Optimization of aluminium die-casting process through predictive maintenance and parameter traceability systems

Mizgan[1], H., Ganea, M.[2]
1. Industrial Engineering, University of Oradea, Oradea, 1 Universității Street Romania,

2. Industrial Engineering, University of Oradea, Oradea, 1 Universității Street Romania

Abstract. The purpose of this paper is to present the optimisation potential for aluminium die casting process through predictive maintenance and parameter traceability systems. Aluminium considered the metal of the future due to its physical and chemical properties, and this paper is specifically focused on the die-casting process, its potential failures and proposed solutions for reduction of defects. The methodology for optimisation is based is focused on the Total Traceability Management (TTM) software and its technical solutions for predictive maintenance. As a key function of the TTM, the predictive maintenance module is based on conditioning monitoring systems. Temperature, colour, vibration, force, chemical, ultrasound, light, laser, dimensional sensors, all these are developing on the global market as part of the 4th industrial revolution, Industry 4.0. The TTM is combining the factory floor technologies with the informatics systems as ERP, Customer Portals, and MES, through a specific algorithm and based on PLC and sensorial hardware. The TTM is becoming a mandatory requirement for automotive and not only industry as stated in the new norms of AIAG (American Industrial Automotive Group), VDA (German Association of the Automotive Industry), and JAMA - Japan Automobile Manufacturers Association. The approach of this paper is a theoretical presentation of the practical experiments presenting the most modern solution in terms of software, sensorial installations, monitored equipment and the realized outputs. The TTM concept are not yet fully mature, various solutions being deployed on the market with specificities for diverse industries.

1. Introduction

The aluminium industry is becoming a major pillar for realizing the circular economy through deployment of new products considering the green principles of sustainability and environmental friendly processes. These technologies are shaping the modern society due their low carbon and energy efficient application. It is estimated that the aluminium demand will strongly increase during the next decades. If currently more than 58% of the aluminium market is based in China, the new zero carbon emission policies are supporting a strong localisation of the products and processes. The increase of fuel costs, and global supply chain disruption in the last years are supporting a fast relocation of production. In this regard, Romania is having a strong position due to its existing know-how, being a member of EU, and state support for new investments.

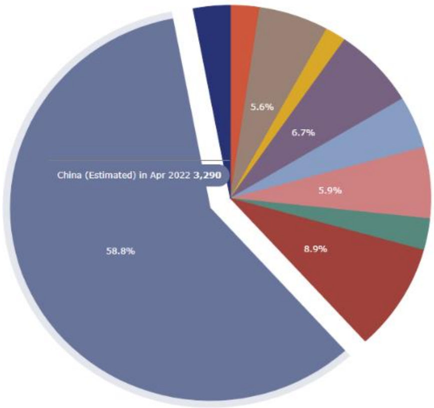

Figure 1. Total for Apr 2022: 5,599 thousand metric tonnes of aluminium(source https://international-aluminium.org/statistics/primary-aluminium-production/)

2. Total Traceability Management

The Total Traceability System is the software which makes the connection be-tween the technical or operation sectors of the factory with the Enterprise Re-source Planning. It is one of the main pillars of the industry 4.0. The fast technological evolution has opened a new reality, which gives birth to a collection of new tools and methodologies: Machine Learning, Artificial Intelligence, Internet of Things, Big Data Management, and Augmented Reality. The focus switched from lean manufacturing factories, with thousands of workers in a perfect synchronization and balance to „dark factories" which run independently, continuously, fully automated with minimal human intervention. The maintenance activities will become more and more critical as the equipment will become more complex, requesting highly skilled technicians and more important, high performance management systems. [7]

As per figure 1 currently worldwide, only 9% of the factories are not planning to follow the industry 4.0 digitization wave, the rest of 91% are using or planning to use various forms of digitization in the near future and 44% are already partially integrated.

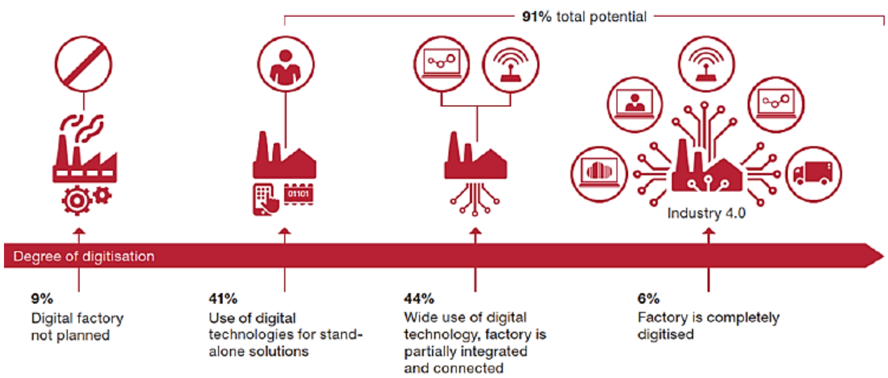

Figure 2. Degree of digitization [15]

2.1. Maintenance Module or CMMS (Computerized Maintenance Management System)

The CMMS (Computerized Maintenance Management System) is a software solution for executing the maintenance activities in the plant. It includes, asset management, maintenance procedure, spare parts management, lessons learned, reports and performance indicators. The maintenance activities are divided in 4 major categories

2.1.1. Corrective/Reactive Maintenance

The corrective or reactive maintenance is perform without a schedule, when the equipment has already failures (run-to failures) and cannot perform the designed tasks. It is expensive due to the unexpected interruptions caused in the production activities. It makes difficult also the spare parts management due to peaks in demand, the equipment repair and the allocation of servicing resources.

The CMMS functions for the corrective maintenance are duration of intervention, and spare parts consumed. No data at this level regarding predictability or preventive maintenance procedures. [20]

Ticketing System stores and provides real data for downtime tracking the data is stored for lessons learned and reporting. The reporting accuracy is increasing via ticketing due to the mandatory electronic validation of every intervention is required. It contains a standardized root cause identification and a process of solving similar issues. It is also having different layers of authorization and being able to be access web based, or from designated computers.

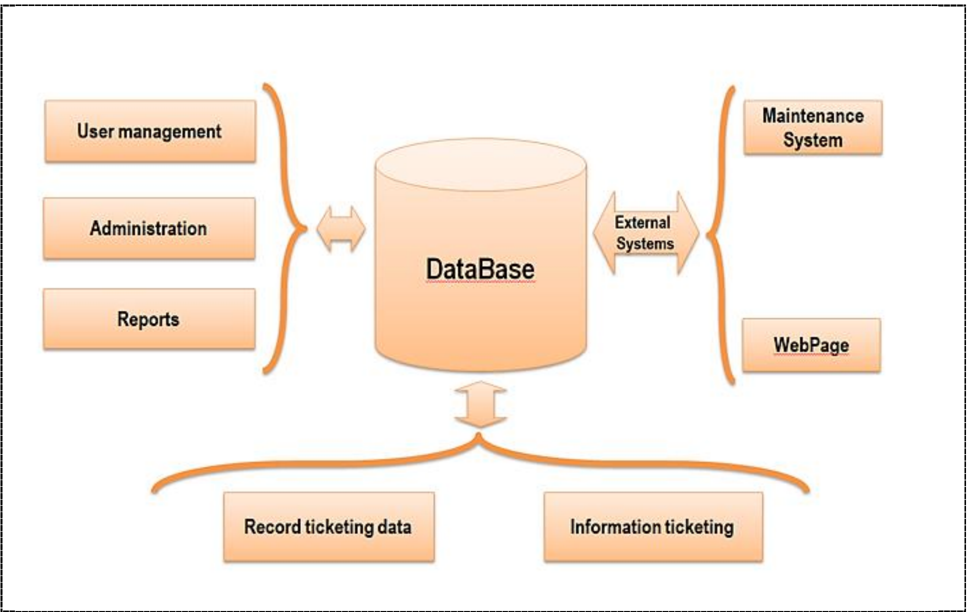

Figure 3. Ticketing System used for corrective maintenance monitoring [7]

2.1.2. Preventive Maintenance

Is a methodology that uses data to anticipate the equipment failures based on historical data, factory benchmarks, supplier inputs, and market experience and events. It is performed on a clear schedule therefore optimizing the resource allocation in terms of service employees but also spare parts stocks and consumption compared with the corrective maintenance. It is a living methodology being consciously updated with lessons learned from equipment behaviour or product/process modification. As downside for the PM, the resources are allocated for service at equipment which do not need based on their technical status. The CMMS functions for the preventive maintenance are intervention schedules and the results and spare parts consumption. [3]

2.1.3. Predictive Maintenance

Predictive maintenance is based on real-time data from various parts of the process and aims to anticipate problems before they occur. Following conditions are necessary to execute preventive maintenance:

- Real-time monitoring of the machines
- The analysis of corrective maintenance
- Analysis of spare parts stock consumptions
- Analysis of equipment performance (Overall Equipment Effectiveness performance indicators)

Fig.3. Traceability Communication with the machines [7]

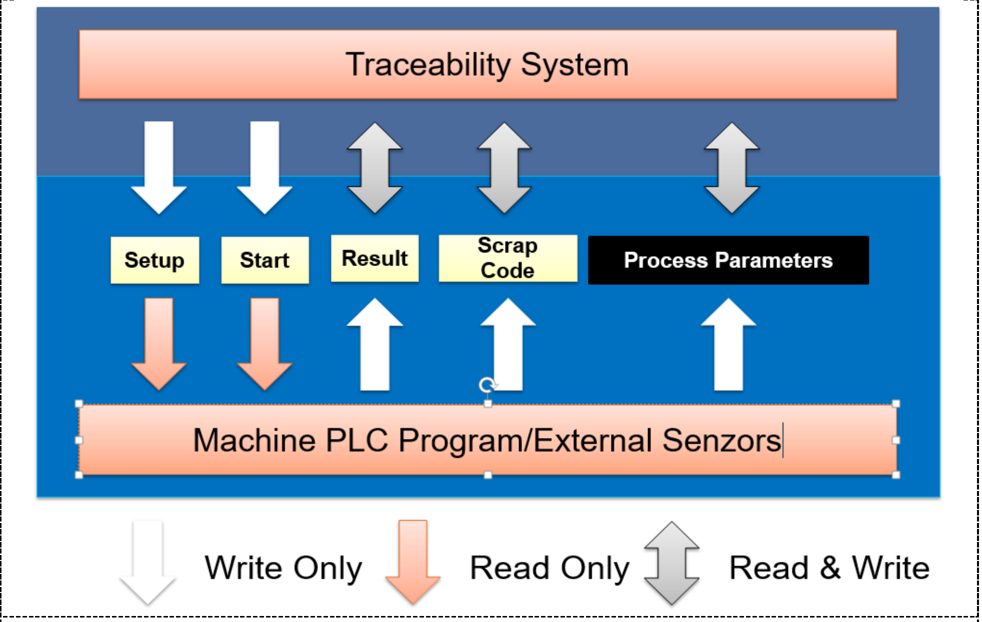

Figure 4. Traceability Communication with the machines [7]

Technology has reached a sufficient maturity level to allow the deployment of a robust predictive maintenance methodology. Internet of things, Artificial Intelligence, integrated systems, evolution of sensors like vibration typologies, thermal imaging, online automatic optical inspections, are all built to connect and communicate, sharing data and proposing solutions for potential problems. The tools are all integrated in the traceability (TTM) which is interfacing the CCMS (Computerized Maintenance Management system) to upload the technical information regarding equipment status and potential failures as in figure 3. [7], [9], [17]. Every machine generates a vibration, a heat, an image, or other quantifiable parameter during operation. Because of, e.g. unbalance misalignment or resonances, these parameters can exceed acceptable limits and damage the machine. The basis of developing the conditioning based equipment is the Tribosystems diagram, which is connecting the input variables (amplitude, frequency duration, velocity etc.) with the outputs (motion, power, and information matter, material) through an interaction function varying on material type, surface treatment, conditions of utilization, as in figure 5.

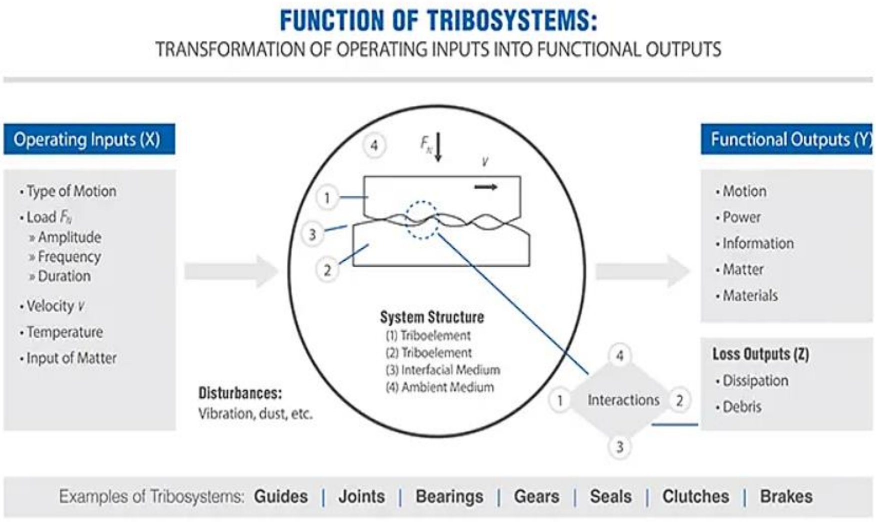

Figure 5. Function of Tribosystems [4] [6]

Condition-based monitoring allows early detection of upcoming machine damage. Maintenance work gets more predictable and the remaining life of important components can be optimally used [14]. The following typologies of strategies can be used:

- Vibration Sensors
- Thermal Imaging
- AOI-Automatic Optical Inspection
- Dimensions Measurement
- Electrical Parameters Measurement
- Pressure, Force Measurement
- Example Vibration Sensor Reading:

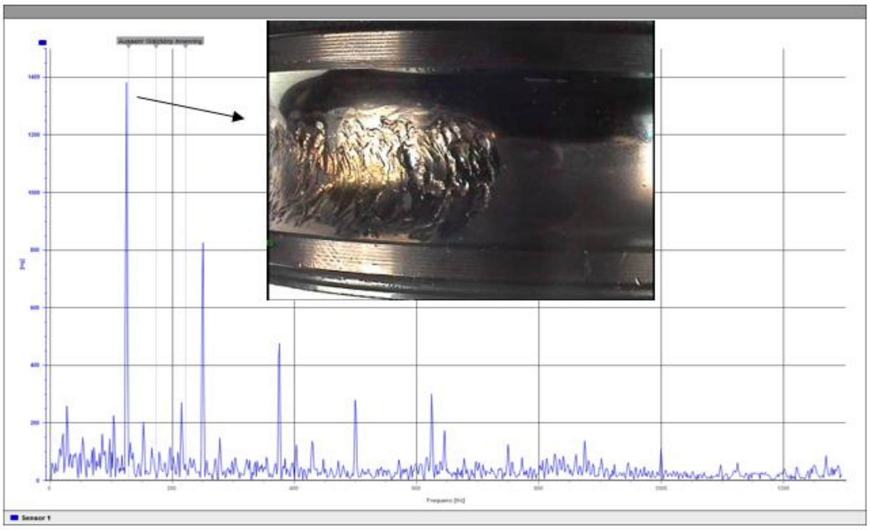

Figure 6. Vibration Sensor reading for bearing behaviour [8], [10], [16]

Fig. 5. Vibration Sensor reading for bearing behaviour [8], [10], [16]
The detailed behaviour of the vibration measured proves that there are 5 stages (as per figure 5):

- First peaks in the ultrasonic range (cannot be measured with octaves)
- First carrier frequencies caused by the fault
- Peak at the fault frequencies in the HFFT
- Peak at the harmonics of the fault frequencies in the HFFT
- Peaks at the unbalance and the harmonics [2], [12], [13]

2.1.4. Autonomous Maintenance

This is the method to empower the machine operators to take the responsibility for basic maintenance activities. Its major focus is to improve the OEE and is doing this by following two rules:

- See, verify, inspect recurrently and preventively, the operator acts as the owner of the equipment and based on the CMMS inputs and his own observation we decides the necessary adjustment/repair steps
- Keep it clean- The equipment is permanently in a clean state of work

This empowerment must be controlled by the CMMS as the storing location for the lessons learned. The most important asset from the company are the employees and the CMMS is facilitating the access to maintenance information for them. For a successful deployment a consolidated and intensive training plan must be executed in terms of software and equipment utilization. The CMMS functions for autonomous maintenance are including on-line verification checklists, inter-active work-instructions, augmented reality procedures, 3d modelling of the station for defect localization, recommendation for tasks from artificial intelligence based on previous experiences. In the autonomous maintenance the operator is developing standards for lubrication and inspection based on a digital record which is connected to video method. [5]

3. Die-Casting Process and PdM via Thermal Imaging

The thermal imaging is used for temperature verification with infrared camera. HPDC applications (High Pressure Die-Casting) are suitable for this inspection typology.
This HPDC is performed in 11 distinct phases (The thermal imaging is used for temperature verification with infrared camera. HPDC applications (High Pressure Die-Casting) are suitable for this inspection typology.
This HPDC is performed in 11 distinct phases(for steering wheel automated production): receiving of alloy(1), spectrometer verification(2), pre-warming 450 degrees(3) , melting in the furnace at 680 degrees(4), casting= injection of molten metal in the mould at a high pressure (>1000 bars), solidification in the mould, mould opening with controlled parameters including infrared thermographic inspection(5), extraction of casted product, mould cooling with a special lubricant sprayed on the inner surface (6), laser marking(7) and association in TTM, trimming (8), washing (9), quality inspection inline, dimensional and aspect(10), integrity inspection (11). [7], [21].

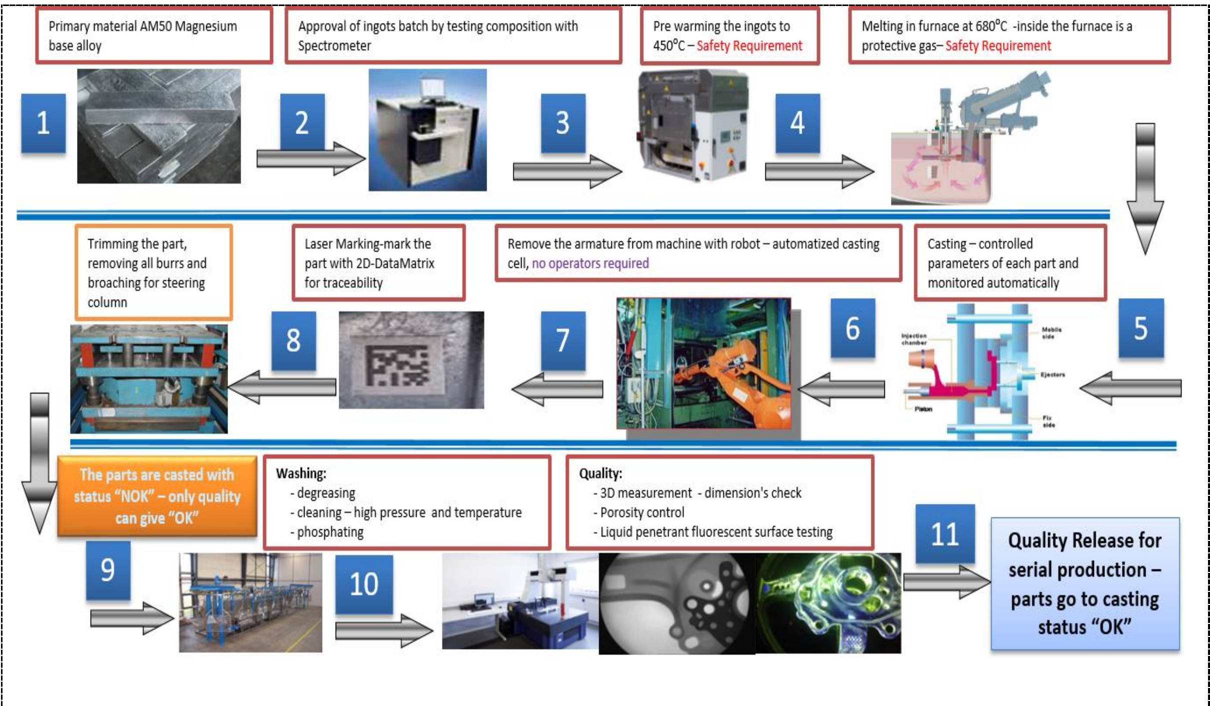

Figure 7. Steering die casting process casting process Al/Mg [1], [7], [11]

At the step number 5, the casting, after the opening of the mould, a thermal imaging inspection is performed. The concept is described in fig. 7. The accuracy of the measurement is depending on accuracy of the camera, environment density and surface uniformity. The total radiation received by the system:

$$L_{tot} = \tau < \varepsilon_{7.5-13} > \int_{7.5}^{13} L_{\lambda}^{\circ}(T)d\lambda + \tau\left(1 - < \varepsilon_{7.5-13} >\right)L_{env} + (1-\tau)L_{env} + (1-\tau)L_{atm}, \; [18]$$

The first term represents the transmitted radiance from the body at a certain temperature (T) transmitted by the atmosphere and T is the transmission of atmosphere in front of the camera in the range 7.5-13μm. The second term is the reflected emission from the environment L_env. The last term is the influence due to the last one is due to emission of the atmosphere〖 L〗_atm.

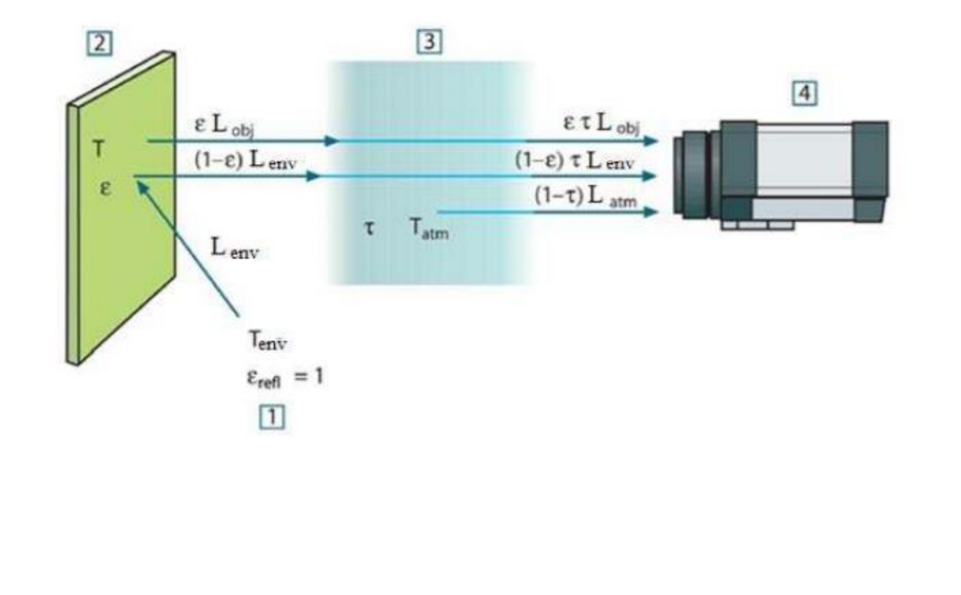

Figure 8. A schematic representation of the general thermography

measurement. 1: Environment; 2: Object; 3: Atmosphere; 4: camera, [19]

The simulation versus reality (fig. 9) are proving that data gathered from software Magma Flow (or similar) used for advance die casting simulations can be automatically integrated in the thermal imaging programs resulting a reliable verification point of the processes and product. The temperature measurement of the moulds and products can provide important predictive data or information needed further root causes analysis in case of malfunctions of the moulds or product/process deviations (safety failures like high porosity and cracks).

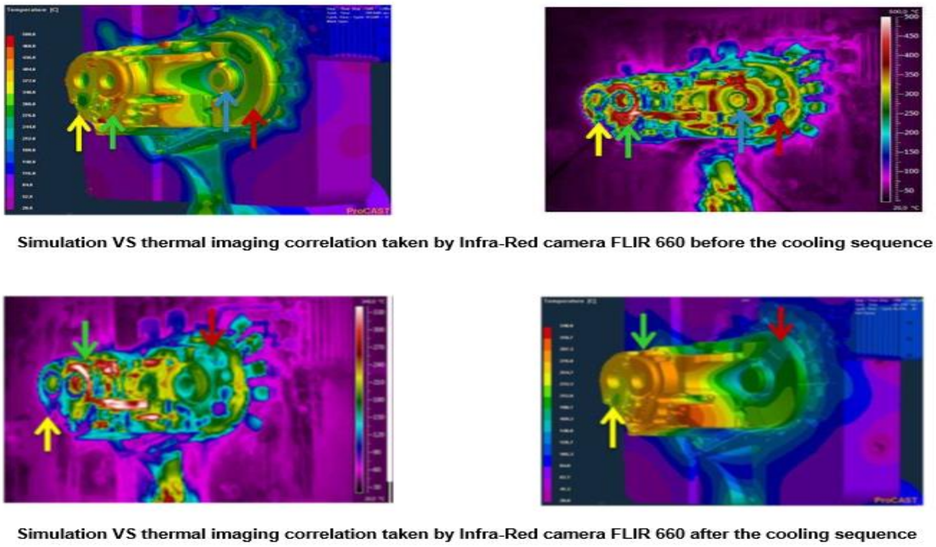

Figure 9. Example of a simulation before and after cooling sequence with FLIR 660, [18] Compared with preventive maintenance the predictive maintenance has the following advantages and disadvantages

Compared with preventive maintenance the predictive maintenance has the following advantages and disadvantages:

- PdM is shutting down the machine only before impending failure, increasing the OEE
- PdM has a higher cost due to complexity, skill level required to operate, and additional cost of condition monitoring equipment.
- PdM synchronizes the intervention moment for the service team due to accurate predictability
- PdM utilizes the Internet of Things (IoT) as ground for deploying a robust predictive maintenance program and it’s based on quantifiable feedbacks from sensors, vision system, measuring equipment.
- The CMMS functions for the predictive maintenance (PdM) are including sensors monitoring, condition equipment monitoring, predictive algorithms, artificial intelligence for repairs connecting thought the PLC which are consequently connected to the TTM through the operational PCs (as shown in fig. 9). This connection allows instant access to date and continuous monitoring of the equipment status and risks.

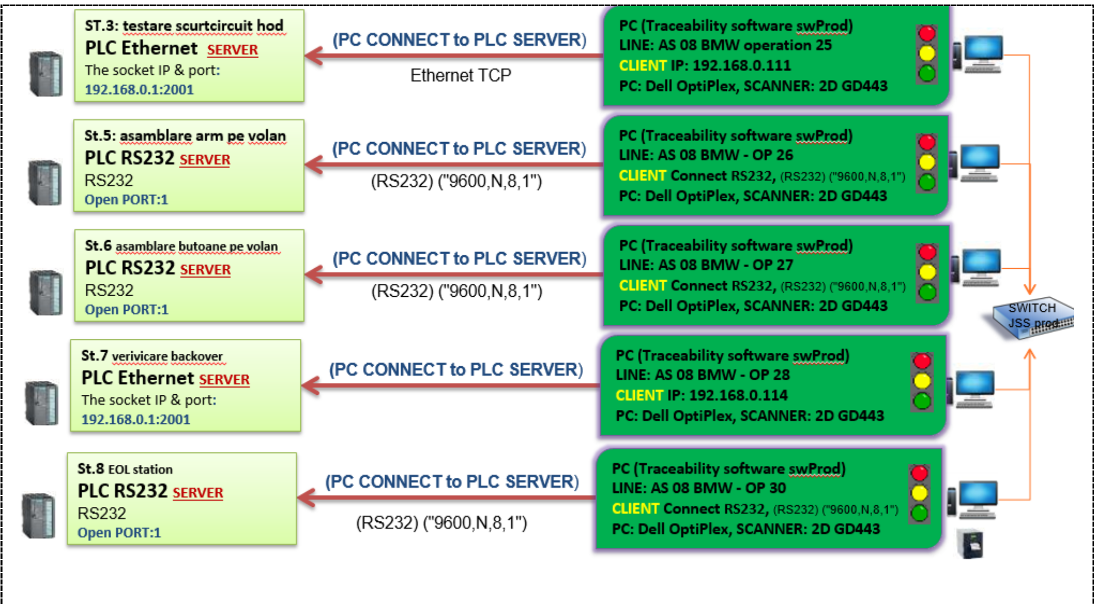

Figure 10TTM connected with CCMS [7], [11]

Fig. 9. TTM connected with CCMS [7], [11] for steering wheel automated production):

4. Conclusions

The aluminium products will become more present in the industrial environment and their geometry and technologies more complex. Controlling the parameters of the processes in order to obtain required and repetitive quality will become a key competitiveness factor.

The optimizations of process, based on predictive maintenance with thermo-scanning and parameter correlation for a die-casting process can reduce the downtime caused by damaged moulds with 75 % , the overall process scrap can be diminished with more than 50%, and the potential safety incidents with more than 90% percent.

The current applications of TTM and CMMS are bringing an obvious revolution in the equipment control. Tools as Augmented Reality, Artificial Intelligence, Machine Learning, Internet of Things, and Big Data Management are becoming standards in the companies as more than 90% started the deployment in the operations. The increase speed of processors, the boost in sensor resolutions, quality, and connectivity are supporting this transformation. On medium term the costs of the predictive maintenance solutions will decrease as the market will increase production capacity. The augmented reality is providing important safety steps, as we can now provide services in areas where before was impossible, creating the ground for Industry 4.0.These are important factors why this technology will be a key asset for the future maintenance activities:

- It is reducing the amount of time spent doing service
- It is increasing the machine utilization
- It is optimizing the spare part needs
- It is reducing the costs for maintenance and non-quality with values from 25-50 %(spare parts cost, downtime cost, breakdown cost, service costs, scrap costs)
- It is facilitating the new worker introduction due to immediate access to the les-sons learned and work instruction databases, as the operator is guided by the CMMS through the needed process steps
- It is having complete history, allowing instant access to data for root cause analysis [7], [15], [22]

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