g. Milling, turning, blasting, electropolishing, coating).

  2) Software development: Programming of designed software.

  3) Purchasing of new components to suppliers.

  4) Assembly of components.

f) Test & validation

  1) Test manufactured upgrade component on a test rig or in line at factory.

  2) Virtual commissioning: It creates a simulation model of a manufacturing plant so that proposed changes and upgrades can be tested before they are implemented to the actual plant.

g) Commissioning

  1) Plan implementation if it requires equipment downtime.

  2) Prepare documentation.

  3) Training to operators and maintenance technicians if it is necessary.

  4) Implement and commission upgraded system or component.

  5) Monitoring of component/equipment performance.

h) Adopt lessons learned from test and validation of upgraded component. If necessary, change and/or improve upgraded design based on test results

Stepwise execution of these actions and steps are illustrated in the protocol flowcharts below:

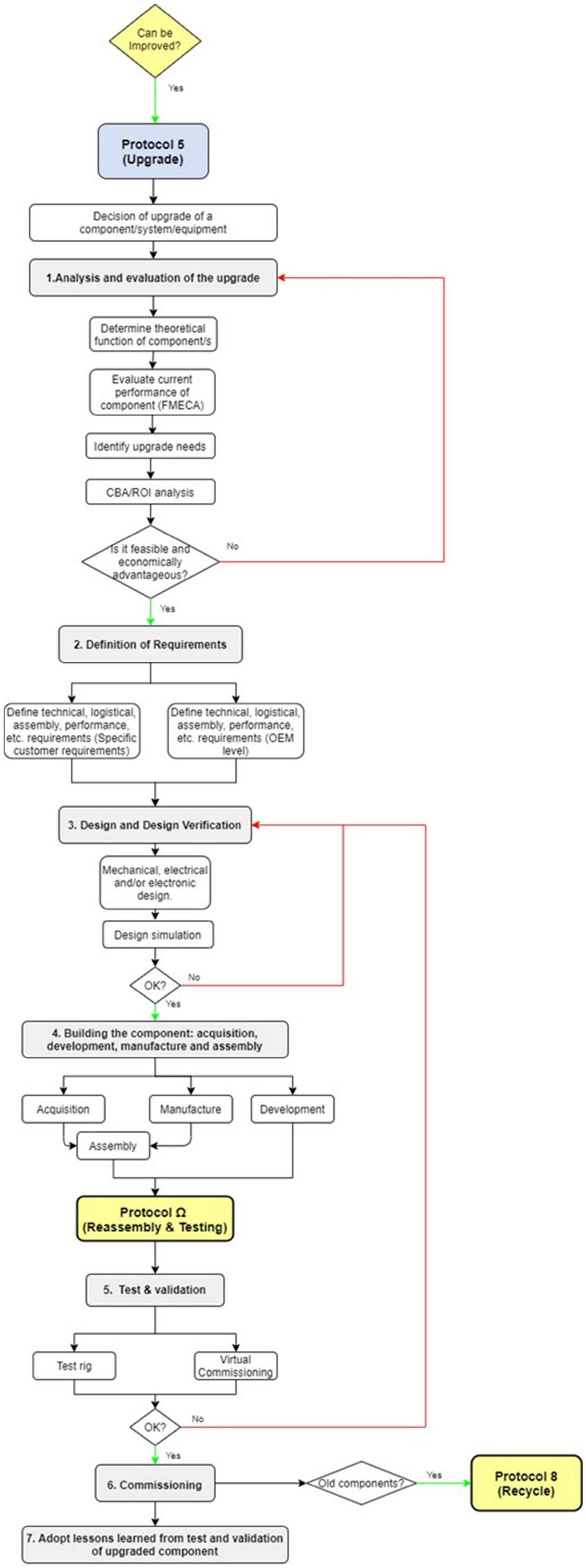

Figure 22 — Protocol Upgrade workflow

6.8 PROTOCOL 6 – REPAIR

6.8.1 Protocol definition and summary

This protocol can be executed both while all components are in place or after disassembly. In the first case, refurbishment actions (Protocol 3) on the painting or tool adjustments and calibration (Protocol Ω) can be executed. In case the components are removed from the machine (Protocol 4), the process can also include laser cladding and electropulsing techniques and different pre and post-processing operations. The virtual model of LEVEL-UP will simulate the various scenarios to identify the most suitable repair. After the repair protocol is applied, Protocol Ω – Reassembly & Testing and Protocol 8: Recycling, might be triggered.

6.8.2 Protocol actions and reference workflow

Eleven main actions are organized to support the protocol application:

1. Source of faults. Identify the source of faults whether they are caused by (1) corrosion of parts; (2) part misalignment due to geometrical distortion of parts/machines or; (3) the presence of defects (e.g. cracks).
2. Repair of geometrical distortion of parts. Light machining can be used to correct any minor geometrical distortion of parts, but this will require subsequent adjustment and calibration of the machine to compensate on the slight change of dimensions of the machined parts.
3. Identify the location and characteristics of cracks present in faulted parts. The location and size/types of cracks need to be identified by in-line and off-line inspection, in order to make informed decision on the choice of repair method.
4. Repair of surface cracks. Surface cracks can then be repaired using light machining and/or laser cladding depending on the size and the quantity of cracks.
5. Repair of internal cracks. Internal cracks can then be repaired using electropulsing treatment providing they are not too large.
6. Repair of through thickness cracks. Through thickness cracks can then be repaired using fusion welding methods including brazing, MIG/TIG welding, laser welding.
7. Estimation/simulation of repair cost. A prediction of the repair cost will allow the selection of most cost-effective method of repair.
8. Post treatment of repaired parts: Depending on the type of materials and repair method, the parts may need subsequent heat treatment step (e.g. tempering/annealing) after the repair process to reduce the residual stress and maintain good metallurgical characteristics within the repaired areas.
9. Recheck repaired parts to verify its condition.
10. Adjustment/calibration of the machine after implementation of repaired part. After the implementation of the repaired parts, if needed, it will take the “calibration and compensation” action in the Protocol Ω Reassembly & Testing to adjust / calibrate the machine to ensure machine accuracy.
11. Handling of waste from repair process. Any waste material generated from the repair process will be dealt with according to the Protocol 8: Recycling.

Stepwise execution of these actions and steps are illustrated in the protocol flowcharts below:

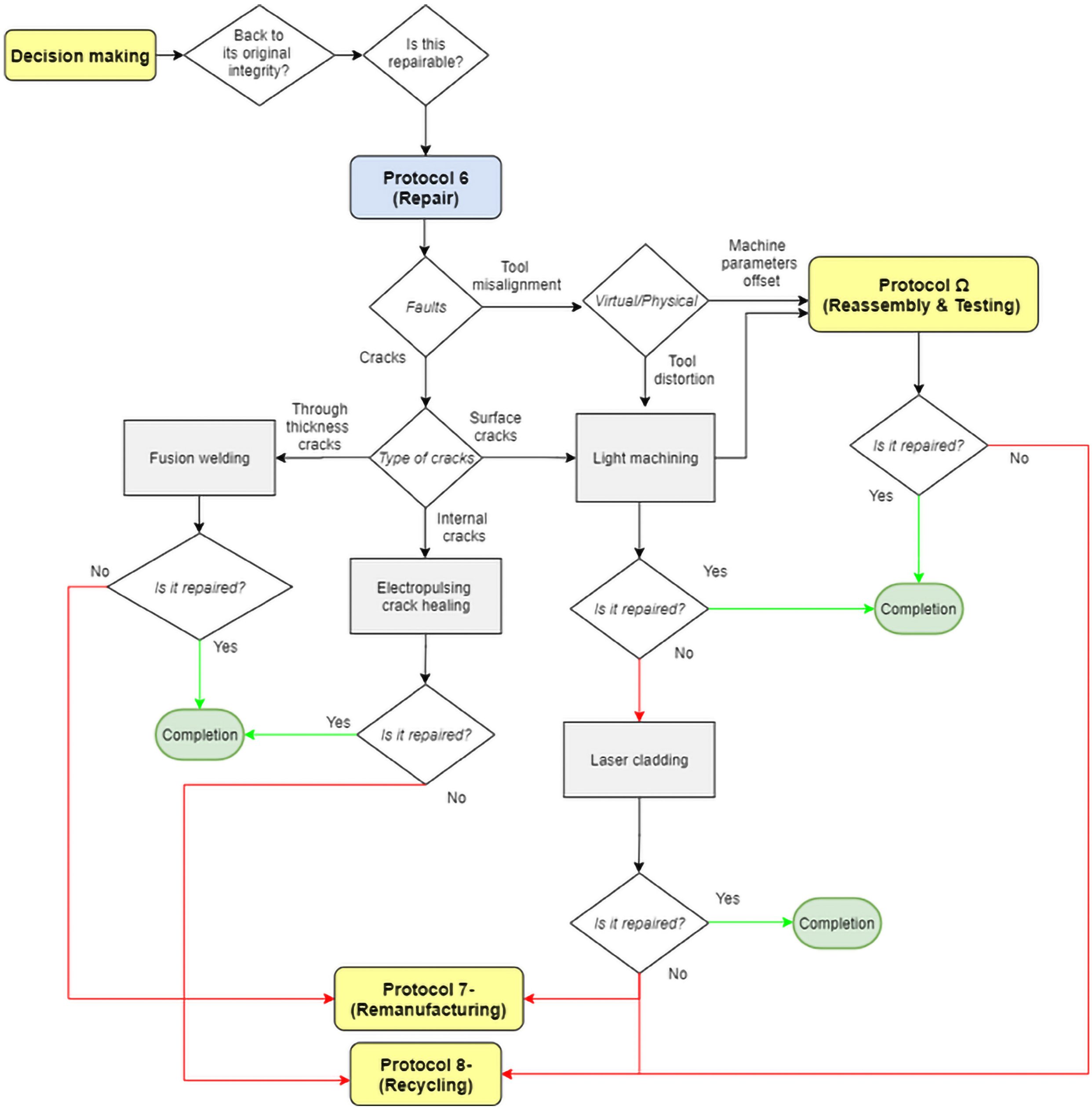

Figure 23 — Protocol Repair workflow

6.9 PROTOCOL 7 – REMANUFACTURING

6.9.1 Protocol definition and summary

The remanufacturing protocol is intended to restore parts' original functionality. It is mostly suitable for parts that are non-repairable and thus, situations where there is clear advantage for the remanufacturing and not replacement, for several industries. It allows the remanufacturing of one or more missing parts as well as the recovery of the original design and/or material. The virtual digital twin of the component is essential during the process to ensure the success of the remanufacturing procedure.

6.9.2 Protocol actions and reference workflow

Six main actions are organized to support the protocol application:

1. Analysis of material(s). The material of original part and alternatives are evaluated based on availability (if the raw material supplied is suitable for process implementation) and desired properties. Based on material choice, optimal process parameters (laser power, scan velocity, powder flow, substrate temperature) are defined and validated with preliminary material test depositions. Material choice is also to be considered when selecting cutting tools.
2. Digital model analysis. The shape of damaged part acquired in digital form by means of a 3D scan in order to have a 3D digital model of damaged part. The 3D model of damaged part is compared to the one of the original part to evaluate the remanufacturing process (toolpath, part orientation, volume of material, etc.).
3. Computer Aided Manufacturing. Toolpath of deposition tool is generated with specific software tools, based on digital model correlation and subtraction. Afterwards, machining toolpaths are also generated with the part´s final geometry with required dimensions and tolerances. In this stage, digital twin model is ran to simulate manufacturing process.
4. Manufacturing process. Substrate (core material) surface is cleaned with at least one technique: chemical, laser or blasting cleaning (Protocol 3 Refurbishment). In the first stage, metal is deposited in the substrate\part. In the second stage, machining process is applied to create desired final geometry. Localized heat is provided for enhancement of printing and deposition properties.
5. Heat Treatment. The part undergoes a heat treatment process for final mechanical properties (surface hardness for example), or laser shot peening techniques are used for localized and targeted areas.
6. Remanufacturing validation. Validation of new part with non-destructive methods (dimensional control, 3D scan and 3D model correlation) and functionality. If any non-conformance is detected, steps 1 to 4 are executed again when applicable. Often, simulation takes place to assess the criticality of defects or inherent changes to the part due to the process.

Stepwise execution of these actions and steps are illustrated in the protocol flowcharts below:

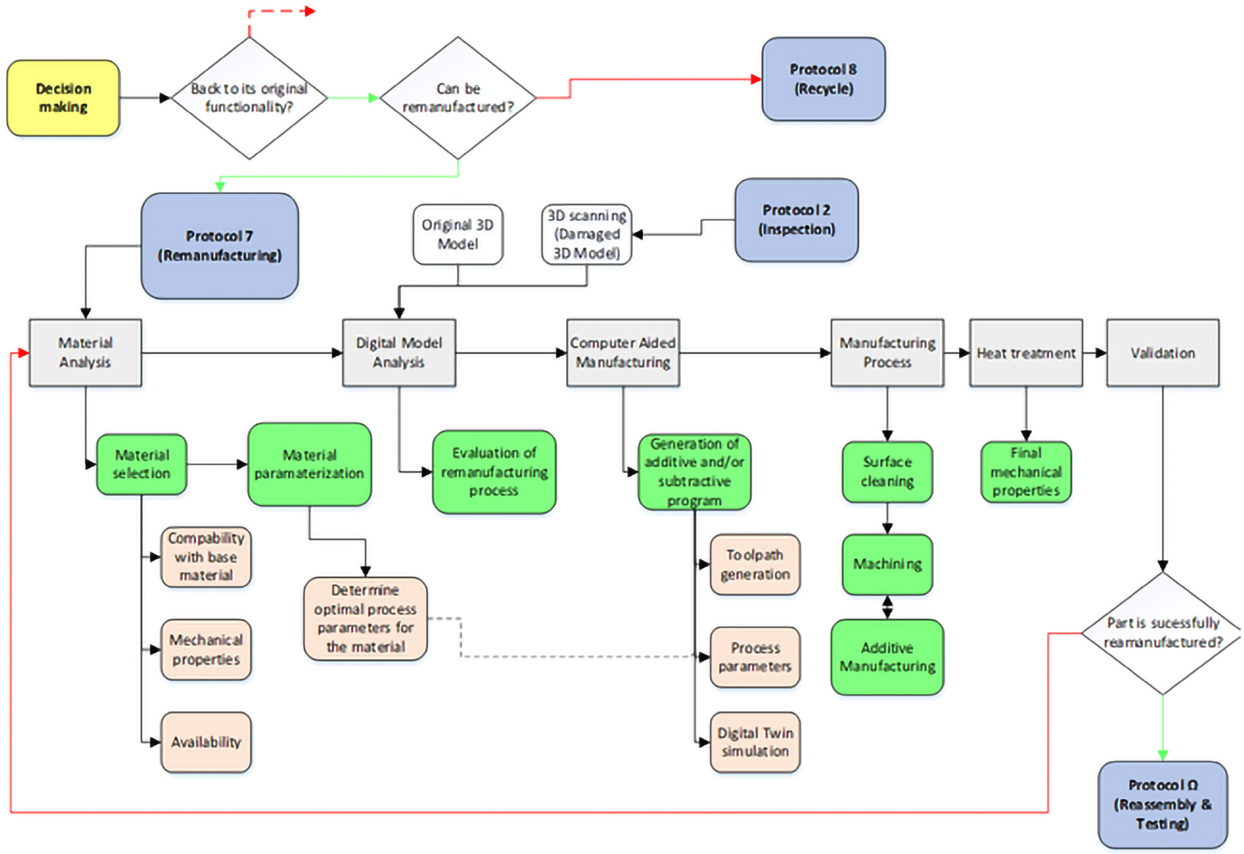

Figure 24 — Protocol Remanufacturing workflow

6.10 PROTOCOL 8 – RECYCLING

6.10.1 Protocol definition and summary

Protocol 8, Recycling, consists in the recovery and valorisation of materials from components that cannot be repaired as well as other waste generated in various processes. The protocol is triggered at different stages, mainly:

— At decision-making stage, which follows the functional diagnosis, inspection or disassembly: if a machine is deemed unrepairable for technical, economical and/or environmental reasons.

— At refurbishment, repair, remanufacturing and upgrade stages of the machine: old, disfunctional components may enter the Recycling protocol.

— At any stage, waste material generated (e.g. plastic scraps, old cables, etc.) may also enter the Recycling protocol.

The aim of the protocol is to have a clear set of guidelines to determine how these materials can be managed, treated and recycled to recover inherent value and minimize the impact on the environment.

6.10.2 Protocol actions and reference workflow

Eight main actions are organized to support the protocol application:

1. Reuse of functional components. In the case of a whole machine being disposed of and entering the Recycling protocol, identify if some components are still functional, and what reuse potential exists for them. This could be:

    a. In your own facility (e.g. electric cables)

    b. At manufacturing level: check with your manufacturer if he is interested to recover functional parts for reuse (e.g. engine). Alternatively, refurbishing companies may be interested to recover old parts to integrate in second-hand machinery.

    c. Other industry: other industries may find some use for various components.

2. Material identification. Identify main material composition of the non-functional, unreusable components entering the recycling protocol (such as carbon alloys, aluminium, brass, stainless steel, plastics, electronic parts, etc.).

3. Waste management process identification. Identify the best management process for materials according to the waste hierarchy (see diagram below), the waste management infrastructure available in the country and legal requirements. Depending on the local legal framework and the waste material considered, a particular treatment process may be imposed.

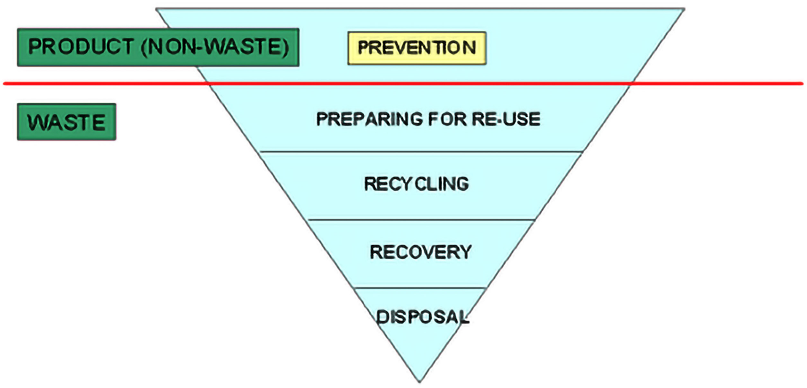

Figure 25 — Waste hierarchy diagram [2]

4. Pre-processing requirement identification. Identify if pre-processing is needed. This mainly consists of dismantling and sorting, but could possibly also include shredding, stripping, etc.

    a. Separation of materials that will be treated by different recyclers may be necessary to comply with legal requirements (for example separating parts containing steel from plastic or separating electronic components from the machine metallic frame).

    b. Depending on whether the material type has a positive value on the market (such as metallic waste), sorting may be profitable as it may reduce the waste management costs or increase the benefits from the sale of the waste.

5. Pre-processing. Proceed with the pre-processing activities identified in the previous step.

6. Safe storage. If the waste is hazardous, store it according to legal prescriptions to ensure the protection of the workers and the environment.

7. Waste service providers identification. Identify local waste management partners for the treatment of specific material waste streams. Ensure they hold the right type of permits.

8. Waste hand-over. Coordinate with the local partners for the waste management formalities, waste pick-up process and subsequent recycling / disposal option.

These steps are illustrated in the recycling protocol flow chart below:

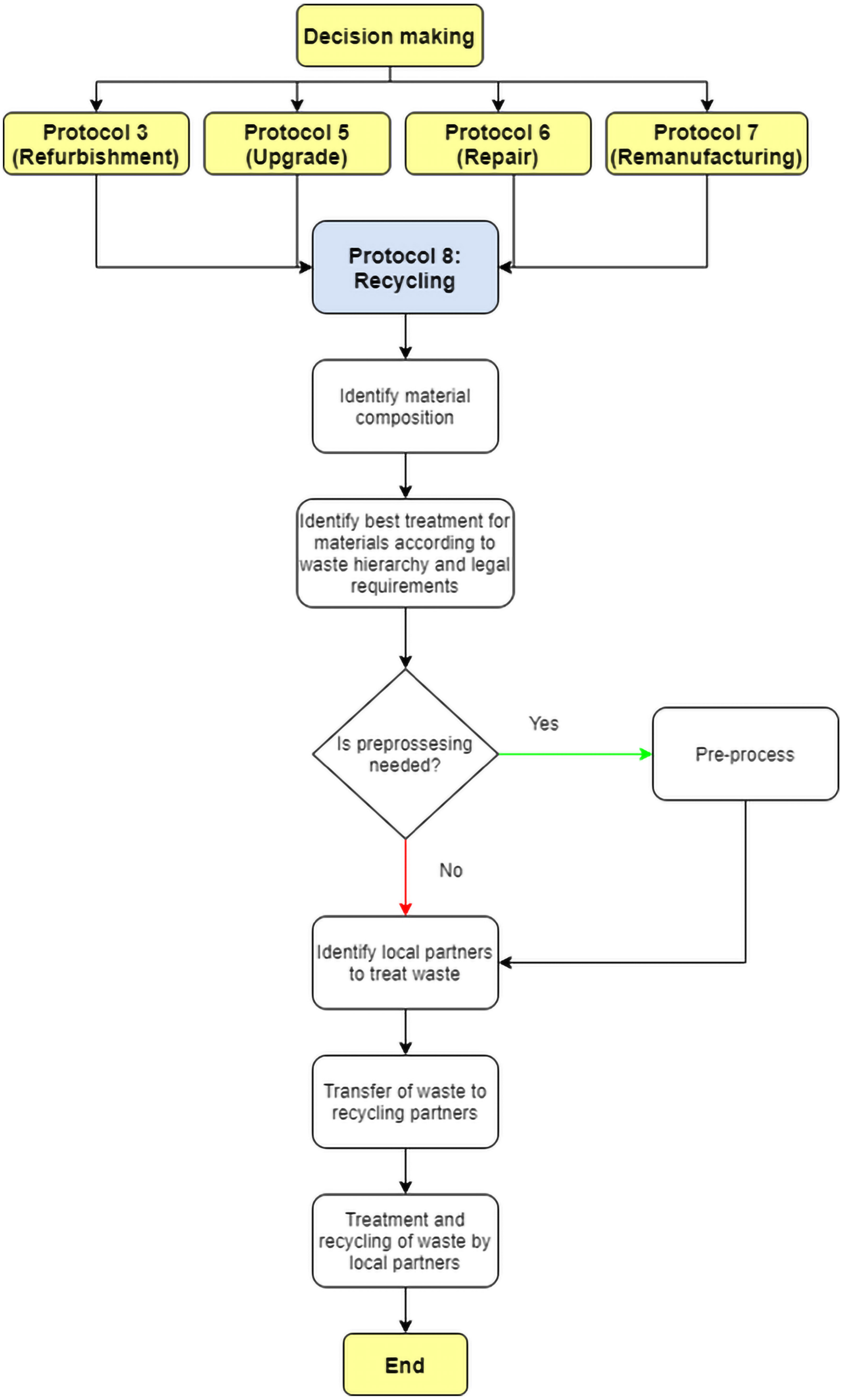

Figure 26 — Protocol Recycling workflow

6.11 PROTOCOL Ω – REASSEMBLE AND TESTING

6.11.1 Protocol definition and summary

The protocol Omega is the last protocol aiming at putting machine back in production without problems or flaws. In order to achieve this goal, some actions are necessary. The first action concerns the reassembling activities related to the mechanics of the machines (e.g. frame, powertrain, guiding parts), physical components of the control system of the machine (e.g. control cabinet, el. cables, HMI, sensors, limit switches, safety devices) and of the CPS (e.g. additional sensors, edge device). Furthermore, the mechanical adjustment of all such components, if needed, is carried out so that the machine is ready for operation from the mechanical point of view. In the following action, the control system of the machine is put in operation. This can involve establishing the communication between control system units and all sensors, running the safety system, setting of servo drives and programming special routines. In the next step, the machine is calibrated and compensation modules (e.g. volumetric compensation, thermal compensation) are implemented/activated. In this state, the machine can be run but without any functionalities related to digital twins. The launch of (a) digital twin(s) is performed in the further action. Here, the software for (all) virtual twin(s) are installed and put into run. Since virtual twins can provide a deeply insights into behaviour of the machine, they can be used for further optimization. Beside the optimization, this action also involves the verification of the function of virtual twins. In the last action, the machine is put back in production, i.e. run the machine in production conditions. In this action, some tests are performed in order to avoid failures in the production. Every action in this protocol is proofed through testing or measurements. The test results can reveal a potential and/or weaknesses for the further operation and maintenance of the machine.

6.11.2 Protocol actions and reference workflow

Six main actions are organized to support the protocol application:

1. Reassembly. All physically existing parts and components related to mechanics, control, CPS are assembled in an inverse way to disassembling protocol in case of reused components and in accordance with instructions from the producers/suppliers/developers, in case of new (e.g. from Protocol “Modernize”)/upgraded ones (from Protocol Upgrade). The assembling is accomplished with mechanical adjustment in order to ensure the desired accuracy of the assembly.

   After the action “Reassembly”, the machine is completely assembled but not able to perform any driven movement.

2. Virtual Commissioning. The virtual simulator, developed for testing the mechatronical upgrade, is used within this action. Using this simulator, the program codes for the NC and PLC can be tested for various operational technologies in term of HW/SW in the loop. In such way, the program codes can be very quickly modified, and thereby, the process of putting in operation can be shortened significantly.

   After this action, the program codes for PLC and NC are ready for putting in operation.

3. Put in operation. The control system involves the drives, the control units (e.g. NC, PLC and IPC) and sensors. The communication between the control units and sensors is established and the safety functionalities are launched. Furthermore, the drives are put in operation and the servo drives or the parameters of the servo drives are set/optimized. This action also involves testing activities in order to ensure the correct functionalities of the control system and the drives especially servo drives.

   After this action, the machine is actually ready for operation. The accuracy of the machine is not fully reached yet due to the pending calibration and compensation. Moreover, the CPS is not in operation therefore the add-on functionalities for the operation, monitoring and maintenance are not available yet.

4. Calibration and compensation. The calibration and compensation represent actions ensuring the accuracy of the machine. In principle, both require to take measurements for quantifying the actual state of the machine. Afterward, correction values between the as-is state and the target state are generated. In case of calibration, correction values depend on single input unlike a compensation where multiple correction values depend on multiple inputs (e.g. volumetric compensation). Thus the effort for calibration is much lower than the effort for compensation.

   After this action, the machine is ready for operation with the desired accuracy.

5. Run virtual twins. This action covers every activity being carried out to make the virtual twin be running with all the aspects like installation the software, connection to sensors and to the control system as well as establishing the data transfer from/to other systems (e.g. cloud, ERP, MES, Intranet, Middleware). While the physical installation is performed within action “Reassemble”, this action only aims at works related to software. Furthermore, the verification of the computed results, if any, as well as the validation of the virtual twin belong to the activities within this action. If necessary, some optimization of the machine with the digital twin can be performed (e.g. optimization of control parameters).

   After this action, the machine is fully ready for the production with all features.

6. Put machine back in production. This action aims at the fully inclusion of the machine in production. In order to make this without problems and flaws some tests are necessary. All the tests conducted in the previous actions show the capability of the machine for the production partly or indirectly. In this action a production test is performed in order to confirm the capability of the machine for the desired production result, i.e. quality/accuracy, productivity and resource usage, or to reveal the need for some modifications, improvements or optimization. In case of insufficient production test, previous activities are revised. It cannot be excluded that other protocols have to be triggered in order to reach the desired improvements. In such case, a systematic analysis should be carried out (e.g. FMECA) before triggering other protocols.

After this action, the machine is producing under desired criterion.

Stepwise execution of these actions and steps are illustrated in the protocol flowcharts below:

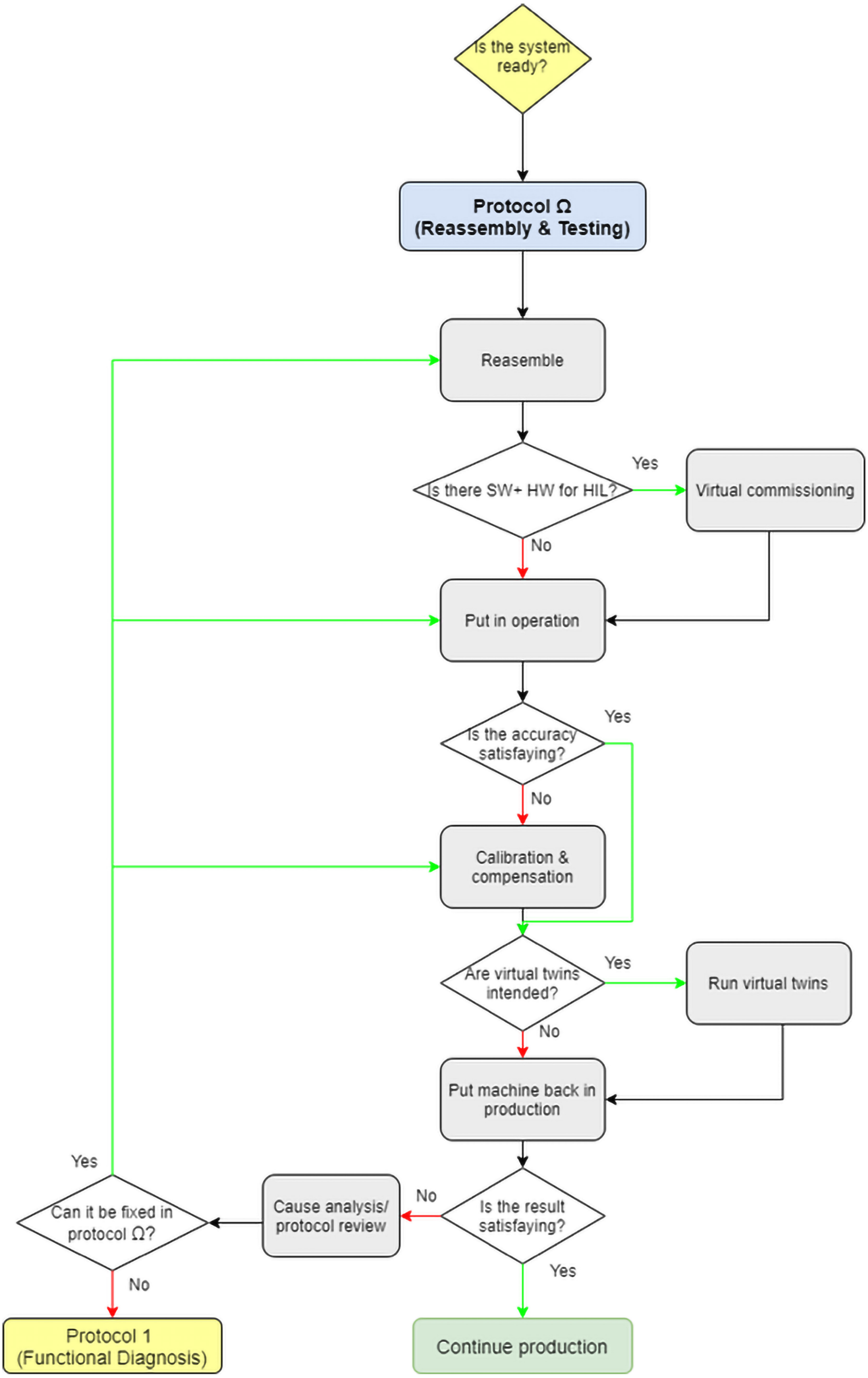

Figure 27 — Protocol Reassemble and Testing workflow

7 Development of a Digital Thread Tool for Protocols

7.1 General

The last section provides guidelines for the ten LEVEL-UP protocols. Depending on the condition of a capital item, the manufacturer chooses and performs a series of activities to extend its useful life. For example, when a machine malfunctions, the manufacturer may first carry out inspection activities, and then decide whether it needs to be refurbished, repaired, remanufactured, or upgraded, according to the inspection result. This process involves various stakeholders and systems and has a significant impact on the capital item's lifecycle. It is a challenge to enable cross-collaboration between these different stakeholders and systems, and provide the manufacturer a holistic view of the activities carried out along the entire life cycle of a capital item.

The Digital Thread (DT) is "an integrated information flow that connects all the phases of the product lifecycle using accepted authoritative data sources (e.g., requirements, system architecture, technical data package (TDP), three-dimension (3D) CAD models) "[3]. Digital Threads complement digital twins for better data management to improve the production process and performance and ensure continuity and traceability of information [4]. It offers an opportunity to handle the discussed challenges, with the capability of weaving together all activities carried on a capital item along its life cycle. Transparent information flow in a DT allows stakeholders to have a clear view on, for example, which life extension activities have been performed, why an activity is required, and which data is necessary for the execution of that activity.

This section presents the development of a Digital Threads tool. It digitalises and integrates the LEVEL-UP protocols into the DT design tool for managing product life extension activities applied on capital items.

7.2 Introduction of Digital Threads

The DT refers to "the communication framework that allows a connected data flow and integrated view of the asset's data throughout its lifecycle across traditionally siloed functional perspectives "[5]. It aims to link heterogeneous information systems and data sets across the various domains of the product lifecycle (e.g., design, manufacturing, quality) in dynamic ways, and enables the holistic view and traceability of an asset along its entire lifecycle [3] [6]. The DT includes any data, behaviours, models, protocols, security, and standards related to the asset and the context where it is expected to operate [6].

Literature and commercial vendors describe the application of DT in many areas, such as product design, manufacturing, and product lifecycle management [7] [3] [8]. The DT offers the opportunity to connect activities with data, stakeholders and applications in the process of product life extension. It would foster interoperability and close collaboration between them and enable traceability of activities.

7.3 Motivation for the development of Digital Threads Tool

The extension of product useful life involves the collaboration between many stakeholders (e.g., technology providers, industrial manufacturers, industrial equipment OEMs, engineering and maintenance companies…) and systems. This is due to the fact that each stakeholder has expertise only on certain technologies and activities. For example, the company in charge of the recycling activities may have no expertise in upgrade or inspection, but a sustainable approach relies on close collaboration between each other. The recycling company recycles the old components discarded from the upgrade activities. The decision to perform upgrade activities depends on the inspection results. In basic terms, it can be viewed as the exchange of information, models, parts and materials between multiple stakeholders and systems along the life cycle of products. To support this kind of exchange, integrate information flow besides physical material flows is helpful.

Meanwhile, it is necessary to monitor and track the activities performed on a capital item. This is important for product owners because it provides a clear view of their products' historical and current status. For technical partners and engineering and maintenance companies, it is meaningful for decision-making, for example, to understand why a repair activity is performed and when is the best time for the next maintenance action.

We intend to investigate the integration of LEVEL-UP protocols and DT approach for product life extension. The LEVEL-UP protocols support product life extension, and the DT approach can support the management of connected information flow and cross-collaboration between stakeholders. It seems promising to digitalise the product life extension approaches from the LEVEL-UP protocols and manage them in DT design tools for guiding and supporting manufacturing companies extending the useful life of capital items.

7.4 Approach to develop Digital Threads Tool

In the last chapters, we adopted the top-down approach to develop a systematic guideline in the form of organised Circularity Protocols. It started at Protocol Z-Modernise, and going through Protocols-Functional diagnosis, Inspection, Refurbishment, Disassembly, Repair, Remanufacturing, Upgrade, Recycling, to finally reach Protocol Ω - Re-assembly and Testing (Fig. 28). We described the synergies and interactions between these protocols. The systematic guideline provides a holistic view about different approaches that can be applied for product life extension. It would guide companies to choose and perform suitable actions for product life extension in the physical world.

Figure 28 — LEVEL-UP Circularity Protocols

This section describes further activities in the development of the DT tool. They are mainly to digitalize the systematic guidelines & manage the product life extension actions in DT tools. We defined interfaces and digitalised all actions/activities in the systematic guideline to support interoperability and close-collaboration between stakeholders in a digital world. For all life extension activities, we defined a clear interface about their expected input and output. This is to ensure that participants on the activities to be aware, for example, of which information is required, in which formats, and according to which standards. So that, the right information can be delivered to stakeholders and systems in other activities. This kind of interface definition is important to achieve interoperability and close collaboration between stakeholders. Finally, the Circularity Protocols were realised and integrated into a DT design tool. We developed a DT design tool with a digital representation of all protocol actions, i.e. product life extension approaches and actions. It allows companies to stepwise plan, apply, and track various life extension actions applied on their capital items. The DT design tool helps manage the digitalised product life extension activities, their connected information flow and the collaboration between stakeholders. It provides companies in the digital world a holistic view of all performed product life extension activities.

In the following subsections, we take the Refurbishment protocol as an example to illustrate these two further steps. In these two steps, we describe how to realise the Circularity Protocols into the DT design tool with the example of refurbishment protocol. It first presents the building of the Digital Thread ontology based on Circularity Protocols (i.e. refurbishment protocol), and then introduces the subsequent integration of the ontology into the DT design tool. The definition and development of a Digital Thread ontology are presented with the example Refurbishment protocol, but the approach is applicable for all 10 LEVEL-UP protocols.

7.4.1 Develop a Digital Thread tool for product life extension

This step includes developing a DT design tool to support the plan, execute, and track the protocol actions performed on capital items. For that purpose, the first goal is to develop a Digital Thread ontology based on the protocol guidelines and defined interfaces. The ontology manages all important semantic concepts within the Digital Threads for product life extension. It enables an ontology-driven derivation of needed actions and parameters for a given protocol. Fig. 29 provides an overview of the domain ontology for Digital Thread. More details about the Digital Thread ontology will be described in the deliverable D3.2. Based on the Digital Thread ontology, we will develop a DT design tool. The DT design tool is a web application that provides a model editor for DT. The model editor uses a variant of the PrimeFaces FlowChart, whereby the underlying meta-model is not pre-defined. The available DT related activities, properties and steps are derived dynamically on a DT ontology. The DT ontology is linked to the DT design tool and enables the tool to derivate the meta-model and corresponding UI modelling elements.

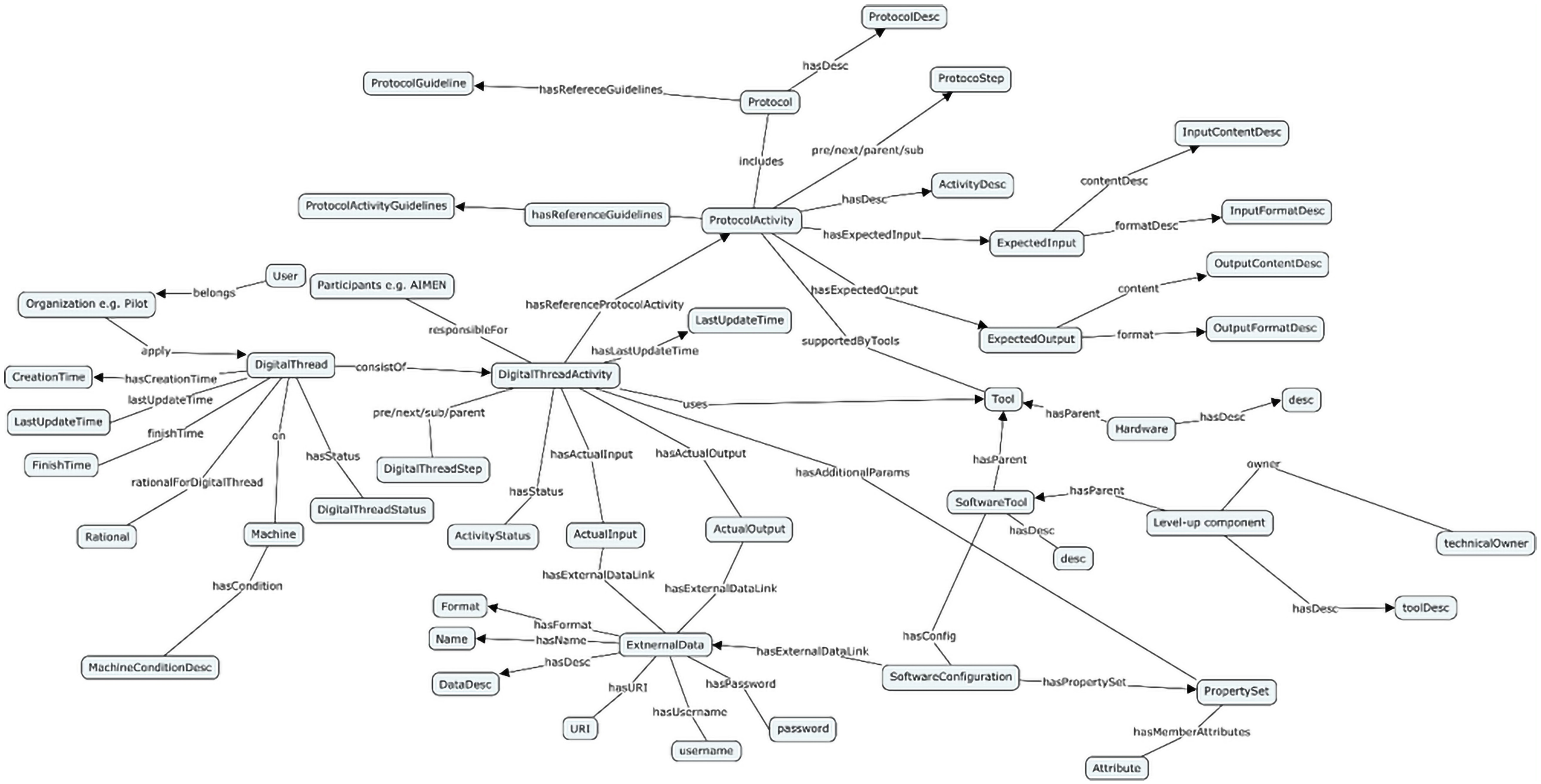

Figure 29 — Concept map of the digital thread onotology

The definition of a Digital Thread ontology for a specific protocol is based on OWL-DL. The ontology aims to define the protocols, their activities, the steps, the meta-information, and the corresponding instantiation as the DT. Information about protocols and their activities are mostly from the protocol guidelines presented in the last chapter. In order to support collaboration and information exchange between partners in the digital threads, there is a need to have more metadata information about the protocol activities/actions, for example, about the expected input and output. It defines the information exchange interfaces for each protocol action, so that the right information in the right format can be prepared and delivered by partners. For that purposes, we have prepared an excel file " "LEVEL-UP Digital Thread - Protocols actions metadata" to collect this kind of metadata information for protocol actions. Table 1 shows sample interfaces for the action "Clean component/machine surfaces" in the REFURBISHMENT protocol about its' expected input and output.

Table 1 — Interfaces of Action "Clean component/machine surfaces"

Expected input (information content)	Expected Input (Characteristics of Information)	Expected output (information content)	Expected output (Characteristics of Information)
(1) Refurbishment protocol selection and Machine inspection checklist from Protocol 2- Inspection. (2)Summary of Refurbishment actions performed before.	PDF/.docx/.xlsx. Ideally, web questionnaire.	(1) List of cleaning actions performed/ date/ personnel /pictures of the machine before and after/other important information. (2) Other protocols trigger	PDF/.docx/.xlsx. Ideally, web questionnaire.

The protocol actions such as Clean component/machine surfaces for the refurbishment protocol are defined as protocol activities and belongs to the concept Protocol_REFURBISHMENT_ACTIONS. Each specific protocol action is an individual of the type Protocol_REFURBISHMENT_ACTIONS. The example of the individual P_Ref_Clean which represents the action Clean component/machine surfaces is shown in Fig. 30.

Each protocol activity, such as the individual P_REF_Clean, has meta-information to add information for the instantiation. The current ontology version covers meta-information such as, the defined interfaces (e.g. input and output), and the potential support of hardware or software. The definition of mappable hardware, software and data sources are also added as concepts and corresponding individuals inside the ontology.

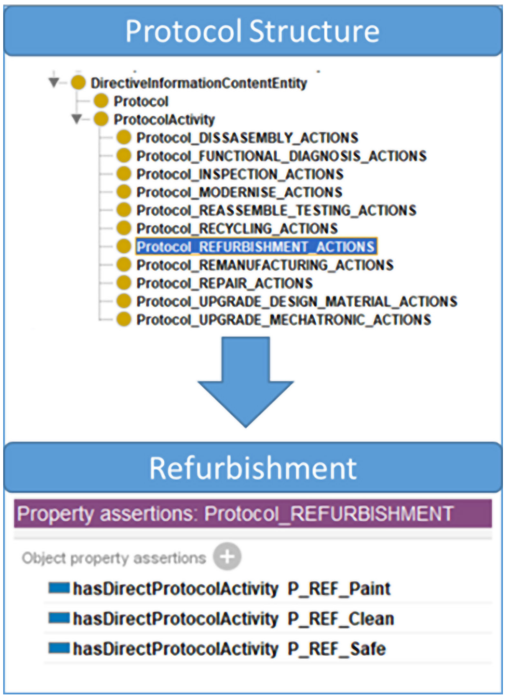

Figure 30 — Representation of refurbishment protocol actions in the Digital Thread ontology

A DT is an individual of the Digital Thread's concept and supports the definition of a sequence of DT activities. Each Digital Thread's individual defines a sequence of activities whereby each activity can contain a couple of meta-information. The example of a DT and linked DT activity is shown as individuals in Fig. 31.

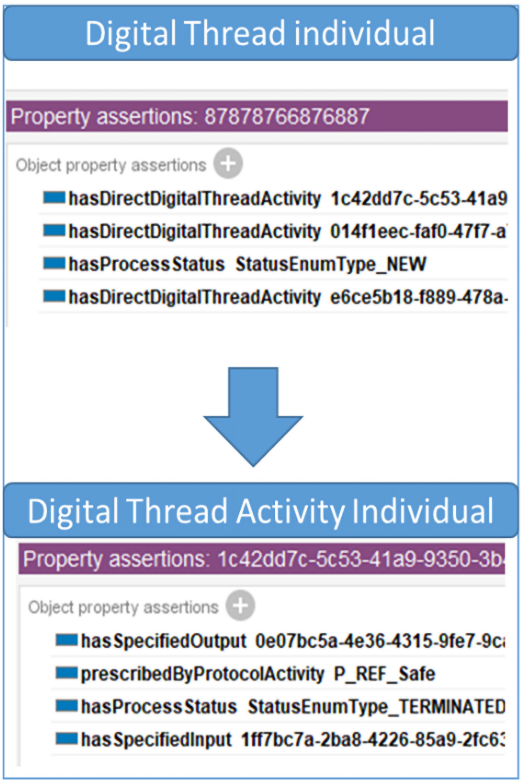

Figure 31 — Example of Digital Thread individual

As presented before, the ontology defines the protocol, protocol activities, and Digital Threads. Thus, this ontology enables the interoperable representation of Digital Threads but cannot be applied by Digital Thread's stakeholders because they are more familiar with mechanical engineering or system engineering instead of description logics.

To solve this barrier, the DT is embedded into a web application. This web application focuses on the modelling of flows whereby a flow describes a DT. The primary purpose of the DT design tool, namely Digital Thread Wizard, is to:

— Define the Digital Thread as flow

— Update the Digital Thread activities by different stakeholders

— Inform stakeholders by events when the Digital Thread's status has changed.

The ontological content related to protocol activities, data sources, tools is available as a palette inside the tool. A menu above the modelling editor represents the palette. Each menu entry adds the corresponding ontological individual as a flow's node to the DT's flow. Figure 32 shows the available palette. It lists all the LEVEL-UP life-extension protocols, as well as the actions to be performed in each protocol. For example, in the refurbishment protocol, we have the action for cleaning, painting, and safety upgrade. The right side shows some metadata or guideline for the cleaning actions, for example, about its expected inputs, outputs, and data formats.

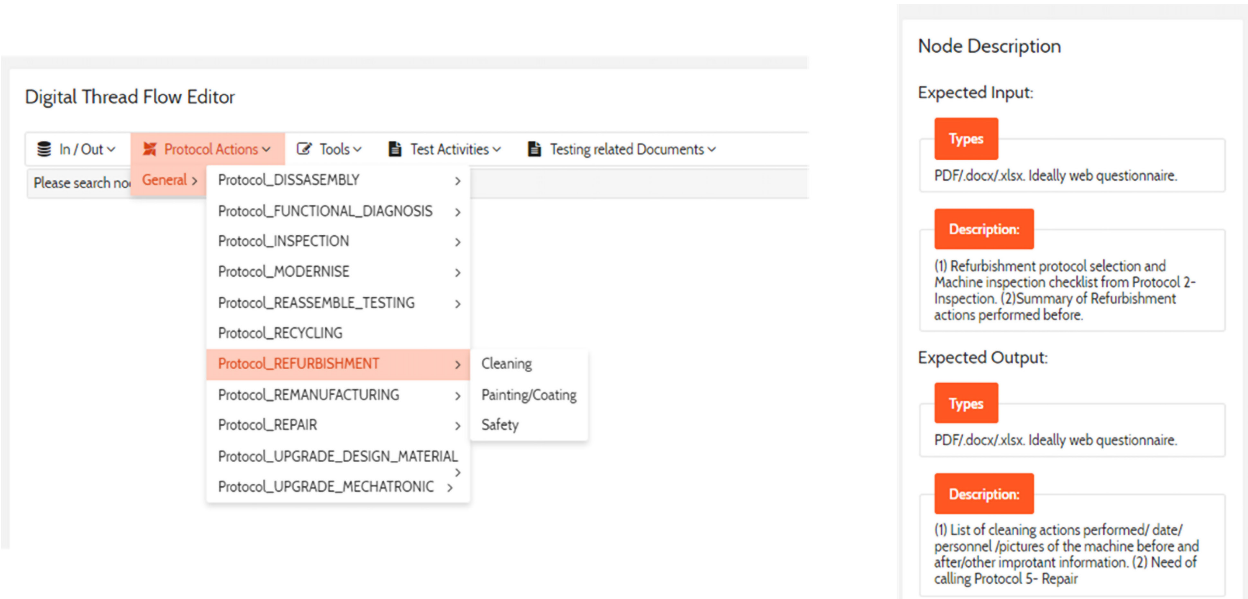

Figure 32 — Screenshot of protocol's palette as a menu

Each selected menu entry appears as a node on the editor. Connections between protocol activities model the overall DT. The role of connections from data sources and tools to the protocol activities is to map the protocol activity's input and output. Figure 33 demonstrates the DT for the refurbishment as a flow. Besides, each flow's node contains parameters that can be set or updated during the Digital Thread's lifecycle. One of the mandatory parameters is the status of a DT activity.

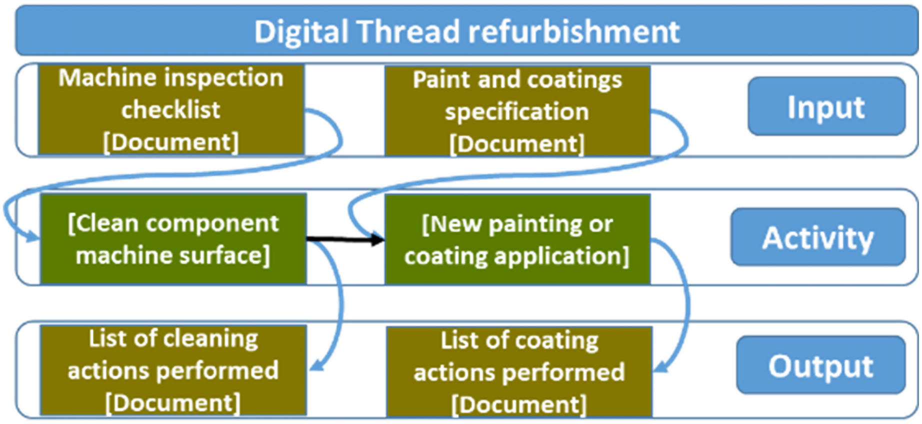

Figure 33 — Sample refurbishment Digital Thread

The comprehensive tool supports the creation and status monitoring of Digital Threads inside a web application and supports the deployment as a service. A screenshot of the Digital Thread modelling view is given in Figure 34.

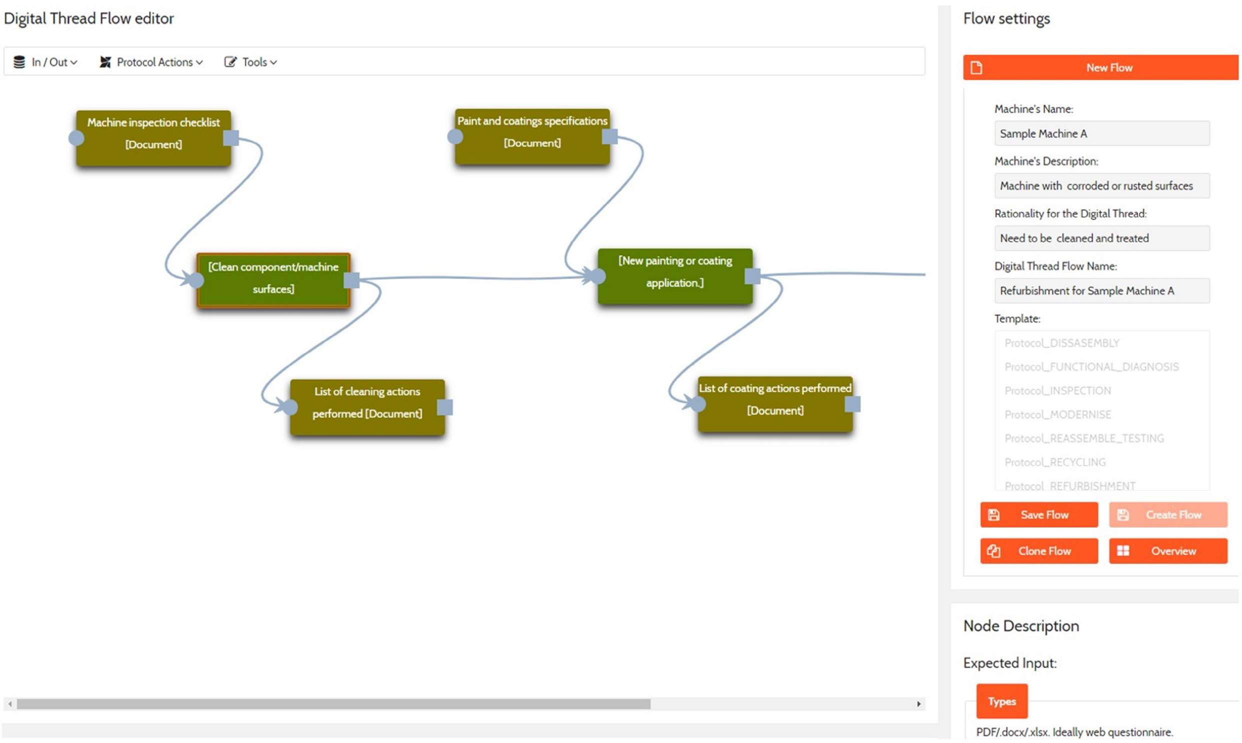

Figure 34 — Screenshot of the Digital Thread Wizard

The available protocols, protocols activities, tools, data sources and their parameters are not fixed inside the Digital Thread Wizard. The applied approach reads the information from the Digital Thread ontology and updates the modelling environment accordingly. This approach guarantees the extendibility and adaptability to specific domain-specific regulations.

7.4.2 Deploy digital thread in industrial pilots

Table 2 gives a brief technical overview of the developed Digital Thread Tool. The deployment focuses on loosely coupled services on the Internet. Docker is used to enable the simple deployment of the microservices and Apache Fuseki. For that purpose, a Docker-compose.yml file has been created to start and configure the service. At the moment, BIBA hosts the Digital Thread Tool at its own IT infrastructure. It is accessible with the URL: http://www.digitalthread.eu/. In case of necessity, it can also be easily deployed in the IT infrastructure of the industrial pilots with the configured docker-compose file.

Table 2 — Technical stack of the Digital Thread Tool

Item	Value
Nature	Spring Service based on Spring 2.3.1
System requirements	Microsoft Windows, Linux
Programming Language	Java 8
Development Tools	Eclipse EE
Additional Libraries	*PrimeFaces*, JAXB, Spring-Kafka, Jena, kafka-oauth-common, kafka-oauth-client
Application Server	Apache Tomcat 8
Databases	Apache Jena Fuseki TripleStore; MySQL
I/O formats	REST using JSON for I/O, Kafka using JSON

With the developed and deployed DT tool, companies can work together with partners to plan the actions that need to be performed according to the conditions and status of their own machines. Based on the plan, they can afterwards manage and keep track of the execution of these life extension actions. Figure 35 gives an example usage of digital threads for the refurbishment protocol.

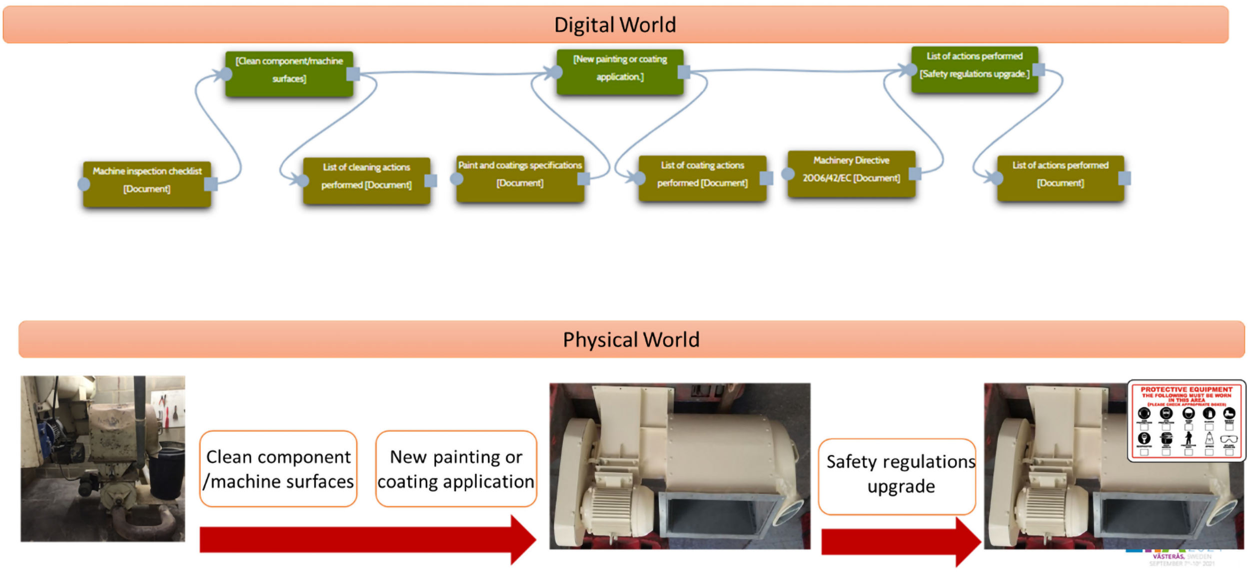

Figure 35 — Example usage of the Digital Thread tool for refurbishment

7.5 Conclusion

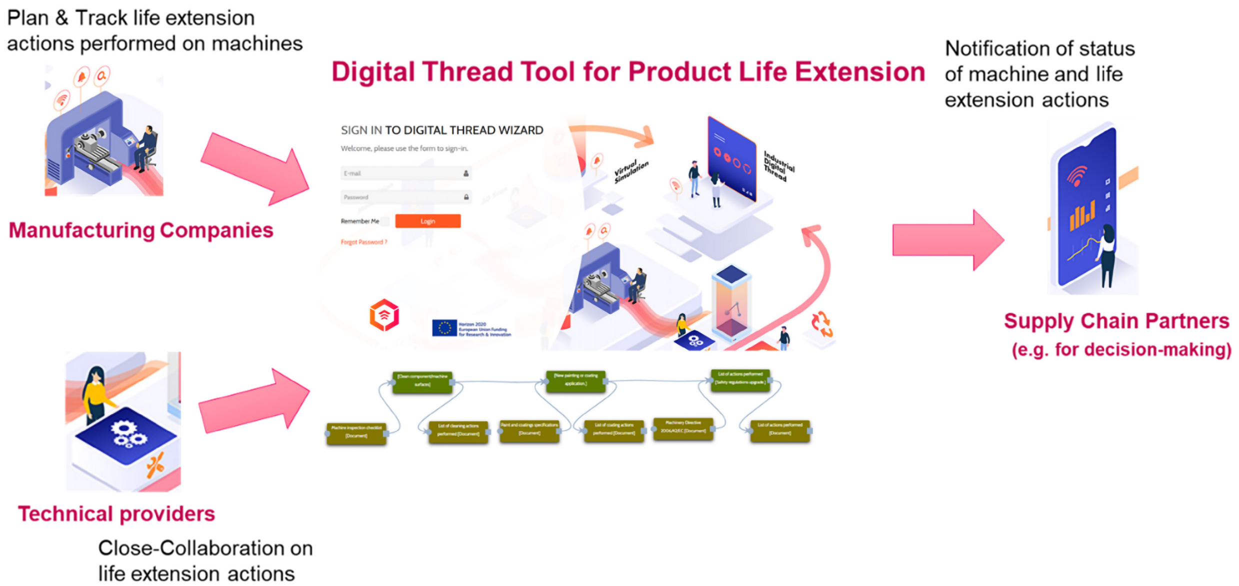

Figure 36 — Overview of the Digital Thread Tool Usage

Figure 36 provides an overview of the usage of the DT tool. In summary, we have developed a DT tool for Extending the Useful Life of Capital Items in Manufacturing Companies. With this tool, manufacturing companies can plan and track the execution of different actions to extend the useful life of their machine. Technical partners can participate in the plan and support the execution of these actions. And the latest status of the machine, as well as the information about performed actions, can be automatically sent to relevant supply chain partners. We have validated the concept and the DT with several technical partners and industrial pilots.

8 Application of Protocols and Digital Thread Tool in Industrial Pilots

8.1 General

In order to support the pilots and technical partners to understand how to apply the LEVEL-UP protocols for product life-extension, and how to manage the plan and execution of protocol actions with the developed Digital Thread Tool, we have organized training and validation workshops together with partners. Meanwhile, we have prepared a user guide documentation that can be found here. This section presents the workshops and describes further LEVEL-UP Protocol & Digital Threads application activities.

8.2 Workshop for LEVEL-UP Protocols & Digital Thread Validation

The main objective is to validate that application of LEVEL-UP protocols & digital threads for the Repair process of a large metallic component with repair/maintenance providers. For the workshop, AIMEN communicated with WP 5 partners on this validation process. The online workshop named ‘Digital thread validation for the Repair process of ESMA-FAGOR gear’ is planned as following.

— Objective: partners involved in the repair flow to test the digital thread tool developed in LEVEL-UP utilizing the real flow prepared for ESMA-FAGOR gear repair and provide feedback as potential users.

— Partners involved: AIMEN (as repair services provider), FAGOR (as maintenance provider, OEM), ESMA (end-user), ESI, THAD, BIBA.

*INEGI, KMWE, BRUNEL and TRIMEK. Partners who do not participate directly on ESMA repair case it is not ‘compulsory’ to attend, but anyway as they are involved in other repair/remanufacturing/upgrade works, could be beneficial to have they testing the tool and have your feedback on it.

*SOFIES. Partner who could be interested in participating and testing the tool too to any potential application that they might see for the recycling protocol, process...

— 2 hours of workshop (30’ explanation from BIBA side on the tool +1 h validation /’play around’ + 30’ of feedback reporting from partners)

8.2.1 Organization and Summary of the workshop

The online workshop took place on 3th Nov. 2021. Fig. 37 gives the agenda of the workshop. It has a list of attendees from the following partners: AIMEN, TRIMEK, FAGOR, ESMA, IDEKO, INEGI, SOFIES, BRUNEL, ESI, KMWE, THAD, and BIBA.

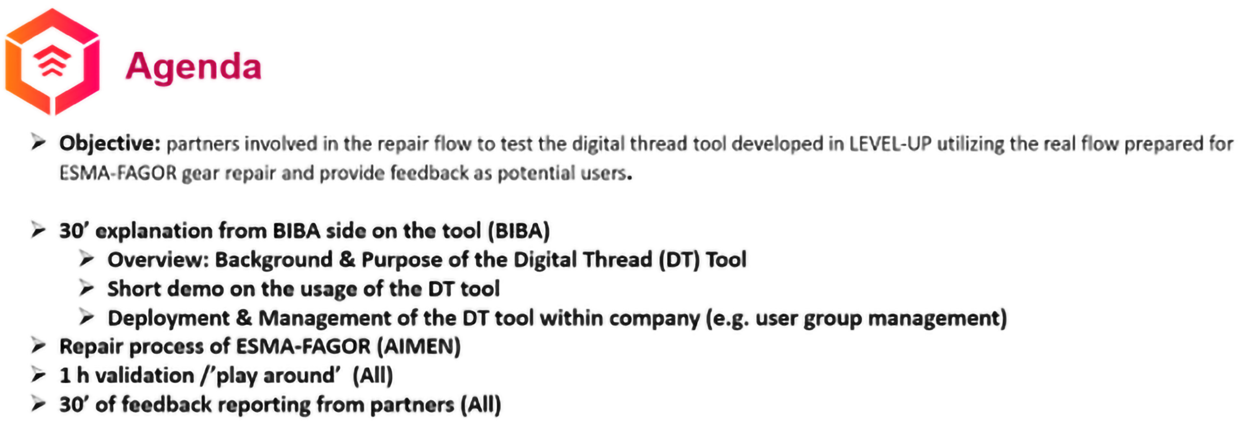

Figure 37 — Agenda of the online workshop for Digital Thread Validation

In the first part, BIBA presents an overview and short demo of the digital thread tool. With the presentation and live demos, it gives a short training, and illustrates, answers mainly the following questions related to the protocols and the DT tool developed in the LEVEL-UP Project:

— Q1 : How can I know which protocol & protocol action is applicable for my machine considering the current status of the machine?

— Q2: How can I apply the protocol & protocol actions on my machine? E.g. Which kind of information/document is required?

— Q3: How can I involve partners with different competencies to work on the protocol? For example, information/document exchange between partners?

— Q4: How can I have an overview about protocol action applied on the machine? And manage & track the history of protocol & protocol actions applied on the machine?

Afterwards, AIMEN presented the real digital thread flow prepared for ESMA-FAGOR gear repair. Based on the presented repair flow, the workshop has organized further activities for validation and play around. Due to time limitations, the attendees planned to continuously validate the protocols and digital thread tools after the workshop.

8.2.2 Feedbacks about LEVEL-UP protocols & Digital Threads

We have prepared a feedback form to collect feedback about the LEVEL-UP protocols and Digital Threads Tool (Table 2). After the workshop, we have received several filled feedback forms from the participants.

Table 3 — Feedback Form

<table>
<tr><td colspan="5">WORKSHOP INFORMATION</td></tr>
<tr><td>EVENT TITLE</td><td colspan="2">Digital thread validation for the Repair process of ESMA-FAGOR gear</td><td>DATE</td><td>3th Nov. 2021</td></tr>
<tr><td>OBJECTIVE</td><td colspan="2">Digital thread validation for the Repair process of a large metallic component with repair/maintenance providers</td><td>TIME</td><td>13:00-15:00 (CET)</td></tr>
<tr><td>PLAN</td><td colspan="4">2 hours of workshop (30’ explanation from BIBA side on the tool +1 h validation /’play around’ + 30’ of feedback reporting from partners)</td></tr>
<tr><td colspan="5">RATING SCALE: 1 = SUBPAR 2 = SATISFACTORY 3 = AVERAGE 4 = GOOD 5 = EXCELLENT</td></tr>
<tr><td>DIGITAL THREADS</td><td colspan="3">COMMENTS</td><td>RATING</td></tr>
<tr><td>a. Is it able to support the plan of protocols, i.e. protocol actions applied on capital items?</td><td colspan="3"></td><td></td></tr>
<tr><td>b. Is it able to support the execution of protocol actions? Do you need additional information about protocol actions besides required input, output and tools etc.?</td><td colspan="3"></td><td></td></tr>
<tr><td>c. Is it able to support information exchange, share and collaboration between partners on protocol plan & execution?</td><td colspan="3"></td><td></td></tr>
<tr><td>d. Is it able to track & monitor the execution of protocols on capital items?</td><td colspan="3"></td><td></td></tr>
</table>

e. How is the user-friendliness & usability & aesthetics of the tool?		
f. How is the learnability & understandability of the tool?		
SCORE OUT OF POSSIBLE 30 0% 0		
Technical bugs?		
What other improvements should be made for the future?		
ADDITIONAL COMMENTS ON PROTOCOLS & GUIDELINES		
a. Are the protocol guidelines (including protocol actions, flowchart) suitable to guide companies to select & apply protocols, i.e. protocol actions for their capital items?		
b. Which additional protocols are required?		
c. What improvements should be made for the future?		

The feedback about the LEVEL-UP protocols and Digital Thread Tool is positive. It has a rating score on average, around 3.7 out of 5. In general, the Digital Thread Tool can meet the key purposes: 1) Support the plan & application of different LEVEL-UP protocols for product life extension; and 2) Monitor, track and have an overview of the protocol activities performed on a capital item. It is quite user-friendly and easy to use. Meanwhile, partners have also provided valuable suggestions about additional features and improvements for later versions of the Digital Thread Tool. The following lists some of the suggested improvements:

— data-space for storing different documentation, files and reports that are generated as result from the applications of protocols. The digital thread tool keeps currently only a link to the documents, rather than storing them in a central data-spaces.

— zoom in/out of the digital threads.

— clear view of relevant tasks & protocol activities for each partner.

— export to, e.g. excel file with selected parameters of objects – to be able to create “to do” list, to have overview what is missing in a selected thread

— select more objects together for movement (e.g. by window or with holding “Ctrl” like in PowerPoint)

— graphically express in which state the object is – if it needs to add some information, if the action is completed (use colour of the frame or some icon…)

— ….

About the LEVEL-UP protocols, it has potential for further improvement according to the feedbacks. The Following gives some sample feedback.

I think the protocols are fine, but the actions of each could be reviewed and completed

I don´t see the necesity of more protocols

For Level-Up it might already be enough, for real use additional protocols might need to be developed according to needs.

I see no need of more protocols

In short, the developed ten protocols in the LEVEL-UP project are fine and enough for the LEVEL-UP projects. Meanwhile, there is possibly a need to review the protocol actions in some LEVEL-UP protocols. On the side of the Digital Thread Tool, in case of new protocols are developed, they can be easily integrated into the Digital Thread Tool thanks to the semantic model developed in task T3.2.

8.3 Protocol & Digital Threads application activities in pilots

The LEVEL-UP partners have tried the protocols and digital thread tool on different occasions, such as WP meetings, workshops, and the WP 6 tasks for technology validation. In the GA meeting between 30th Nov. and 2 th Dec., one hybrid (online + physical) workshop is organized. It is to: 1) demonstrate and give short tutorial to all partners about the application of LEVEL-UP protocols and the Digital Thread Tool; 2) provide a timeslot and collaboration workspace, in which pilots can work together with their technical parterns together to plan and create a Digital Thread flow for their machine with the application of one or more LEVEL-UP protocols. During the workshop, the partners tried the developed protocols and DT tool in small groups, and mostly, partners with experience on it were showcasing individually the tool to pilot line leaders or partners with less experience with the tool. Other partners were reviewing real flows already incorporated in the tool, for example, LUCCHINI is working together with ESI and KMWE on the nozzles upgrade flow. The feedback form is shared for feedback collection. The video recordings and presentation slides can be found here.

As shown in Fig. 38, there is in total 74 DT flows in the DT tool until 13th Dec. 2021. The latest updated DT flow is about the application of the LEVEL-UP UPGRADE protocol. Some DT flows are just for trying, demo and test, and some of them are from the pilots and their technical partners to apply LEVEL-UP protocols for the life extension of their machines.

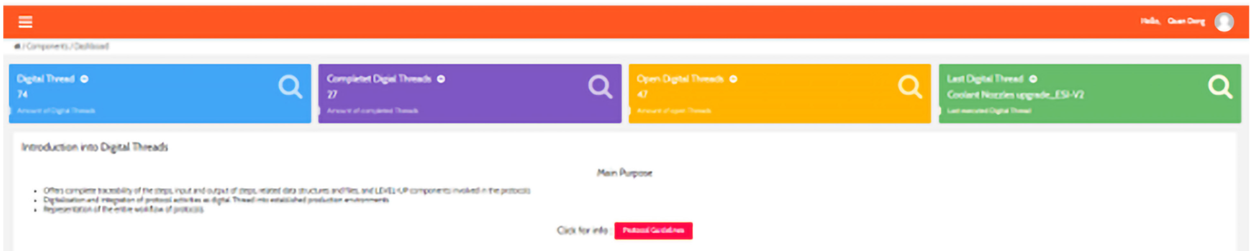

Figure 38 — Overview of DT flows within the DT tool

Fig. 39 – 45 provides some sample digital threads managed by the 7 LEVEL-UP pilots. It shows only some digital threads that LEVEL-UP pilots have shared with all LEVEL-UP partners. Fig. 46 gives a screenshot with more details about the DT flow with applying the LEVEL-UP Repair Protocol on the machine “FAGOR press” in the ESMA Pilot.

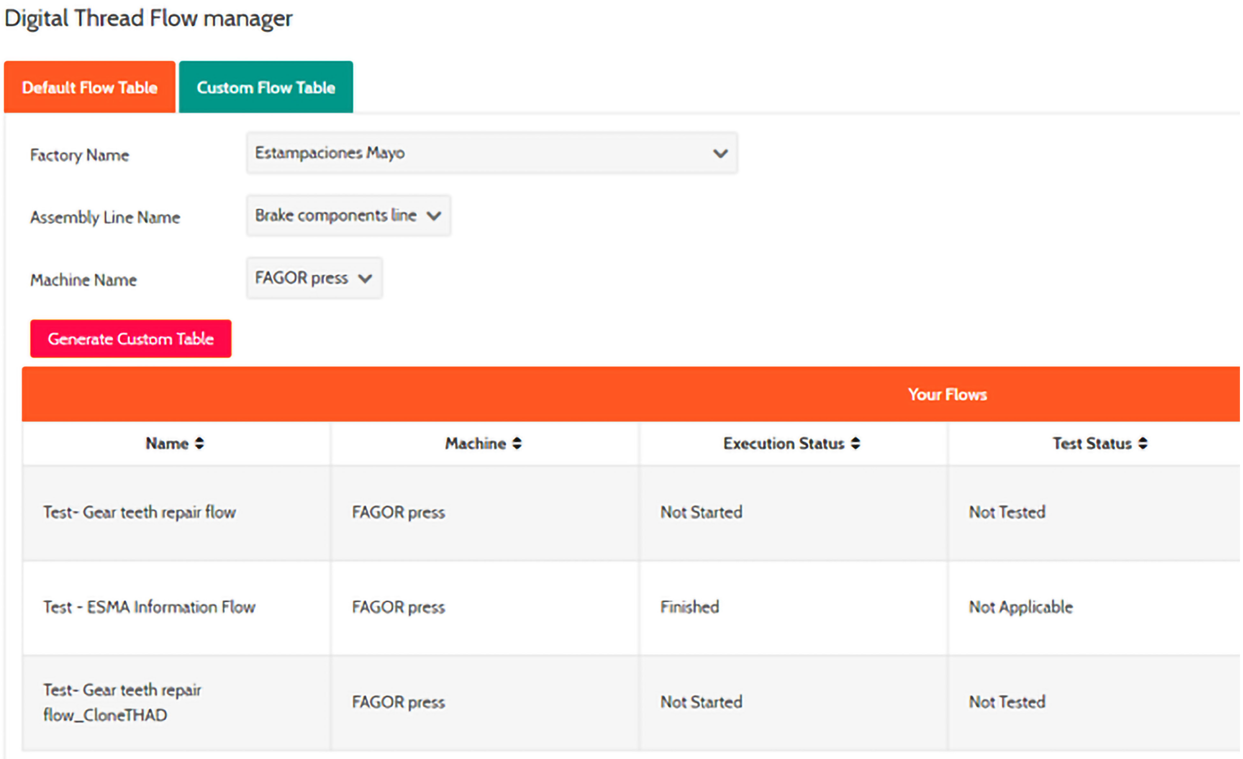

Figure 39 — Sample digital threads in the ESMA pilot

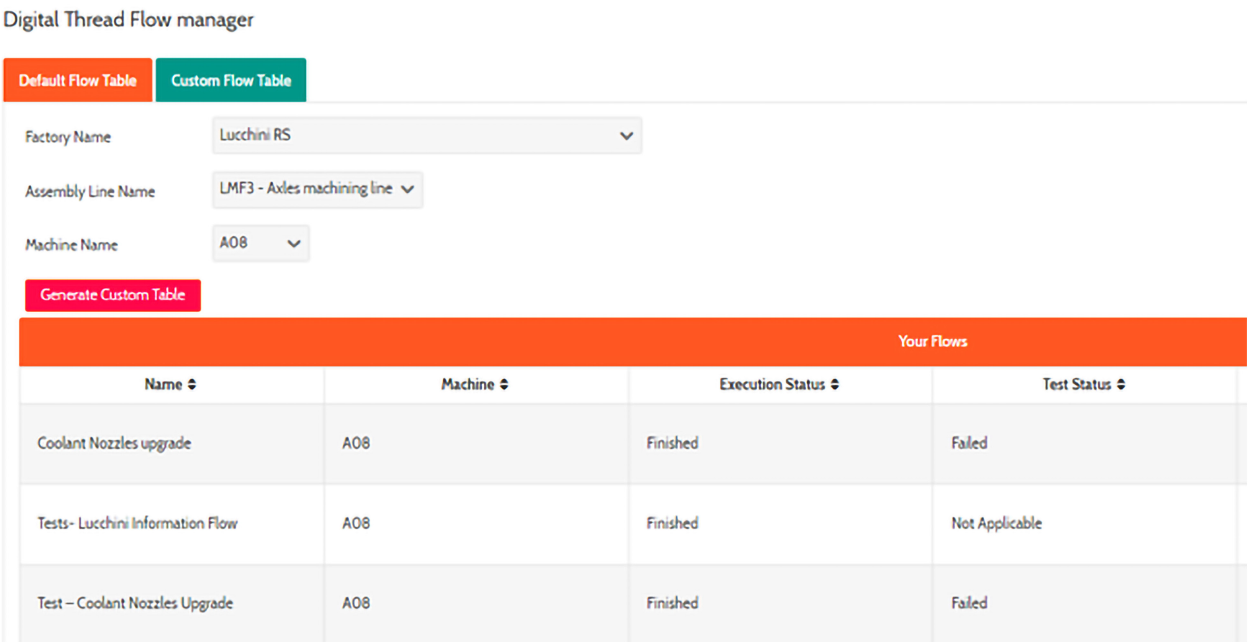

Figure 40 — Sample digital threads in the Lucchini pilot

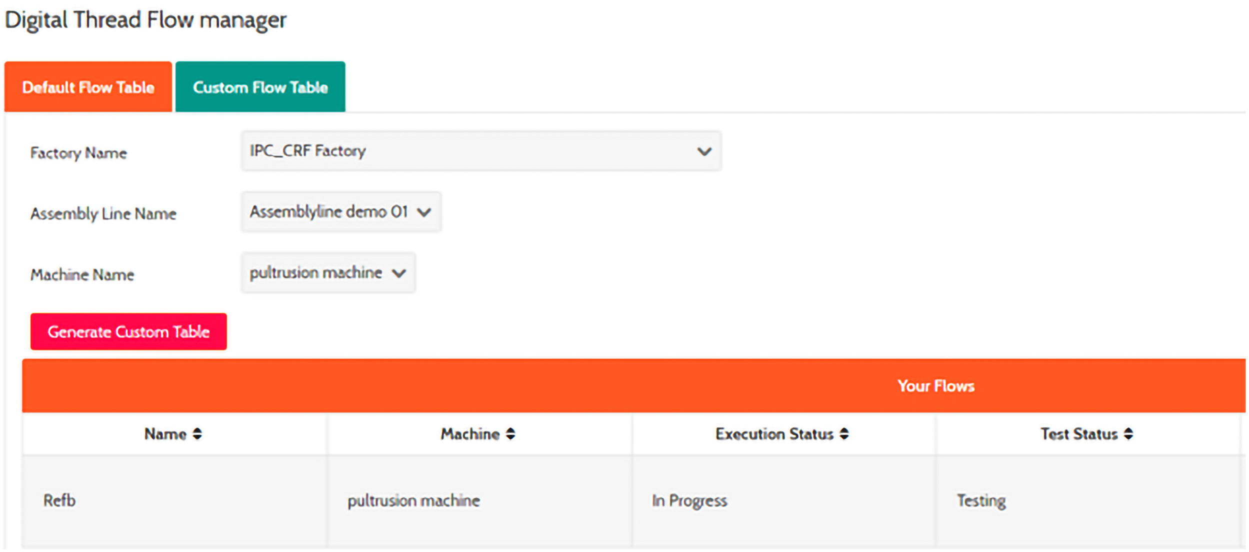

Figure 41 Sample digital threads in the IPC-CRF pilot

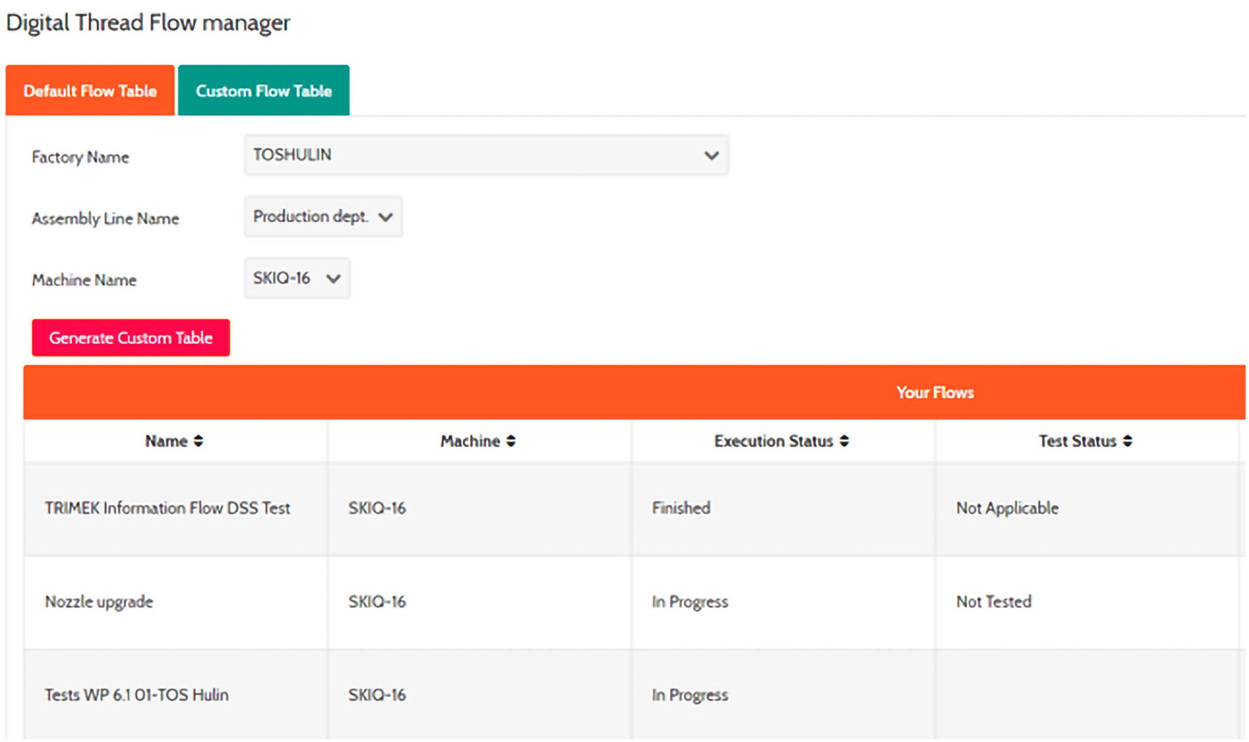

Figure 42 — Sample digital threads in the TOSHULIN pilot

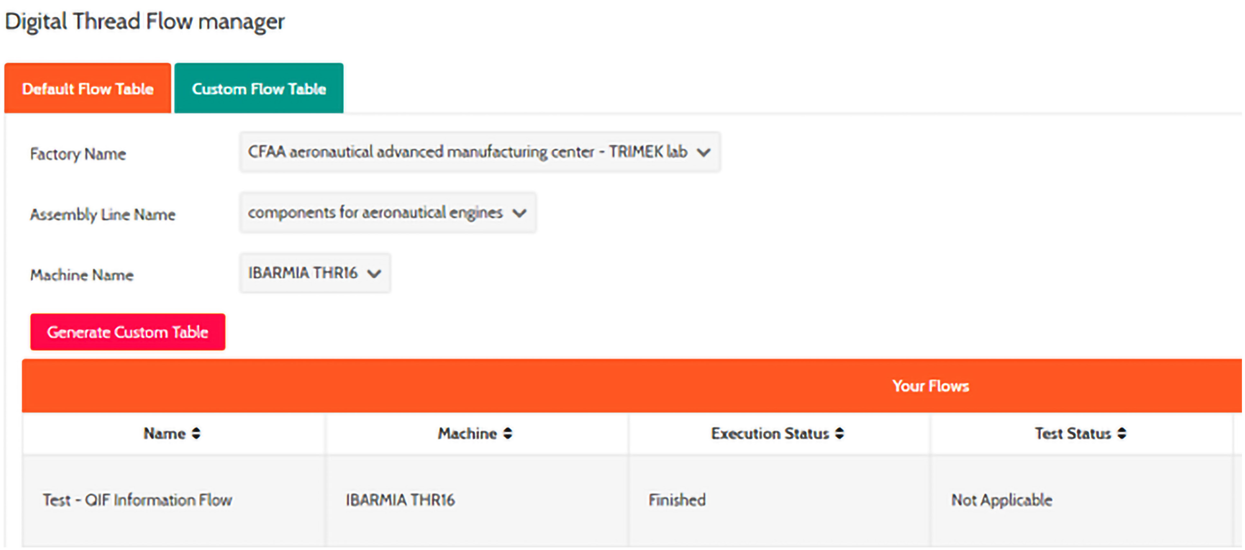

Figure 43 — Sample digital threads in the TRIMEK pilot

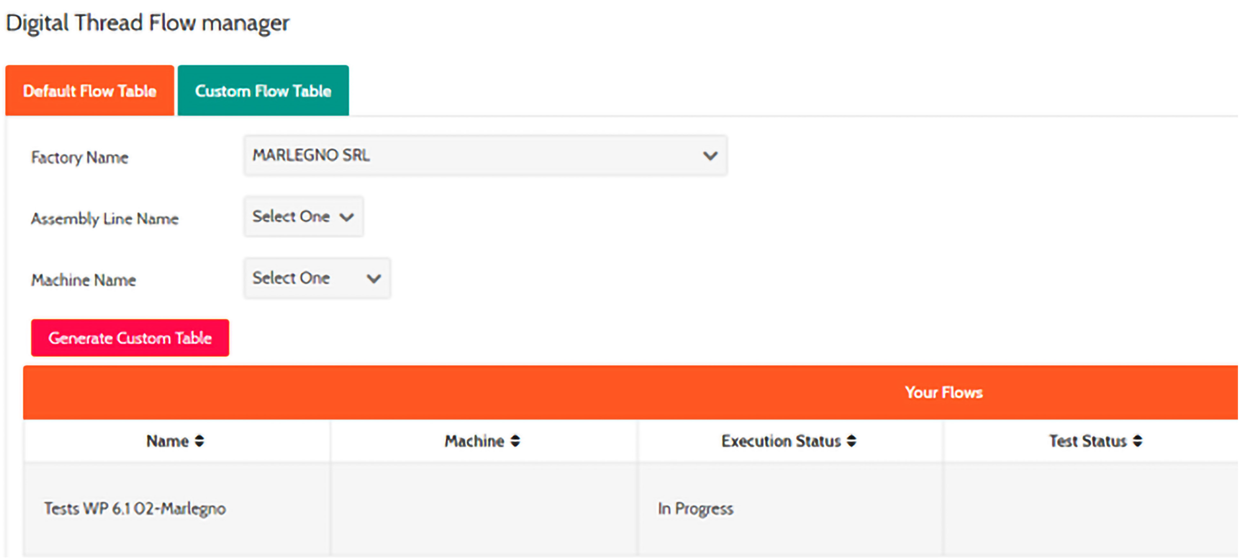

Figure 44 — Sample digital threads in the MARLEGNO pilot

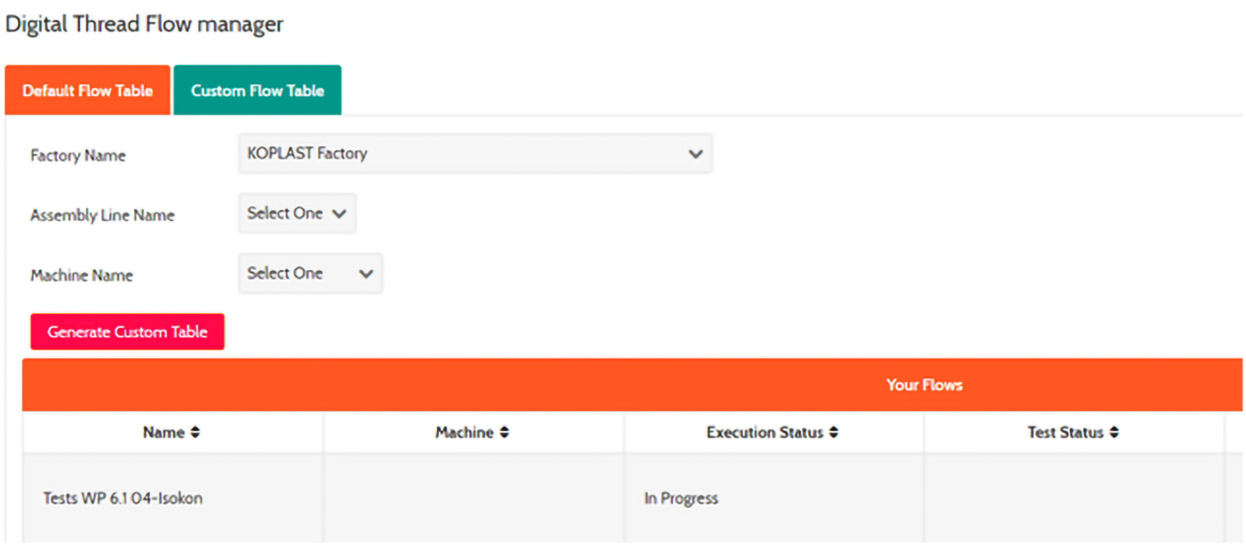

Figure 45 — Sample digital threads in the KOPLAST pilot

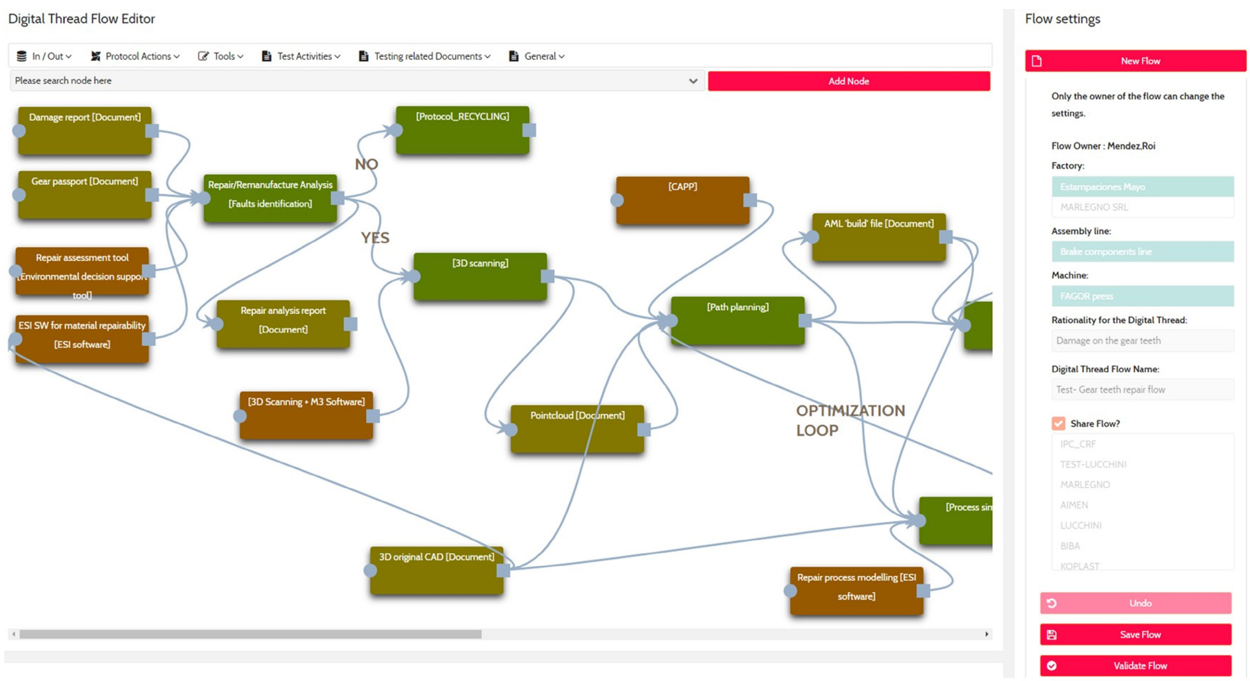

Figure 46 — Sample DT flow with applying the LEVEL-UP Repair Protocol on machine “FAGOR press” in ESMA Pilot

9 Conclusions

This deliverable introduces the LEVEL-UP Protocols and provides the final version of the formal LEVEL-UP Protocols Specifications Document. We have built a workgroup for each protocol. It involves the contribution from all partners, especially the efforts from protocol coordinators. The first version provides the protocol guidelines. On the basis of the protocol guidelines, this version involves mainly the digitalization of protocols and the development of the Digital Threads Tool for managing the plan, collaboration, and execution of protocol activities on large industrial equipment. The results of this deliverable have been partially published in the papers: „Circularity Protocols for Extending the Useful Lifetime of Obsolete Large Industrial Equipment and Assets“ [9] , and “Development of a Digital Thread Tool for Extending the Useful Life of Capital Items in Manufacturing Companies - an Example Applied for the Refurbishment Protocol” [10].

The main highlights include:

— To introduce a methodology for the development of the formal LEVEL-UP Protocols Specifications Document.

— To give a holistic view of the LEVEL-UP protocols, including the synergies and interactions between the ten protocols. It provides a reference flowchart to guide users to find applicable protocols for problem-solving in their industrial settings.

— To provides detailed protocol guidelines for each LEVEL-UP protocol. Each protocol guideline covers protocol definition, a clear description of supportive action and steps, as well as a visualized flowchart.

— To develop a Digital Thread tool supporting the sustainable application of protocols. It has a web application for the management and execution of the DT, i.e. protocol actions.

— To deploy, evaluate and validate the protocols & Digital Thread design tool with industrial use cases

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