Proceedings in Manufacturing Systems, Volume 15, Issue 3, 2020, 103-111 ISSN 2067-9238

COMPUTERIZED MAINTENANCE MANAGEMENT SYSTEM (CMMS) IOTIA – MAINTENANCE PLATFORM IMPLEMENTATION FOR INDUSTRY 4.0

Crina Narcisa DEAC[1,*], Gicu Călin DEAC[2], Cicerone Laurențiu POPA[3], Costel Emil COTEȚ[4]

1) PhD student, Robots and Manufacturing Systems, University Politehnica of Bucharest, Bucharest, Romania
2) PhD student, Robots and Manufacturing Systems, University Politehnica of Bucharest, Bucharest, Romania
3) Associate Prof., Ph.D., Robots and Manufacturing Systems, University Politehnica of Bucharest, Bucharest, Romania
4) Prof., PhD, Robots and Manufacturing Systems, University Politehnica of Bucharest, Bucharest, Romania

Abstract: *IOTIA (Internet of Things and Industrial Automation) Platform is a computerized maintenance management system which manages all type of maintenance within a company: breakdown maintenance, preventive maintenance, predictive maintenance and prognostics and health management, aimed at improving maintenance operations, coordinotion of teams and communication between production and maintenance departments. This software application, unlike existing solutions on the market, is intended to facilitate monitoring, prediction and maintenance interventions at the component / subassembly level and not at the machine level, by creating a virtual configurator based on which production lines can be subsequently defined by simply instantiating all the existing machines in the factory, which have been previously defined and configured in this configurator. Through the configurator, within each machine, its subassemblies and components can be defined, thus optimizing the maintenance process, with a much better view at the component level. Thanks to this virtual configurator, the application becomes very flexible and can be extended, as it can configure any type of machines / production lines and can define any types of maintenance operations. The IOTIA software application is connected to an augmented reality AR application, for tablet / mobile, designed to facilitate the work of field maintenance operators, by quickly and focused visualization of scanned information using QR codes assigned to subassemblies / machines and an application video conference implemented in the IOTIA application, for communication and remote support for maintenance operations.*

Key words: *computerized maintenance management system, IoT, maintenance application software, Industry 4.0.*

1. INTRODUCTION

Computerized maintenance management systems (CMMS) are software packages that manage an informational database of maintenance operations in an organization aimed at improving communication and coordination between production and maintenance departments. These software packages (web-based or hosted on the company's server) generate status reports, analyzes, and detailed or summary documents about maintenance activities, spare parts inventory, repair schedules, and equipment history.

CMMS are used for order planning, setting priorities for maintenance requests, and integrating maintenance activities into the entire production system.

In the last years, the development of CMMS together with other technologies have led to a new concept of maintenance: e-maintenance and more recently the concept of Prognostics and health management (PHM). This consists in tracking the condition of equipment using data provided by sensors, which are analyzed and allow predictions to be made, in order to be correctly interpreted/manipulated by analysts (Data Scientists). PHM uses a holistic approach to identify problems and includes in the same time: detection and fault diagnosis, (using a corrective strategy, by identifying potential problems based on input data through an error analysis logic), status-based monitoring (using a corrective-preventive strategy, focusing on monitoring certain measurements to determine if there is a problem or is about to occur) and predictive maintenance (following a preventive-predictive strategy, statistical learning techniques are used to predict a problem). The new concept of e-maintenance allows companies to manage all kind of maintenance: break-down maintenance, preventive maintenance, condition based maintenance and predictive maintenance into a single tool and prepares the steps for the entire data system thus collected to be assigned or to eventually become a cyber physical system that can make decisions later in the context of the new industrial revolution. Going further, in the context of fourth generation maintenance within Industry 4.0, computerized maintenance management systems will become a cyber physical system based on 5 levels according to J. Lee [1] (the structure of 5C): intelligent collection level, conversation level, cyber level, knowledge level and configuration level.

* Corresponding author: Splaiul Independentei nr. 313 Sector 6, Bucuresti, Romania;
Tel.: 0741 073 007;
Fax: 0344080800;
E-mail address: *crina.deac@impromedia.ro* (C.N. Deac).

At the level of intelligent collection, accurate real-time data is collected from the physical world, which can be measured by various methods and transferred to the central server via the Internet. The sensors are usually installed together with the microcomputers in an integrated system that communicates with the server.

At the level of the conversation, the data is processed and transformed into useful information that leads to the current identification of the state of the system and to the decision-making process of the producers. Transforming data into information is done with various analytical tools and algorithms that give self-knowledge and self-predictability to machines. This software classifies, normalizes, and standardizes the data collected for further analysis and review. Sufficient memory space is required for proper data storage.

Then, at the cyber level, with the help of information stored in cyberspace, specific analytical tools are used to provide a clearer view of the status of each machine equipped with the self-comparison feature. The similarities between machine performance and historical data can be measured to predict the future behavior of the machine [2]. To achieve the desired results, advanced analysis tools identify certain patterns of failure modes in similar machines. At this level, a tween model is created for existing machines and components, identical to the production system, in cyberspace. This tween model will continue to run and record useful information throughout the life cycle of these items, even if the actual machines or components fail. Continuous simulation of such a tween model requires a powerful computer capable of processing all data. At the level of knowledge, an in-depth knowledge of the monitored system is generated and at the same time reasoning is issued to correlate the effect of the different components of the system. Having the comparative information from the tween model and knowing the individual status of each machine, decisions are made on the priority of tasks to optimize the maintenance process [2]. Remote virtualization of the current state of the production system for employees is obtained, they have access to all these results, perform collaborative diagnostics and make decisions.

The configuration level refers to the feedback from the cyberspace, cyber physical systems collects feedback from the cyberspace, and the actions are taken either with human intervention or in the form of a surveillance control to make the machines self-configure, to be self-adaptive, and to perform self-maintenance [2]. As a final goal of maintenance systems based on CPS cyber-physical systems, the central processing unit (CPU) will have to learn different failure modes, analyze the information collected from sensors in the physical world as well as from the tween model in cyberspace and react to different situations, making decisions about the maintenance activities required for certain machines in order to improve the performance of the production system. Therefore, the factory will be able to self-adjust to variations and self-optimize to disorders.

Nowadays, many industrial companies still perform corrective and preventive maintenance, being only in the second generation of maintenance that focuses on improving maintenance planning and scheduling, while others are already adopting third generation maintenance techniques, focusing on predicting, preventing and avoiding the consequences of equipment failures, adopting condition-base monitoring. The goal is to reduce manual inspections and build predictive models that can help them mitigate risks [3]. One solution on the market, which allows condition-based maintenance and remote monitoring at scale, across the enterprise, is the new IBM Maximo web-based solution from IBM, other major implementations of CMMS being available from Microsoft and PTC.

According to Nowlan and Heap's 6 failures patterns, more than 50% of component experience early-life failures and there are more than 50% chance that whenever a component is replaced or repaired it will fail early in its life possible due to: *human error* during maintenance, testing and calibration activities because the lack of knowledge of the operator, due to *system error* (the repair has not been properly inspected and tested after a high risk intervention), due to *design error* (lower quality, component fails during periods of high performance demand) or *part errors* [4]. Therefore, in the maintenance activities, assistance software tools and devices using technologies like Augmented Reality (AR) or streaming, connected with CMMS, are necessary to provide information, technical libraries, or remote support for operators.

The fourth generation of maintenance will focus on failure elimination, rather than prediction or prevention. Failure elimination involves a more effective understanding of the application of organizational, systemic and cultural controls [4]. A good cooperation and teamwork between *maintenance*, *production*, *engineering* and *supply* could be supported and reflected also by the e-maintenance concept, this offering transparency and synchronicity in the development of production and maintenance.

The present research aimed to develop a maintenance application that, unlike existing solutions on the market, to facilitate monitoring, prediction and maintenance interventions at the component / subassembly level and not only at the machine level, as in the case applications already on the market. By creating a virtual configurator based on which production lines can be defined, comprising machines, where within each machine one can define subassemblies and components, one can optimize the maintenance process, with a much better view at component level, not just at machine level one. At the same time, in this configurator, technical libraries can be defined, including manuals, documents, videos, for each level (component / subassembly / machine), as well as a glossary of errors at subassembly level, which are particularly useful in the maintenance interventions and can be made available to operators through an AR application included in the platform and also a maintenance operations configurator related to subassemblies/components.

2. IOTIA PLATFORM

2.1. The platform concept

The IOTIA (Internet of Things Industrial & Automation) platform is a pilot project, being in implementation for one of the largest bakery companies in the country. Its purpose is to be a tool for the management of all types of maintenance and to be applied to several types of production in the industry but also scalable in the case of a company that owns several factories. All graphic illustrations in this paper are part of the pilot implementation performed at this company.

IOTIA's structure is modular and allow the configuration of the assets (Configurator section), setup for defining the factories, personnel of the companies, permissions and roles, the departments and the system of ticketing for support (Setup section), the instantiation and administration of the assets production lines and the maintenance operations (Administration), Maintenance section, containing three parts: management of the maintenance operations and scheduler (Preventive and Break Down Maintenance), monitoring the assets on the production lines (Machine Monitoring), the models associated to different types of machines connected to different databases in Jupyter notebooks (Preventive Maintenance), Utilities section containing several Pdf Libraries related to standardized health safety and environment practices, technical documentation, personal document libraries for existing users, Journal of Activities, Announces setup and Database Backup (Utilities), Dashboard.

The platform uses a Model-View-Controller approach, and it is a web-based platform.

2.2. Dashboard

Dashboard is the introductory panel that is configured according to the logged in user, whether the user is the general manager, chief information officer, maintenance director, engineering assistants, foremen or technician operators.

It displays a quick view of user access areas, according to permissions given in Setup area. It shows the maintenance operations that has to be performed, grouped according to the status and priorities (assigned tasks), the request history to Procurement for spare parts (components) with status regarding the response from Procurement for order and delivery, the latest announcements from the factory management or the production/ maintenance departments, a list of Todo actions entered by the connected user for a better management of his activities and the last alerts received from monitoring systems for those machines where the user has access (Fig. 1). Dashboard also displays a graphical statistic of the scheduled operations after the status and a calendar comprising not only personal tasks or programmed events but also all other public events available for entire personnel from the factory.

2.3. Configurator

The Configurator contains 9 subsections of configuration:

- defining the languages of the platform;
- defining components;
- defining subassemblies;
- defining machines;
- defining suppliers;
- defining consumables;
- defining the maintenance operations- the planner;
- defining the glossary of errors;
- defining the factories.

The platform is initiated in 6 languages (Fig. 2), but it can support as many language modules as needed.

The first subsection – Language management, allows new language insertion and the editing phrases in all defined languages, using an import procedure in CSV for the expressions to be translated, but also a local procedure for translation. This feature facilitates platform operation in a multicultural organization.

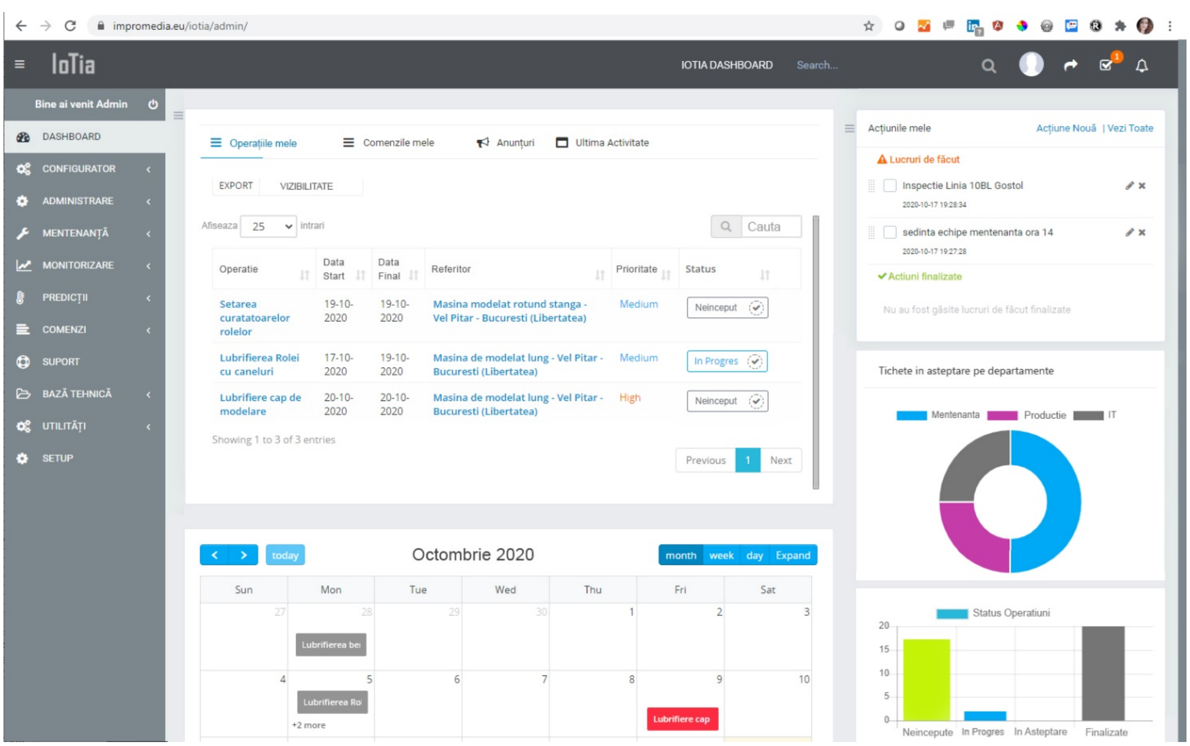

Fig. 1. Dashboard.

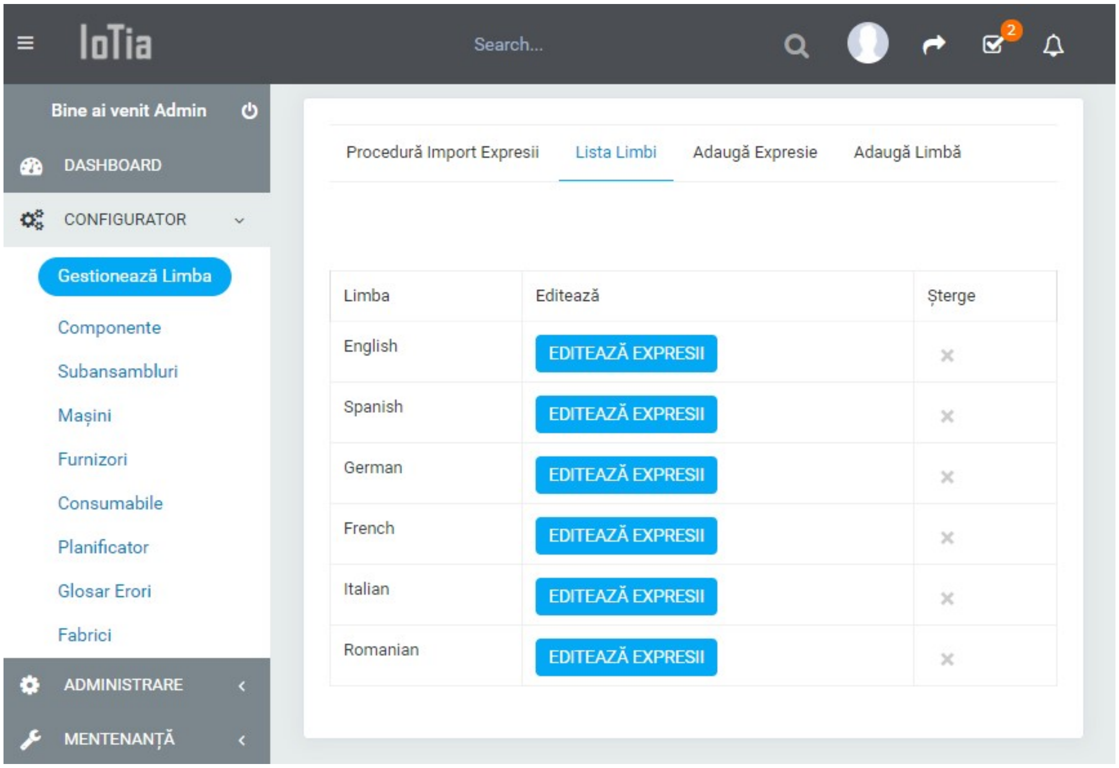

Fig. 2. Configurator – Manage Language.

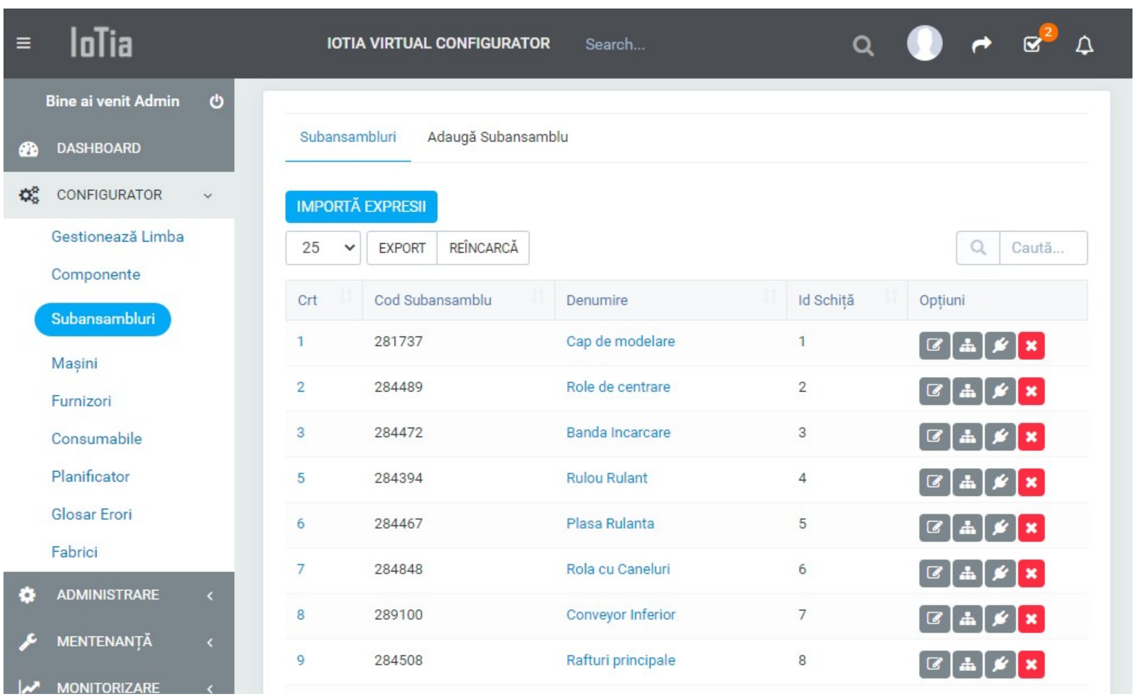

Fig. 3. Configurator – Subassemblies.

The second subsection – Components, initiates all the component codes that compose the machines used inside the factory, according to the documentations from the technical books of the manufacturers along with other features of the component, as well as a technical file library. The exact entry of the component code is followed. The lifetime in hours is set according to the manufacturer's data and is subsequently recalculated on the basis of component replacement data as an average of the operating hours between two successive replacements. Next, having initiated entire list of possible components, in the third subsection of the configurator – Subassemblies, one can define all subassemblies that compose the factory machines, using again the subassembly code provided by the manufacturer and adding a specific library of files for these (Fig. 3).

The section Machines initiates all the factory machines, and each asset is connected here with the substructures of subassemblies and components. In the sixth subsection the Consumables indicated by the manufacturer are defined and each consumable is assigned to a list of subassemblies, so that, when scanning AR of a subassembly code, the operator can easily check the consumables indicated in maintenance operations. Also, this subsection is connected with the Suppliers.

The subsection Planner in the Configurator configures all the maintenance operations existent in the technical documentation of the assets, each operation being related to a subassembly code. In addition, the Configurator administrator will generate an operation called generic “break-down” for each subassembly code (used for break-down interventions) and a generic “component replacement” operation for each component code assigned to a subassembly, this operation having as frequency – the estimated average number of operating hours of the component. In the name of the component replacement operation, the script will automatically include the component code and the positioning index from the subassembly diagram, for quick identification. Once initiated each operation by subassembly, when instantiating the real production lines and machines, planning the maintenance operation becomes an easier task, because all the operations are instantiated based on a frequency set in the Planner, automatically into a Cron script or manually (especially in the case of breakdown maintenance) by the Planner operator. The operation sheet also contains the frequency of operation in number of hours, the warning window in number of hours, a file library (which accepts any extension accepted in Setting) available to operators during the intervention and all consumables allowed for the subassembly.

Configurator also registers a glossary of errors, where the empowered user set all error codes by subassembly / machine code. In this way, in the maintenance operation sheet, operator could add the error code that triggered a specific event, this being also valuable later in prediction algorithms, in estimating the remaining lifetime of a component. The error code is accompanied in the library by information such as potential causes and ways to fix the error which can help the operators during interventions.

The last subsection is Factories initiation with contact data, location, factory code and staff representatives.

2.4. Administration

This section instantiates and manages the real entities in the factory: production lines, machines on the production lines, subassemblies and components, according to the Configurator, all these entities being assigned to a factory (code) and having a unique ID which is an integer number, defined inside the database, once each entity is created, in addition to the manufacturer code. In this section could be administrated the production lines for one or multiple factories if there are multiple production sites. Once selected a production line, all the machines are displayed showing the actual status (Available, On Pause, In Maintenance, Unavailable) in suggestive colors and the real structure of subassemblies and components entities ID.

Each component ID tracks the number of replacements during operation time of the machine. Also, each entity will be assigned in this section, an AR code, for quick scanning during interventions.

Administration area also contains the generator of interventions on the production lines, planned or break-down types. The generation of planned operations is performed by selecting the final date until which the

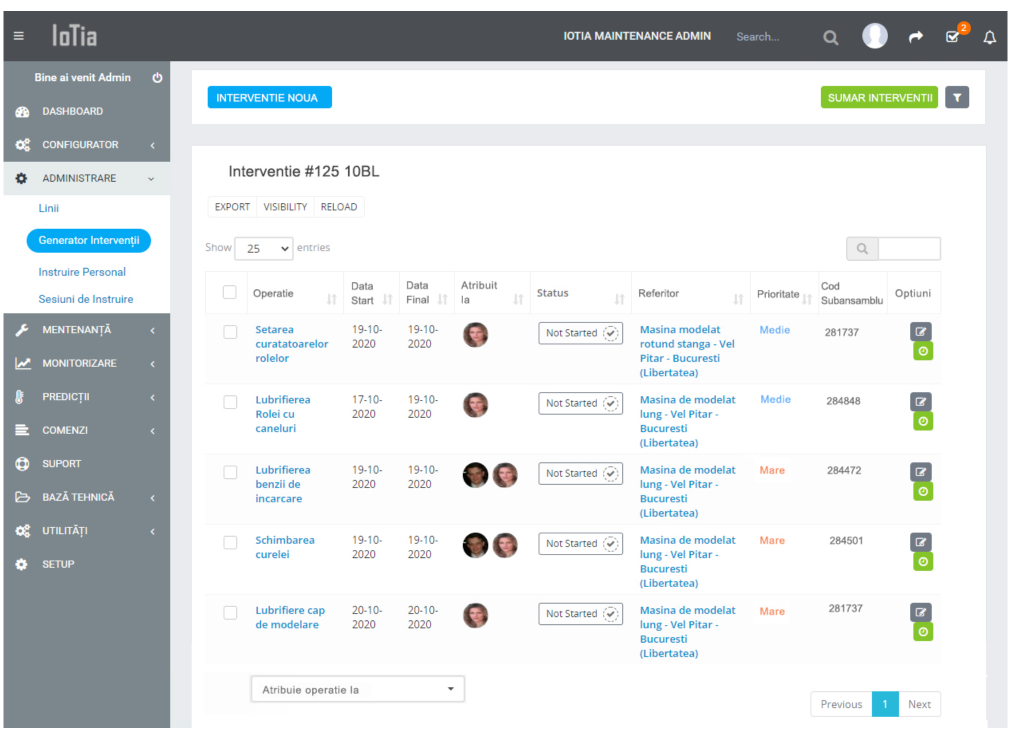

Fig. 4. Administration – Intervention Generator, Scheduler.

planned operations in the configurator are to be displayed for the selected production line, considering the last planned operation and performed on each subassembly. Then administrator will check the operations wanted to be performed and will set a start date and a final date for the intervention.

In case of break-down intervention, the operations defined as "break-down" in the configurator will be selected, assigned to the subassemblies where the intervention will take place. It will be added in the Intervention Form, the reported error ID, the reporting date of the error and the observations. After generation, administrator will setup the personnel from the staff which will perform the operations or the subcontractors if the case (Fig. 4). Each operation inside intervention sheet will also contain a Status (Not Started set by default, In Progress, Awaiting Feedback, Complete) and a Priority (Low, High, Medium). Thus, it will be possible to report in the Maintenance section regarding the interventions and the status of the operations as well as the sending of alerts depending on their degree of priority.

The training sessions are initiated in the administration and once they are defined, the employees' trainings are set,
Through completing the name and date of the training, the trainer, the grade and the date of the next training.

This level of operation configuration, assigning a time interval to each intervention, assigning tasks to operators for each intervention, prioritizing, but also operator feedback, will give a clearer picture of the status of activities and generate a Gantt view of operations in the Maintenance section.

2.5. Maintenance

The section reflects all the items set inside Administrator but filtered after the degree of permission and user type and contains:

- Productions Lines (visualization of the assets on the production lines with all entire subassembly and components structures information and libraries defined) that are allowed for the user.
- Interventions (visualization of all interventions where the user is assigned to do operations, in List and Kan Ban mode).
- Operations (visualization of all operations from of all the interventions assigned to the logged in user)
- Alerts (a list of alerts sent to the user).
- Support (the subsection of Support, containing all the tickets (opened, in progress, answered, on hold and closed) between departments (Maintenance, Production, Acquisitions, IT, etc.).
- Trainings (all training sessions per connected user or per team / factory, depending on permissions and role).

The items in this section are related to only preventive and break-down maintenance, the condition-based.

The items in this section are related to only preventive and break-down maintenance, the condition-based maintenance and predictive maintenance have separate modules. The first subsections, Production Lines and Interventions, allow user to see all the information

Fig. 5. AR Glasses – Vuzix M400.

related to the assets and interventions in two modes, one from inside the platform, and the second using a web-based AR application, designed for the resolution of the tablet and AR glasses. For the pilot project we have used Vuzix M400 model for AR glasses (Fig. 5). Also, we have created, for remote assistance, a Video Conference application based on Web RTC, used by AR glasses.

Using the AR glasses or tablet, the code on the subassembly will be scanned and the following data will be viewed:

- subassembly (subassembly sketch and component positioning indices) and constituent Components list;
- video libraries and document libraries;
- instructions for maintenance operations defined, at the scanned entity, in the Configurator;
- consumables applied;
- interventions list in the subassembly (the most recent).

The operator will have to select the Interventions submenu and will choose the last generated intervention. In the Intervention Form, the operations assigned to the intervention will be selected in order and their status will be marked. For operations already completed, the effective date of completion of the operation will be marked. If the operation is of type "component replacement", the component code assigned to that operation will be automatically marked in the system, in the table – Replaced Components, together with the date of replacement and the component ID.

The Intervention Form will also mark the consumables used by ticking and the operator will be able to mark other codes of replaced components, different from those specified by the operation, by ticking in the list of components of the subassembly. Each operation also has a free field of observations in which the operator can enter observation notes. If a new purchase is required, the operator will access the Delivery Request button, in which he will tick the code of the requested components, from the list of the subassembly and the number of pieces, thus generating a delivery request to the purchases. All delivery requests will be also viewed on the platform, in the Delivery Request submenu. The entire operating inside Intervention Form described above, could also be done directly inside the Platform by selecting the intervention inside the Interventions subsection or by accessing directly the Operations subsection, where operations are listed in List or Kan Ban mode, by status. Intervention Sheet, inside the Platform, will contain additionally a Discussions zone, where discussions can be created

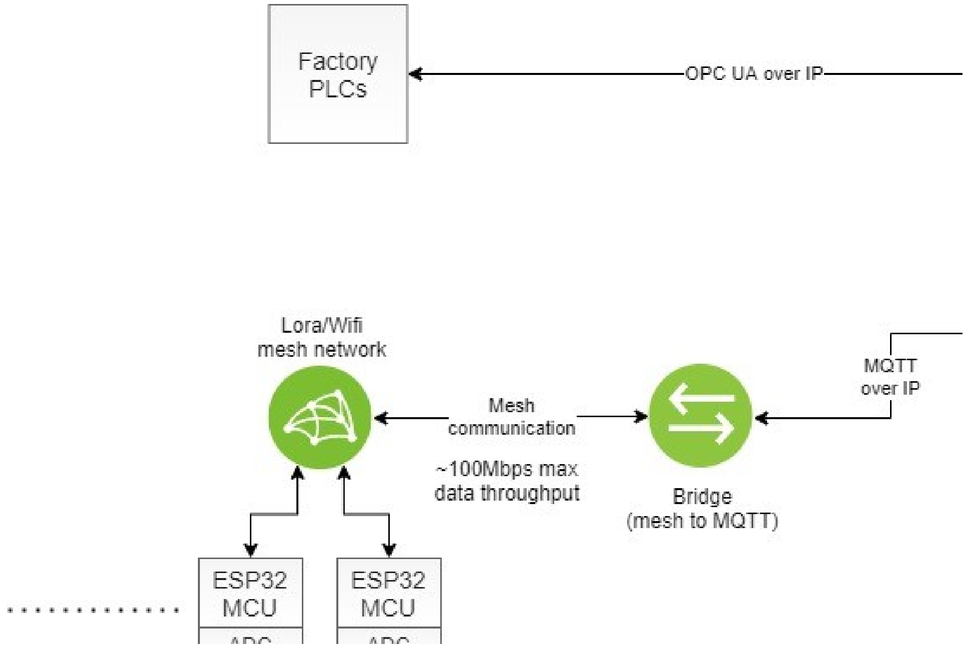

Fig. 6. Factory data path.

between the users assigned to the intervention (the messages are also sent via email) and a Gantt View. Both the platform and the AR application have the Video Conference button in the Intervention Form that launches the video conferencing application if remote support is requested. Videoconferences could be registered and loaded later inside the video Library of the Configurator.

The Support subsection allows the communication between departments, each open ticket can contain a sequence of answers in chronological order and several states depending on its status. Next, the Training subsection displays the situation of the training sessions for each employee and highlights through colored alerts those that were not performed by the employees.

2.6. Monitoring

The sensors mounted on the machines are wired respectively to multiple esp32 microcontrollers (MCU), via ADC (analog digital converter) channels on the MCU. The microcontrollers communicate in a Wi-Fi mesh (or LoRa mesh) network with a dedicated MCU as an exit bridge which converts the custom mesh communication in MQTT over IP protocol to the local gateway server, the data received is collected and further analyzed (Fig. 6). Additionally, telemetric data from the machines are collected from the PLCs via OPC UA over IP or other supported protocols. To view the data, Grafana Dashboards are used.

The monitoring section displays the production lines with the monitored machines and a subsection with error alerts based on the error logs from the local servers. Selecting an asset an overview of the machine will be displayed. It contains: data about the machine like: name, code, ID, machine type, machine number, production year, weight (kg), nominal voltage (V), frequency (Hz), connecting voltage (kV), date of installation, the availability in hours, the unavailable time in hours, the total number of alerts, error logs, the total number of critical issues (by numbering all the operations of type “break-down” from the history of interventions, the last regular service with the last intervention (the date) and upcoming regular service with the next intervention (the date). Also, the screen displays a table list of all operations, including break-down, component replacement and all other planned operations by subassemblies from the history of the machine.

Depending on the parameters monitored on each machine, an i-frame visualization, named Panel, generated in Grafana – which is an open source platform for querying, visualizing and alerting on time series metrics and logs [5], displays graphs of status parameters, showing the moving average at 6 or 12 hours, depending of the interval set in configurations, by using the average graph capability, or displays a count over time, using the Legend facility to display the average, min, max, with the plot average line, or other data aggregation such as Mean and Median. The main telemetric parameters that characterize the evolution of the machine will be taken into account in the characteristics that will form the final set of input that will train the predictive model.

2.7. Predictions

This section contains predictive models written in Jupyter Notebook, an open-source web application that share documents that include code, visualization, and text. The platform uses notebooks for exploratory data analysis, running a notebook server (Fig. 7). Connections are made to the central server hosting the unified database and to the local servers from the factory that store the telemetry data received from the sensors or PLC. Data are read and loaded to Pandas. Then other libraries are used for plotting data, visualizations, scientific computing (Matplotlib, Seaborn, SciPy library) and modelling. Models are build using high-level APIs, like Keras for deep learning implementations or scikit-learn for machine learning implementations in Python, for preprocessing, model selection, classification, regression, clustering and dimensionality reduction.

In the current pilot implementation, the purpose is to know what is the probability that a specific machine will go down due to a failure of a critical component in the next interval. Knowing this, one can control the cost of the maintenance, by performing just-in-time maintenance interventions, using limited resources in more cost-effective way. The target label will be the critical component code. Data collected on the platform, from several similar production line (from one or more factories) using the same machines, specified in the Maintenance section, are crucial for data analysis. The telemetry data captured in the monitoring process will be used, such as temperature, pressure, rotation or vibration, and the moving average at a specified interval (like 6, 12 or 12 hours) will be computed with other aggregate measures like standard deviation over a window of time or minimum or maximum value. Then, other features will be added to this set of features, like error logs received from the machine while they are still operational. One will be chosen from the glossary of error only those id errors that are critics and crucial in predicting a future failure event. Basically, the total number of errors of each type for every machine within the lag window will be considered. Also, the component replacement count and the number of days since the last replacement will be computed for each machine ID, using the history of interventions from the Maintenance section, looking for break-down and planned type operations and replaced components history already archived. This is an important feature for the final dataset.

The target variable will be the failure of the of component which will be extracted from the history break-down interventions, from where it will be collected the failure date (date of signaling the fault passed in the break-down type intervention sheet) and the component code. Finally, the features will be labeled with the failure "None" or "Code of the Component" generated by the Configurator. Other useful feature that could complete our feature dataset that will feed the model is the age of the machine that could be taken from the machine datasheet information, considering the date of installation.

In the prediction several classification models, models based on decision trees or models based on neural networks will be considered. The model with the best results in the evaluation metrics will be chosen in the end to do the prediction on the real-time dataset from monitoring.

Another study in the pilot project is evaluating the vibrations on a specific machine, using deep learning approach, based on a couple of sensors attached to the motor housing mounted to a couple of bearings. The challenge will be to be able to label all types of bearing failures after a longer period of monitoring and data acquisition and to succeed in building models for detecting these failures, knowing that different defect diameters cause totally different vibrations and behaviors. The success of the prediction will be in the correct labeling and sufficient time for data acquisition. This study is to be implemented on the longitudinal dough moulding machine in one of the manufacturer's factories.

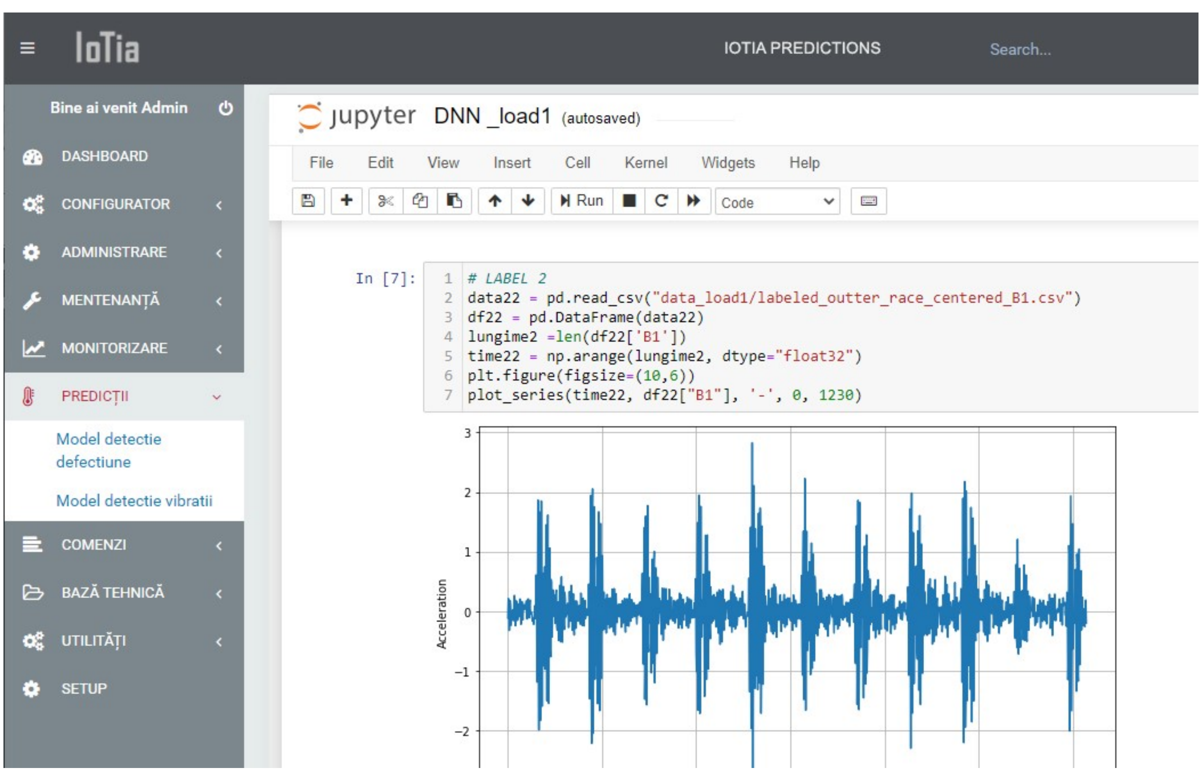

Fig. 7. Predictions Models in Jupyter Notebook linked in the platform.

3. CONCLUSIONS

In this paper, we tried a more general approach to the maintenance process, by implementing a flexible and modular software application that best meets the requirements of the industry. In the future we intend to expand this platform, based on case studies for different scenarios regarding predictive maintenance and to create models as general as possible, valid for more customers.

ACKNOWLEDGEMENTS: This work has been funded by the European Social Fund from the Sectoral Operational Program Human Capital 2014-2020, through the Financial Agreement with the title "Scholarships for entrepreneurial education among doctoral students and postdoctoral researchers (Be Antreprenor!)", Contract no. 51680/09.07.2019 – SMIS code: 124539

REFERENCES

[1] Lee, J., & Bagheri, B. *(2015). Cyber-Physical Systems in Future Maintenance. In 9th WCEAM Research Papers, pp. 299-305.*

[2] Lee, J., Bagheri, B., & Kao, H. A. (2015). *A cyber-physical systems architecture for industry 4.0-based manufacturing systems.* Manufacturing Letters, Vol 3, pp, 18-23.

[3] Joe Berti, *New IBM Maximo Application Suite provides monitoring, maintenance, and reliability applications in one single platform*, available at: https://www.ibm.com/blogs/internet-of-things/iot-maximo-asset-management-suite/.

[4] Sandy Dunn, *The Fourth Generation of Maintenance*, available at: http://www.plant-maintenance.com/articles/4th_Generation_Maintenance.pdf

[5] Grafana Labs, *Grafana Labs*, available at: http://www.grafana.com.