Abstract of the Scientific and Technical Report (aSTR)

Stage IV
Testing and evaluation

Project code: ***COFUND-CHIST-ERA-SOON***
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Project title (in Romanian): *Rețea Socială de Dispozitive Inteligente*
Project title: *Social Network of Machines*
Project acronym: *SOON*

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Introductory note

This document presents a brief summary (rSTR) of the Scientific and Technical Report (STR) specific to stage IV of reporting for the 2022 year with the completion date of the project on 28 April 2022. The STR includes 27 annexes describing additional elements of the report.

1. Objectives of Stage IV

1.1. Background. Preliminary issues

This document, called the Abstract of the Scientific and Technical Report (aSTR), aims to present a summary of the main activities and results related to the Fourth Stage of the project, with a duration of 4 months.

An important direction of evolution in Industry 4.0 is aimed at integrating intelligent technologies in all spheres of industrial production. In the current conception, intelligent solutions, if implemented, can be found at the level of standalone applications, with heterogeneous character, which in most cases operate in isolation, without the possibility of interconnection and effective cooperation in order to perform integrated multi-system functions, even if they have a close physical location. The central motivation of the proposed research aims at developing a paradigm of easy interconnection of processes, data, things and people in a holistic paradigm that extends the concept underlying the authentic Internet "of all things", with functions of certain degrees of intelligence.

In this project, the proposed holistic paradigm is centered on a multi-agent framework that shapes machines, processes but also the people who operate or monitor them. Even though automation has taken over many of the functions of human operators, their presence is still essential from the point of view of technical expertise, which from the project perspective is one of the sources of knowledge used by software agents along with other data sources that are used by the algorithms for deep learning and extracting details and characteristics, with the aim of providing new, essential information, otherwise difficult to extract by human operators. The results obtained from the data collected, respectively from the merger and analysis of "big data" (big data) and real-time, of a heterogeneous nature, provided by sensors (vibration, temperature, etc.), by automation and information systems (such as systems for planning and supervising the enterprise's resources), respectively by human operators who compete in the synthesis of decisions generated by the developed multi-agent solution.

The main goal of the project was to identify and propose innovative solutions for optimizing manufacturing processes through intelligent predictive maintenance methods. The way to solve this problem within the SOON project starts from a set of predictive maintenance scenarios established in collaboration with three industrial companies (from Slovakia, Spain and Switzerland). The choice of these three industrial partners, with a completely different industrial profile, was based on increasing the generality of the project approach and proving the suitability for a great diversity of industrial manufacturing processes. Finally, we intend to demonstrate that the introduction of Industry 4.0-specific principles, combined with recent developments in machine learning, and the application of an architecture based on a multi-agent social system can ultimately lead to the achievement of a significant innovation in the optimization and modeling of industrial processes.

In Stage IV of project reporting, the consortium of three universities, a research institute of a national academy and three industrial companies with a distinct production profile (machine tool production, steel industry, recycling and plastics production) from different European countries

focused on completing the implementation of the SOON proposed solution.

The SOON project implementation consortium is composed of the following entities:

- Univ. of Applied Sciences and Arts West Switzerland (HES-SO), Switzerland, project coordinator;
- Slovak Academy of Sciences (SAV), Slovakia;
- University of Oviedo (UNIOVI), Spain;
- "George Emil Palade" University of Medicine, Pharmacy, Sciences and Technology of Târgu Mureș (UMFST);
- Tornos SA (Tornos) company from Switzerland, industrial partner;
- MAT-obaly s.r.o. (MAT) from Slovakia, industrial partner;
- ArcelorMittal (AMI3) from Spain, industrial partner.

1.2. Objectives of Stage IV

The general objective of the SOON project aimed at investigating the impact of the use of social networks type structures, in this case adopted being a solution based on intelligent autonomous social agents, for the optimization of industrial production processes within Industry 4.0 from the perspective of keeping in operation at nominal parameters and ensuring continuity in operation, by applying adequate measures of predictive maintenance. The proposed solution consists mainly in anticipating and early detection of the occurrence of failures, identifying the nature of the failures, respectively their location. Figure 1. conceptually illustrates the idea of the social network structure of smart devices.

Figure 1. Conceptual representation of the Smart Device Social Network solution

The general objective of Stage I, consisted mainly in identifying the particular needs of the industrial environment represented through industrial partners and the requirements related to the tools integrated into the concept of Industry 4.0 proposed for development in this project, was realized and fully successfully achieved.

The general objective of Stage II, aimed at designing a framework for the integration of predictive maintenance solutions using a multi-agent cooperative paradigm that would include modules that

implement algorithms for the intelligent recognition and prediction of the failure of machines, devices and sensors along with a method of intelligent interfacing between machines, respectively advanced human-machine interfacing, it was done entirely successfully.

The general objective foreseen for Stage III, consisted in the analysis, development and integration of the prototype solution based on multi-agent social network for predictive maintenance, based on a specific elaborate architecture, an open development framework, algorithms and methods of interconnection at the level of intelligent devices and advanced human-machine interfacing, was achieved and fully successfully implemented.

The general objective associated with Stage IV, which focused on the development of predictive maintenance algorithms based on artificial intelligence techniques, including solutions for predicting the failure of equipment and sensors, respectively the design and execution of scenarios for the evaluation and testing of the pilot solution, was entirely successfully achieved.

Under Stage IV, the specific objectives were the following:

- **Objective 1**. Research and design of predictive maintenance algorithms based on Artificial Intelligence (AI) techniques. (accomplished by Act. 4.1);
- **Objective 2.** Design, implementation of the module for predicting the failure of equipment and sensors with AI algorithms, along with the extension of the functionality of the research infrastructure based on the requirements resulting from the project, including the improvement of the testing and evaluation platform based on IoT / IIoT technologies for predictive maintenance (achieved by Act. 4.2);
- **Objective 3.** Designing scenarios for evaluation and performance testing of pilot industrial solution. (accomplished by Act. 4.3);
- **Objective 4**. Project management, communication, dissemination and exploitation of results. Effective planning of all these tasks by also taking into account the current pandemic context with the SARS-CoV-2 virus. (made by Act. 4.4)

1.3. Specific activities of the current stage

All the specific activities of this stage, Act. 4.1-4, were carried out in accordance with the Project Implementation Plan. The Act. 4.1-3 activities are described in Section 3, called Scientific and Technical Description.

Act. 4.1 Exploration and design of artificial intelligence-based maintenance algorithms. *(Act. 1.3 begun in Stage I continued in Stage II with identifier Act. 2.5; continued in Stage III with identifier Act. 3.3; continued in Stage IV) [conf. plan of achievement; fully achieved, successfully completed]*

The activity focused on the design of algorithms based on artificial intelligence techniques (in the project proposal, WP4: T4.1, T4.2).

Act. 4.2 ***Implementation of algorithms for fault detection using AI techniques.*** *(the activity started in Stage II with identifier Act. 2.9; continued in Stage III with identifier* Act. 3.7*; continued in Stage IV) [according to the plan of realization; fully achieved, successfully completed]*

The activity focused on the implementation of the module for predictive detection of defects using Artificial Intelligence algorithms (in the project proposal, WP4: T4.3).

Act.4.3 Testing and evaluation of developed industrial solution.

(Activity started in Step III with the identifier Act. 3.6.*; continued in Stage IV) [according to the plan of realization; fully achieved, successfully completed]*

The activity focused on testing and evaluation within the industrial prototype implementations (in

the project proposal, WP6: T6.2).

Act. 4.4 Project management, communication and dissemination

(Continuation of Act. 1.4 of Stage I; continued in Stage II with the identifier Act. 2.8.; continued in Step III with the identifier Act. 3.8*; continued in Step IV) [according to the plan of realization; fully attained; successfully completed]*

It includes specific project management, communication, dissemination, visibility and exploitation activities. (in the project proposal, WP1: T1.2, WP7:T7.1). During the entire stage, the exploitation strategy was explored, elaborated and adapted.

2. Summary of Stage IV

Specific activities for the implementation of SOON solution carried out in Stage IV

Stage IV included various R&D-test-evaluation activities specific to the project implementation, mentioned in section 1.3., which were successfully carried out according to the implementation plan.

Working with SOON project partners

A close collaboration was maintained with SOON project partners, both academic and industrial. On a monthly basis, videoconferencing related to the ordinary meetings attended by all the partners in the project were organized. On these occasions, progress reports were presented on the side of all partners. Depending on the needs, meetings were established for bilateral discussions on topics of particular interest.

Scientific and research collaboration between SOON and FIREMAN projects

The scientific collaboration between the CHIST-ERA projects SOON and *framework for the Identification of Rare Events via Machine learning and IoT Networks* (FIREMAN), initiated in the first stage of the project, was extended and continued during the current reporting period, being motivated by the complementarity existing between the two projects, respectively by the vision of obtaining in the research sphere of benefits on both sides.

2nd Edition of the Smart Technologies in Industry Workshop 4.0

At the current stage, a new edition of the International Workshop on Smart Technologies in Industry 4.0 (RATIONALITY 2022) (https://soon.umfst.ro/rationality.html) was organized. At this event were presented scientific results and progress reports on the side of both SOON and FIREMAN projects. The organization of this new edition was also contributed the Research Center on Artificial Intelligence, Data Science and Smart Engineering (Artemis) (https://artemis.umfst.ro - the new web platform is under construction) within UMFST.

The new edition consisted of two main sessions, the first dedicated to the presentation and debate of the scientific results obtained within the activities carried out by the two projects, and the second session focused on the presentation of progress reports within the two projects, SOON respectively FIREMAN and the discussions, conclusions and directions for exploiting the results derived from the two projects.

***Participation in the CHIST-ERA 2022* Projects Seminar**

The UMFST team participated in the new edition of the CHIST-ERA 2022 Project Seminar (SpCE 2022), organized online between 28-30 March 2022, being the third consecutive participation in the editions of this seminar. During the 2022 edition, on the side of the SOON project, the progress report was presented, in which the UMFST team also participated. The report included both the status of project implementation and the results obtained by the UMFST team.

Participation in the video competition organized within the CHIST-ERA 2022 Projects Seminar

Similar to the previous edition, this year too, the competition on the promotion of CHIST-ERA

projects through video spots within the SpCE 2022 was organized. On the occasion of this competition, the UMFST team, similar to the previous edition (DOI: 10.5281/zenodo.6476470), made a multimedia video-type material with a promotional purpose of popularizing the SOON project in the online environment and beyond. The prepared material can be found both on the web portal of the SOON project on the side of the UMFST team and on the CHIST-ERA web portal.

Updating the bilingual web portal related to UMFST

The SOON project web portal (https://soon.umfst.ro/), accessible at international level (being available in both Romanian and English), provides details regarding the Romanian partner, namely UMFST, a participant in the SOON project, being continuously updated in order to provide relevant information on the structure of the project and how to carry it out. Specific details on all stages of the project can be accessed.

Dissemination of results in Stage IV. Publications in Stage IV

At this stage, three articles were published in open access journals [Dob22, Gec22, Ian22]. Publications have actually appeared and have already been indexed. Some results are under evaluation being submitted to journals.

National patent under evaluation

The Patent with the title: Device and method for predictive diagnosis and maintenance used in the installation for ordering and monitoring the parameters of a production line with electrical drives is under evaluation.

Open science

In the implementation of the project, the principles of Open Science were fully taken into account. The results of the research were mainly published in open access publications. In some of the publications, the data used in the experimental evaluation are fully included. The proposed algorithms are fully described, which allows them to be implemented in any programming language.

Open access data related to the experimental platform based on variable speed drive system

One of the important contributions of UMFST to the project was the development of a collection of data for testing and validating the developed predictive maintenance solutions. This is an important resource for the development of the project but also for the scientific community. Its importance is given by the limited availability of data from real industrial processes due to aspects related to the security and protection of industrial secrets.

The developed resource consists of a published open access dataset, indexed and stored within persistent platforms (Zenodo, OpenAIRE). In order to ensure increased accessibility, independent of the platform, an open format (Comma-Separated Values) was adopted. Interested researchers can download this data in the form of files containing the data labeled for its use as a whole or just sections of interest. The open dataset can be retrieved either by name, by project name or by digital object identifier (DOI 10.5281/zenodo.6473455) allocated through the repository platform.

Open access software

One of the contributions foreseen and assumed in the project development plan consisted in the coordination, design and development of a framework software solution for predictive maintenance based on the multi-agent social platform as *an edge* solution integrated in the proposed industrial scenarios.

The solution completed in the last stage of the project was tested and validated within the industrial scenarios, and in the final stage of exploitation it was made available in open format to the scientific community and to all those interested. For visibility and increased accessibility, the GitHub platform was chosen, the persistent archiving using Zenodo and the indexing through the open research

popularization platform OpenAIRE.

Available in open format, the proposed solution allows further development or use in its current form, being developed for current IoT/IIoT technologies that have a long perspective of time of continuous adoption and use in Industry 4.0.

The developed software component is available with open access on: Zenodo DOI: 10.5281/zenodo.6480321; GitHub: https://github.com/karetkaz/soon2021 being Indexed OpenAIRE https://explore.openaire.eu/search/software?pid=10.5281%2Fzenodo.6480321

3. Scientific and technical description

At this stage of reporting, as previously listed, a number of activities with a high complexity were addressed, both scientifically and applicatively. This section is dedicated to the presentation of the problem and how to carry out the activities carried out. It was considered useful to structure this technical description into sections correlated with the main activities targeted in order to provide an overview of the predictive maintenance solution based on the innovative architecture of a holistic multiagent social system, which integrates machines, devices, operators, ontologies, knowledge, real-time processing algorithms based on AI and big data.

3.1. Preliminary points

In this project we proposed for investigation the efficiency of a solution based on a holistic paradigm formulated in the context of intelligent social agents that are associated with machines as well as human operators. Operators as experts provide knowledge, but at the same time benefit from the results of processing carried out by agents, which can be used in decision-making processes. This involved, among other things, the implementation of various algorithms for the extraction of values and characteristics, respectively deep learning algorithms with the aim of optimizing the functioning of the analyzed industrial processes. There are many algorithms used to solve the problems associated with predictive maintenance [Car19, Zon20]. They must use large amounts of heterogeneous data provided by a wide variety of equipment and devices (sensors, automatic control systems), but which must compete to solve complex tasks on predictive maintenance in real time. Along with real-time measurements, the data sources used consist of historical records, available in the form of time series, some having as source the ERP systems.

The developed solution is based on specifications from industrial companies involved in the project with industrial activity in different fields and profile. The general vision on which the proposed architecture is based is shown in Figure 2. The main design requirement of ensuring scalability so as to enable the dynamic incorporation of entities such as physical machines and processes, devices, sensors and ICT infrastructure consisting of intelligent cloud processing systems, data concentrators, processing and analysis software.

3.2. Exploration and design of artificial intelligence-based maintenance algorithms (Act 4.1)

One of the main points of the project focused on exploring, developing and improving the implementation of a predictive maintenance program in the context of Industry 4.0 with the help of models based on machine learning techniques. In this context, the activities carried out focused on i) forecasting the failure of the technical systems used in industrial production, but also ii) the identification of anomalies that could have as source erroneous data caused by the failure of some sensors using IoT / IIoT implementations, data storage of simple / multivariate time series type, in this case in InfluxDB databases, at the level of edge computing and cloud integration.

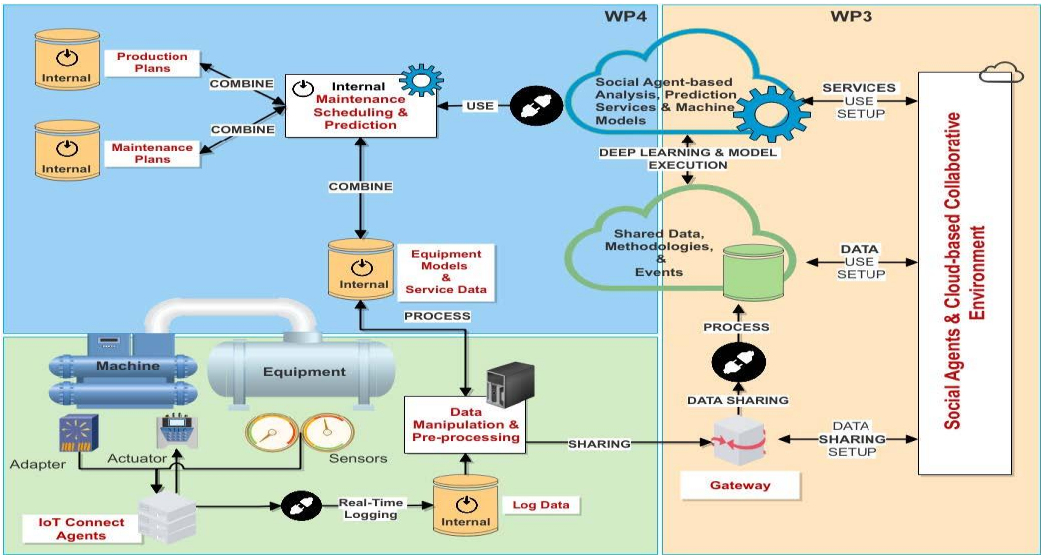

Figure 2. SOON solution proposed for predictive maintenance

The significant challenge associated with this activity concerned the exploitation of one of the most important resources available within the current industrial systems, namely the multitude of data available directly through sensors and sensor networks, or with the help of monitoring and supervisory systems, but also the historical records available through ERP solutions. Significant attributes that had to be taken into account concern the nature, complexity and quantity of available data that have been treated and exploited from the perspective of the central subject of this project, respectively that of predictive maintenance, with the support of existing and proposed ai methods and technologies.

Specifically, there were proposed and implemented developments that focused on exploring, designing and improving the way of implementing a predictive maintenance program in the context of Industry 4.0 with the help of models based on machine learning techniques capable of estimating with increased accuracy the occurrence of defects in the case of technical systems used in industrial production, but also the identification of the type of defect - the detection of failure of a subassembly, component, mode or sensor failure mode.

An important feature of the solution developed is based on the fact that even if in the design stage simulated experimental data were also used, the testing and validation process was predominantly based on actual laboratory experimental data. Thus, the UMFST team resorted to the data provided by the demonstration stand developed for experimental testing using specific sizes of three-phase industrial electric drives with variable speed.

As main functionalities of the algorithms, the prediction of the remaining useful operating time was targeted, and respectively the identification of sensor failures involving logistic regression techniques [Dum22, Lan20], data analysis techniques (data analytics) and machine learning as estimation and classification solutions. The proposed algorithms were tested within the pilot solution that works in real time and integrates the social agent-based edge solution developed taking into account the scenarios designed in collaboration with industrial partners. In conclusion it can be said that a number of tools capable of offering the following functionalities have resulted: i) real-time detection of sensor failure and ii) fault diagnosis, classification, prediction and intervention planning.

The evaluation and validation by experimental testing of the solutions proposed at this stage was based on the analysis carried out in the previous stage that resulted in the establishment and definition

of performance indicators in accordance with the peculiarities of the solutions defined by predictive maintenance. This process also used improved procedures, testing scenarios and the methodology for purchasing and processing the obtained data established with the project partners, along with their own validation criteria.

3.3. Implementation of algorithms for fault detection using AI techniques (Act. 4.2)

Within this activity, the process of implementing and testing algorithms for identifying the classes of defects that may occur during the operating period, including in the case of operational sensors, as well as the monitoring ones for the implementation of the predictive maintenance solution of industrial production machines, devices and equipments, was continued. The activity involved several directions to follow such as: analyzing and identifying the characteristics of the processes targeted to be used as a data source for machine learning algorithms, which included a series of specific subtasks that included the development and implementation of strategies for conditioning, filtering, scientific visualization and labeling of data resulting from the acquisitions made, implementation of algorithms, i.e. formal testing, evaluation and validation. The main purpose of this activity was to find the answer to the hypothesis of achieving improvements in the overall performance of evaluation as well as the correct identification of the failure processes.

Initially, the performance of this activity was foreseen in Stage III, but following the update of the schedule approved by the contracting authority, its completion was extended in Stage IV.

3.4. Testing and evaluation of the developed industrial solution. (Act.4.3)

Within this activity, it was aimed at verifying and validating the possibility of transferring the proposed solutions from the laboratory environment to the real industrial environment. For this purpose, tests and evaluations were carried out under real experimental conditions starting from a physical model consisting of real devices and machines and continuing with the sources of relevant physical signals.

The basic activities focused on conducting the tests in accordance with a series of customized scenarios, considering different types of operating regimes, multiple types of defects, with varying intensities and disturbances of different levels, respectively spatial orientations and framing.

The experimental data used in the research were selected, conditional and organised to be openly accessible by the scientific community through the dataset published within the project.

3.5. Performance indicators of agent-based systems and assessment of data quality

In this section are specified some results obtained by the UMFST team during the project period.

3.5.1. Performance indicators for measuring machine intelligence

MeasApplInt [Ian19a], MetrIntPairII [Ian21] and ExtrIntDetect [Jan19b] are universal metrics that can be used to measure the intelligence of systems regardless of the field of applicability, Industry 4.0, Smart Factories, etc. All methods are described in the form of algorithms that include all the details necessary for implementation in any programming language. All metrics were evaluated experimentally. The data on which experimental evaluations are based are available in published articles.

3.5.2 Indicators for measuring the quality of the data to be used for research purposes

Another result [Ian22] is a method of measuring the quality of industrial data. The method is detailed presented, published with open access. It includes all the necessary details for implementation in any programming language. Testing and evaluation is based on open access data available in the recognized data repository called the UCI Machine Learning Repository.

3.6. Evaluation of results

3.6.1. Methodological highlights

The SOON project has set itself the goal of achieving a number of objectives with a high scientific and technical degree. Achieving these objectives through the results provided represents a high degree of achievement of the project's goal. At the same time, the provision of deliverables characterized by value scales in the upper sections is a remarkable asset of the developments and research undertaken within the project.

This section complements the sections on quantitative outputs and aims to achieve the qualitative direction pursued within the project. In this respect, a plan for evaluating the results of the project was proposed and implemented, following a series of benchmarks, either established, proposed in the scientific literature, or were considered standardized benchmarks. Due to the fact that the field addressed targeted the latest directions, for the evaluation of some of the results, their own benchmarks and methodologies were proposed and used.

In particular, it should be noted that a unified evaluation framework was used throughout the project, structured in the form of a hierarchical model, as shown in Figure 3.

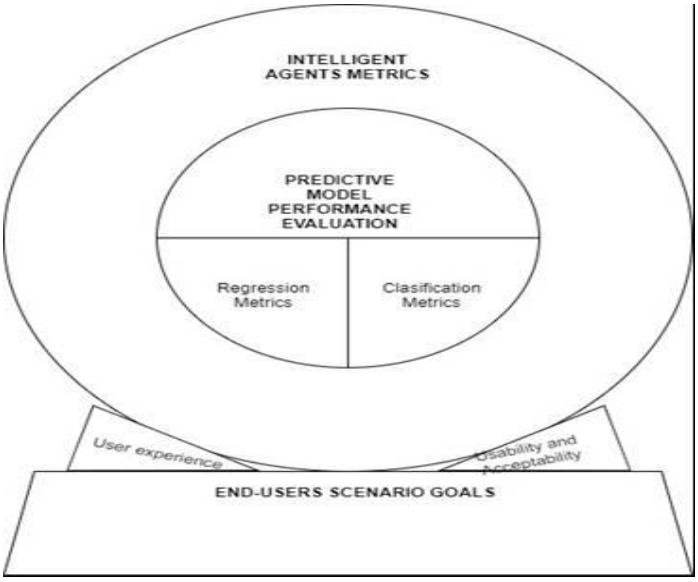

Figure 3. SOON assessment framework.

The evaluation plan focused on three aspects. The first concerned the achievability and implementation of industrial scenarios and demonstrators. In this case, of interest was considered the applicability of the proposed and developed models, centered on the beneficiary of the solutions, taking into account the point of view of the end-user and some qualitative measurements resulting from the processing of evaluations in the Likert scale of usability and acceptability.

Specialists in the field have proposed various models for assessing acceptability from the perspective of users such as the "MAT" technology acceptance model, the "AVM" value-based

adoption model, the "TCP" Planned Behavior Theory, the Unified Theory of Acceptance and Use of Technology "TUAUT". Although some variables are similar between these models, The AVM is widely accepted, being considered as the best model to explain the adoption of AI technologies [Soh20]. MAT [Lee03] is widely adopted when it aims to identify the intention to use technologies such as robots, web 3.0. The TCP and TUAUT indicators have been used in the analysis of systems that involve advanced human-machine interaction.

The second direction aimed at evaluating the "intelligence" of the solutions developed based on the collaborative approach of social network type implemented with structures of type of intelligent agents, for which, however, no concrete, standardized methodologies or considered their own metrics were established. These results can also be considered as stand-alone results were presented in Section 3.5.1.

The third direction approached, addressed the evaluation of the performance of prediction models using established approaches and metrics dedicated to regression models and intelligent solutions for classification and recognition of peculiarities.

For the purpose of evaluating the regression model, metrics such as: quadratic mean error (RMSE), relative square error (RSE), absolute mean error (MFA), absolute relative error (RAE), coefficient of determination (R^2) and graph of standardized residual errors are devoted. Numerous bibliographic works are dedicated to all these metrics, knowing an increased variety of developments. For significant results it was considered to include at least one statistic, among which it is considered a statistic based on an absolute error rate with additional information, such as the standard deviation of the measured data, but also of some graphical visualization techniques.

In the case of classification models, the application of performance metrics over the confusion matrix was mainly considered. In the case of binary classification, the most common metrics targeted are: accuracy, positive predictive value (accuracy), negative predictive value, recall and specificity, and the ROC curve and derived metrics then contributed to the final evaluation of the models. In the case of multiclass approaches, extensions used in the case of binary classification were found.

3.6.2. Assessment plan

Given the complexity of the project, a testing and evaluation based on a single model is not feasible. Within the consortium, following the consultations on dedicated working groups, a unified evaluation plan was designed considering a catalogue of models addressed in the project and the possible categories of evaluation. Specifically, the following situations were identified in the project: multiagent system model, prediction model with subclasses: regression, binary or multiclass classification, and others. The result of this process resulted in a form that provides a template model applicable to all scenarios developed within the project.

The fundamental characteristic of the proposed approach is that the test model can be accessed through a specialization course, having as a starting point the approached scenario and continuing with the type of model to which the scenario belongs. In the case of the present project, respectively of the proposed scenarios, the optimal approach involved the operation on two classes of models organized hierarchically: higher level models, respectively derived models. The top models are in direct correlation with the end-user's objectives, and the derived ones are correlated with the role of the models in the respective scenarios.

This model allowed that, starting from the specificities of each developed scenario, the assessment indicators and metrics appropriate to each situation should be defined.

It should be noted that this approach allows for iterative assessment, by continuously updating it

according to existing or newly introduced requirements.

The catalogue of models shall include different scenarios concerning:

- Intelligent roller maintenance;
- Automatic sensor failure detection;
- Automatic prediction of the operating order;
- Prediction of machining tool wear;
- Smart maintenance;
- Use of electricity consumption for the detection of operating interruptions;
- Detection of failures of electric motors;
- Automatic collaborative machine-level auction to optimize modeling and operation of a workshop.

3.6.3. Evaluation results

The evaluations undertaken started from the scenarios defined following the framework and plan mentioned in the previous section.

The process itself was initially aimed at obtaining the results of different predictive models, continuing with the results of the approaches centered on intelligent agents and ultimately targeting the evaluation scenario dedicated to the end user.

For easy reading, the results of the evaluations were synthesized centered on the scenarios developed within the project as follows:

- Intelligent roller maintenance;
- Automatic sensor failure detection;
- Prediction of tool wear in machining processes;
- Use of electricity consumption for fault detection and prediction of outages;
- Detection of failure of electric cars;
- Automatic collaborative auction at machine level to optimize modeling and operation of a workshop;
- Hybrid optimization of the organization of workshops using multi-agent reinforcement learning;
- Evaluation of agents;
- End-user evaluation.

The results of the evaluations are of great scientific but also practical importance. Specifically, they illustrate the adequacy of the proposed models to concrete situations encountered in the current industrial practice in general, or particular to Industry 4.0, which start from recent established approaches such as regression models, those of artificial intelligence (LSTM, deep learning) or innovative customized or developed in collaboration with the members of the project consortium, such as Random Forest Regressor or Extra Trees Regressor estimators, the automated auction algorithm based on intelligent agents, the new algorithm based on asynchronous backtracking (ABT), or multi-agent optimization based on deep and strengthened learning (Multi-Agent Deep and Reinforcement) Learning).

Below we mention some articles in which scientific results were presented and at the same time the results of experimental evaluations were presented. The method of measuring the quality of industrial data presented in the article [Ian22] was evaluated based on a set of data stored in the UCI Machine Learning Repository. The performance metrics of the type measuring the intelligence of systems called MeasApplInt [Ian19a], MetrIntPairII [Ian21] and ExtrIntDetect [Ian19b] have

actually been evaluated. Article [Vla20] with open access presents the results of the experimental evaluation for the optimisation of smart metering systems with the aim of improving the operation of recording consumption in the electricity sector. The article [Gho21] presents results obtained collaboratively by the whole consortium involved in the implementation of the project.

5. Stage results

The article [Ian22] presents a recent result, representing a method of measuring data quality, published in Stage IV reporting. The journal in which the article was published is ISI, Q, IF 3,757 with open access.

The publication of the article [Gec22] is an ISI Journal, Q2, IF 2.713 with open access.

The article publication [Dob22] is an open-access BDI indexed journal.

Section 3.6.2 presents recent research results on Key Performance Indicator for measuring system intelligence.

Some articles are under evaluation.

The national patent proposal is under evaluation.

The open access data obtained by the UMFST team.

In addition to the scientific results, the project aimed to lay the foundations and support for some future research of its own but at the same time open to the scientific community. For this purpose, a published data collection in the form of an open dataset was developed within the project.

The proposed publication mode allows future contributions consisting of annotations but also additions with new data obtained from the future exploitation of the developments within the project.

The open access software developed by the UMFST team.

Within the project, under the initiative and coordination of the UMFST team, a software module was developed, available in the form of a framework that implements functionalities for predictive maintenance based on the concept of multiagent solution, constituting the edge component of the SOON solution.

The development can be used as a support for an intelligent solution based on IoT/IIoT technologies integrated into Industry 4.0 standards. The advantage of this software is presented by its modular and open structure, which allows adaptations and extensions, both vertically and horizontally. Available as an open-source product, this initiative can be widely used, thus ensuring one of the points proposed in the exploitation plan.

The current version is organized on three levels, which allow integration and connection with purchasing solutions and sensors, edge-level data storage and intelligent processing at the social agent level, as well as cloud integration.

In the current development, the solution can be regarded as a multi-platform approach, being used at the basic level programming languages that allow this: C/C++ and Python, databases for open time series (InfluxDb) and big data (MongoDB), methods of interconnection and communication modern standardization (MQTT), respectively support for access to data through established platforms (Node-RED, FIWARE).

The usefulness and perspective of future developments was validated by the feedback received following the presentations of the solution during Seminars and Workshops (the two RATIONALITY editions, 2020 and 2022 and the CHIST-ERA Seminars).

6. Conclusions on Stage IV project implementation

Stage IV is the last stage of project implementation. With this last stage all the activities were

achieved and fully successfully carried out, they led to the full fulfillment of all the objectives proposed in the project.

In Stage IV, various research results were obtained, some of which were published in the form of articles [Dob22, Gec22, Ian22] and/or presented at conferences. Some articles and the elaborated patent are under evaluation.

The scientific collaboration started in stage I with FIREMAN team members was continued and developed in this last period. The RATIONALITY Workshop 2022 was organized in collaboration by SOON, FIREMAN projects and the Artemis research center.

The Zenodo community "SOON: Social Network of Machines CHIST-ERA Project" (https://zenodo.org/communities/soon/) includes deliverables of the SOON project shared with the scientific community, all of which have attached number two and are indexed to OpenAIRE.

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8. Short report on mobilities and the dissemination and/or training activity

Participation in mobility and work visits

The special conditions determined by the pandemic situation have partially persisted during the period related to the development of the activities of stage IV, however the specific objectives and activities proposed to this stage to be reported have been successfully achieved. That situation has led to the limitation of the possibility of carrying out certain types of activities such as international mobilities, working visits, on-site participation in seminars or conferences.

Participation in the CHIST-ERA 2022 Projects Seminar

One of the important events of the stage was represented by the participation in SpCE 2022, held over several days, respectively March 28-30, in online format. The SOON project team participated in all general and ongoing project sections. Here there was the opportunity to present the stage of evolution of the project implementation, as well as the results obtained.

Participation in the CHIST-ERA 2022 Video Competition

SOON team participated through a short-term video presentation multimedia material in the contest "CHIST-ERA Projects Seminar 2022 video contest" aimed at popularizing the ongoing CHIST-ERA projects to the general public.

The scientific collaboration between the SOON and FIREMAN projects

The scientific collaboration between the SOON and FIREMAN projects it was continued during this period, the motivation being the complementarity and some common research areas existing between the two projects, which suggest beneficial advantages in research on both sides.

RATIONALITY 2022

The UMFST team participated in the organization of the RATIONALITY 2020 Workshop. During this Workshop, the UMFST team made a presentation of the results obtained in the research and also contributed to the presentation of the progress report of the SOON project.