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Implementing Intelligent Asset Management Systems (IAMS) within an Industry 4.0 Manufacturing Environment

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Abstract: This paper aims to define the different considerations and results obtained in the implementation in an Intelligent Maintenance System of a laboratory designed based on basic concepts of Industry 4.0. The Intelligent Maintenance System uses asset monitoring techniques that allow, on-line digital modelling and automatic decision making. The three fundamental premises used for the development of the management system are the structuring of information, value identification and risk management.

Keywords: Asset management, Operation & Maintenance, Decision making, Value management, Risk management.

1. INTRODUCTION

The digital era in which we live, based on Industry 4.0, Big Data, Internet of Thing and Cloud Computing, is offering promising solutions that are transforming the operation and role of many existing industrial systems [1] such as manufacturing systems, in which data quality will make possible to differentiate itself from competitors [2]. Currently, with existing tough market competitiveness, data structuring, collection and analysis become key factor of businesses competitiveness.

Currently, with the high competitiveness that exists in the market, the organization of the data collected is an indispensable requirement, being the structuring essential for the analysis of these, turning maintenance management into a factor whose importance in the business environment is growing day by day [3].

The idea of an intelligent asset management system (IAMS) is to combine digitization and asset management as a single entity. IAMS would be a digitalized system allowing proper knowledge management, fostering progressive and systematic integration of artificial intelligence within the processes defined for an optimized asset management. The SIM (Sistemas Inteligentes de Mantenimiento) research group has developed a IAMS System, based on a designed asset information model [4]. This system has been implemented for railway infrastructure assets management. The main functions of this tool are information management, system analysis, knowledge management and on-site control of systems' conditions, as shown in Figure 1.

The basic concept that leads to maintenance engineering is the continuous improvement of the maintenance management process through the incorporation of knowledge, intelligence and analysis that serve as support for decision making in the area of maintenance, aimed at favoring the result global economic and operational [5].

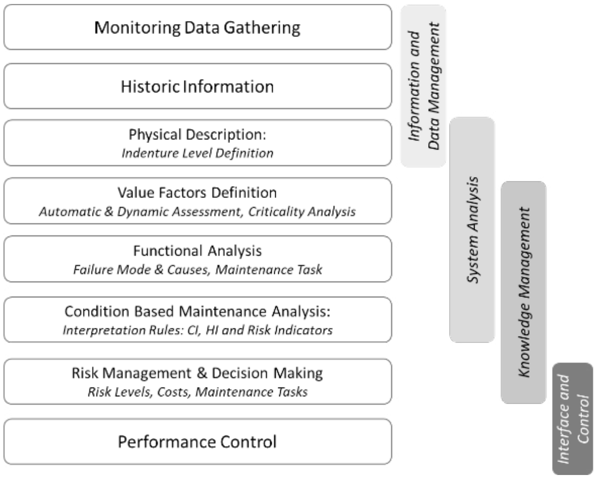

Fig. 1. Main functions and capabilities of the IAMS.

Research on condition-based maintenance (CBM) has been growing rapidly due to the rapid development of computerized monitoring technologies. Research studies have shown that CBM, if properly planned, can be effective to improve the reliability of the equipment at reduced costs [6].

The purpose of this paper is to implement in this IAMS, for the management of assets existing in the cyber-physical teaching laboratory promoted and designed by Manufacturing

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1.1 Industry 4.0 Lab introduction.

The laboratory aims to recreate a scenario in which the student is faced with the different problems that may arise in a manufacturing company. The function of the laboratory can be summarized in three main purposes: communication and consulting, education and teaching, and, the most relevant, research projects.

The integration between Industry 4.0 with innovative solutions of Smart Manufacturing is represented in the central processes of I4.0Lab, in which, through the cohesion of the human factor, the product and the process, the vision of Industry 4.0 is reinforced from the point in view of engineering and management skills.

The I4.0Lab simulates on a small scale the assembly line of a mobile phone, by assembling four components: front cover, PCB (printed circuit board), fuses and back cover. In addition, throughout the process, are integrated monitoring systems, using sensorization, and communication systems and control of variables of interest.

The main systems or modules that make up the laboratory are eight:

- Manual station. It is the only module that requires complete human interaction, in which the operator, once the desired production order is released in the MES (Manufacturing Execution System, software for production control, order management, quality control and data acquisition), take a conveyor with a pallet located at the top and place it on the conveyor belt.
- Front cover magazine, where is placed the front cover on the conveyor in the correct position. The system of placement is an automatic process, but not the process of feeding carcasses, so there must be an operator that supervises the availability of these throughout the process.
- Drill station. The objective is to make four holes in the front cover, whose position is where the fuses will be placed.
- Brach station, which is the conveyor belt that allows to enter and exit through the assembly machine or continue without passing through it.
- Robot assembly cell. It is the most complex station of the whole line. In it the fuses and the base plate are placed on the back cover.
- Quality check station. Digital camera that allows to evaluate if the PCB and the fuses are installed correctly.
- Back cover magazine. It is twin to the front cover station, in which the cover is placed on the part already assembled.
- Press station, which is the last process of the line, whose function is to join the front cover to the back cover, and this is done by means of a pneumatic pressure machine.

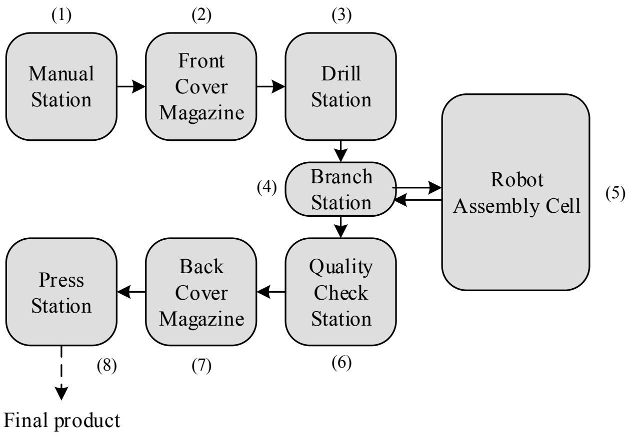


Fig. 2. Laboratory layout.

2. IMPLEMENTATION IN THE ASSET MANAGEMENT SYSTEM

In the next paragraphs, each of the steps followed to implement I4.0Lab in SIM's IAMS will be described, following the logical order of the activities that would be carried out by the maintenance management team.

2.1 Functional structure's definition.

Understanding the functionality of the laboratory, the processes it performs and the components it contains, allows the implementation of the functional structure of the I4.0Lab in the IAMS system. According to UNE 55001: 2014, a structured approach to the systems facilitates the efficient management of assets, thus helping to achieve the objectives proposed by the organization.

The quality of the maintenance services of a company is closely linked to the quality of maintenance data notification procedures. If the quality of the reported data is too low, it can result in wrong decision making and loss of money [7]. As discussed above, the data is assumed to be real, obviating a wrong decision making due to this casuistic.

The IAMS requires the definition of the different levels of the functional structure (functional locations). Four levels have been introduced allowing great flexibility in the description of the laboratory elements:

- **LEVEL 1**. Industry 4.o Lab.
- **LEVEL 2**. Machine functional Group.

- **LEVEL 3**. Sub equipment functional group.
- **LEVEL 4**. Technical location.

The proposed structure responds to two following fundamental needs:

- The detailed identification of the elements. Level of detail that requires subsequent data collection for asset monitoring and for the parameterization of analytical techniques for, among other things, the design of predictive maintenance programs.
- The precise treatment of the parametrizable elements and circumstances contributing to the risk of degradation and/or to the functional failure of the assets. These circumstances can affect the two components of risk: the frequency or probability of failure and the severity of failure effects.

Once the functional locations model has been defined, the data needs to be filled in and the tool can be viewed in the drop-down menu with all disaggregated equipment at the identified levels, obtaining the results shown in Figure 3.

This "assets loading process" into the IAMS can be done manually from the tool, which would be an arduous task since each level for each single asset should be created. But the most simple and easy way to create this structure is automatically filling the Excel template format which the IAMS generates, in which the different levels proposed in the model are predefined in columns.

- *Industry 4.0 Lab*: **Industry 4.0 Lab**
  - *Machine Functional Group*: **Front Cover Application Station**
    - *Machine or Equipment*: **Front Cover Station Control System**
      - *Sub-Equipment Functional Group*: **Front Cover PLC**
        - *Ubicación Técnica*: **Front Cover PLC**
      - *Sub-Equipment Functional Group*: **Front Cover HMI**
        - *Ubicación Técnica*: **Front Cover HMI Button/s**
        - *Ubicación Técnica*: **Front Cover HMI Power Cord**
    - *Machine or Equipment*: **Front Cover Application Unit**
    - *Machine or Equipment*: **Front Cover Handling Unit**
  - *Machine Functional Group*: **Drill Station**
  - *Machine Functional Group*: **Robot Assembly Cell**
  - *Machine Functional Group*: **Quality Check Station**
  - *Machine Functional Group*: **Back Cover Application Station**
  - *Machine Functional Group*: **Press Station**
  - *Machine Functional Group*: **Branch Station**
  - *Machine Functional Group*: **Air Distribution System**

Fig. 3. Example of the technical structure's definition.

These created functional locations may also have intrinsic characteristics of the asset, attributes, defined. And these attributes can be assigned as additional data. The additional data may be merely informative or useful for the rest of the practical applications of the tool, such as for the automation of calculations in the criticality analysis developed in later sections of this paper.

2.2 Value management.

Understanding the value provided by an asset is a fundamental departing point for an asset management model [8]. In the IAMS, tools are provided to measure and control this value, using factors allowing to express value in proper terms.

This quantification is done by means of the so-called severity factors or value factors, which allow the realization of the asset hierarchy as in Crespo et al. [9] within the IAMS framework. Criticality analysis is used to identify and prioritize the assets of an installation based on the importance and consequences for the business of their potential failure events. Criticality analysis identify the assets of a facility over which it is worthwhile to direct resources (human, economic and technological) [10].

The criticality analysis divides the elements in classes that can be managed in a more controlled and auditable manner. But in order to do so, we must first to identify the value factors to take into consideration for the analysis. These prioritization factors may vary depending on the business environment, business objectives or different areas of the company, contracts, countries and their regulation, etc.

Applied to the I4.0 Lab, the value or severity factors proposed to measure the consequences of a functional loss of each of the elements that are going to be analyzed are the following:

- Safety: This factor evaluates the consequences of the functional loss of an element in terms of damage to the personnel or any other person.
- Line Operation: This factor evaluates the consequences of the functional loss of an element in terms of impact on the operation of the production line.
- Finished Good Quality: This factor evaluates the consequences of the functional loss of an element in terms of impact on the quality of finished products.
- Corrective Maintenance Cost: This factor evaluates the consequences of the functional loss of an element in terms of corrective maintenance costs of the item itself.

For each one of these factors, a scale will be established (for example, inadmissible, high, medium and low), to which numerical values are given in such a way that the can be evaluated quantitatively the consequence that said asset will have for each defined severity factor. Likewise, based on the strategic objectives of the system, each factor would have a different impact on the organization, with greater or lesser weight. In this case, the weighting chosen for each factor appears in Table 1.

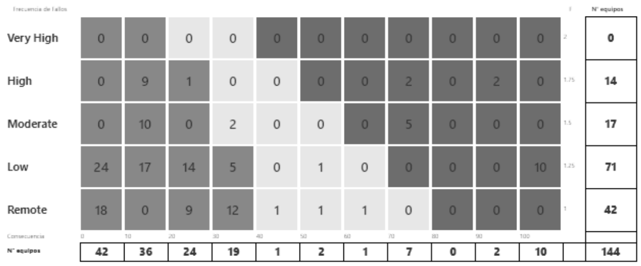
Table 1. Factors to measure the Consequences and their weighting

Factors to measure the Consequences and their weighting			
Safety	Line Operation	Finished Good Quality	Corrective Maintenance Cost
35 %	**30 %**	**20 %**	**25 %**

To establish these values, it is necessary to form an expert group of the business, who know in detail how the installation works. Based on the experience, the weights that each severity factor will have are determined.

Once the weighting values have been defined, it is necessary to establish the valuation criteria of the assets. The valuation of these can be done manually, assessing factors one by one for each asset, or automatically, establishing logical functions (AND/OR) using the values of the intrinsic attributes defined for the asset, these asset attributes being previously identified and loaded as additional data. This automation of the valuation of the factor facilitates and considerably speeds up the process of asset hierarchization, although not all organizations will be possible since they either do not have enough data or influence the valuation extrinsic to the asset itself.

As a result of the hierarchy of assets, the obtained criticality matrix is shown in Figure 4, in which the failure frequencies (failures / year) are represented, in the y-axis, versus the consequence of the failure, x-axis.



Frecuencia de fallos												f	N° equipos
Very High	0	0	0	0	0	0	0	0	0	0	0	2	**0**
High	0	9	1	0	0	0	0	2	0	2	0	1.75	**14**
Moderate	0	10	0	2	0	0	0	5	0	0	0	1.5	**17**
Low	24	17	14	5	0	1	0	0	0	0	10	1.25	**71**
Remote	18	0	9	12	1	1	1	0	0	0	0	1	**42**
Consecuencia	0	10	20	30	40	50	60	70	80	90	100		
N° equipos	**42**	**36**	**24**	**19**	**1**	**2**	**1**	**7**	**0**	**2**	**10**		**144**

Fig 4. Criticality matrix obtained.

In the matrix there are three zones, critical (left), semi-critical (medium) and non-critical (right). This result makes it easier for the maintenance manager to make decisions regarding the planning of maintenance tasks, having to take special care with those assets located in the critical area due to the great impact they cause to the organization.

2.3 Risk management.

Likewise, this analysis methodology for the hierarchy of assets generates criticality results based on the theory of risk, a concept that mixes the reliability factor (frequency of failures) with the factor of severity / failure consequence.

Risk, despite being a key concept in asset management, is a difficult element to model and therefore manage. The tool used provides a multivision risk approach that, accompanied by different techniques and methodologies, supports strategic, tactical and operational decision making. Understanding the risk in three directions:

- Strategic risk, based on the definition and measurement of value and through the use of criticality analysis.
- Economic risk, supported by the Root Cause Analysis (ACR), Total Value of Ownership (TVO) or Total Cost of Ownership (TCO), considering the costs derived from the failure for each mode of failure and the costs of preventive action.
- Real-time risk, by monitoring the system, thus allowing detection, diagnosis, prognosis, calculation of indicators and definition of interpretation rules of these to support decision-making.

These risks can be handled independently. But in many cases, it is of great value to consider different results in the same decision making. Thus, for example a slight real time risk on a very critical asset can motivate an immediate action.

2.3 Real time risk monitoring.

Currently real time risk is being monitored for critical elements of the I4.0 lab identified in the previous steps.

In order to do so, FMECA analysis must be done to these elements and critical failure modes identified are linked to descriptors [11], [12], [13] or monitored variables providing information for failure mode detection, diagnosis and prognosis.

For detection, parameters or input variables are defined allowing calculate indicators reaching the condition monitoring. This monitoring allows to carry out the diagnosis, proposing corrective activities when necessary, or to schedule those tasks in time as a prognosis.

Currently, are being studied what variables are of interest for the monitoring of the system to be profitable. Once the variables to be monitored have been defined, the actual situation in which the system is located will be represented in the scorecard, through the definition of value rules that indicate the risk situation in which it is located. To do this, indicators are created from the defined input variables, risk levels are established (acceptable, mild and severe) so that the maintenance action can be carried out according to their situation.

To perform the monitoring, the input variables are declared, direct or derivatives indicators calculated from these input variables are established. Defined and fed the monitored variables, and based on the experience, risk analysis is created for each failure mode identified, so that by means of logical functions the levels of risk in which the asset can be found are identified for the mode of associated failure, depending on the indicators, in real time.

The tool is supported by another platform in which the results obtained are represented, among others the monitoring of the current state in which the studied system is located, this platform being the control panel that supports the management.

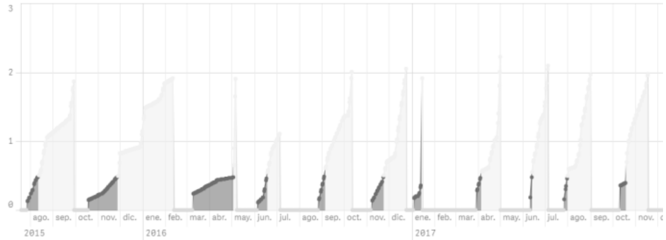


Fig. 5. Real time risk modelling at the scorecard.

Figure 5 shows an example of monitoring the defined input variables and the evolution of those represented in the scorecard, in such a way that it increases in risk level until a maintenance action is executed on the asset. For example, for the measurement of vibrations, thresholds are established, and a corrective activity is executed once the upper limit of the proposed threshold is exceeded, returning the equipment to its proper operating state.

3. RESULTS

The result is the design of an intelligent asset management system, which allows a correct structuring of the information, with analytical capacity based on the management of value and risk, capable of representing and controlling the real state of the system, and that of intelligent support for decision making.

Its application in real systems, such as that of I4.0Lab, among others, allows cataloging the tool as an Intelligent Maintenance Management System, based on basic pillars of maintenance for decision making, with a vision of value and risk latent in the system.

Through the criticality analysis, the assets are ordered based on the consequences of the failure and its frequency of occurrence, allowing to identify which maintenance task to perform on each one. For those assets of greater criticality, and the greater the frequency of occurrence of the failure, predictive analysis techniques will be applied to facilitate the identification of the assets' status and to execute or schedule the maintenance action that returns the asset to its initial condition.

The real intelligence of the system lies in the ability to formulate knowledge, through value rules, which provide the system with decision-making capacity by reading and analyzing the input data from the calculation of indicators.

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