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# TRANSFORMING STRATEGY FROM INDUSTRIAL AUTOMATION TO ADVANCED LEAN AUTOMATION

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***Abstract:*** Industrial automation refers to the control of machines and processes in order to manage variables. Automated manufacturing systems have evolved as advanced technologies have been incorporated, and theoretical approaches have evolved from mass production to intelligent manufacturing, each step introducing superior manufacturing concepts and models, which allowed increasing processes, organization and work. One of the newest approaches refers to distributive automation, in which the system allows reconfiguration and self-organization of autonomous subsystems in a distribute environment. By incorporating integrative Industry 4.0 technologies, an automated industrial system becomes an intelligent, fully digitized and reconfigurable manufacturing applications platform. At the same time, through digitization and virtualization, the automated manufacturing system can employ the Advanced Lean Manufacturing conceptual support. This paper addresses the transforming challenges of an existing automated manufacturing system to the Advanced Lean adaptive automated manufacturing level, taking into account the limits due to attributes, properties and capabilities of physical manufacturing assets. The proposed solution describes a versatile and dynamic architecture, which allows the organization / reorganization of manufacturing flows, scalability and connection with the external environment, according to advanced cyber manufacturing requests.

***Key words:*** industrial automation, industry 4.0, dynamic architecture

## 1. INDUSTRIAL AUTOMATION

Automation refers to the industrial processes and machines control, through embedding command and control devices, programmable logic controllers of machines and processes. The manufacturing automation system collects information from its environment (at sensors level) and responds and interacting with this environment (through actuators). Also, the automated manufacturing system integrates others control system functions in order to adapt to the environment, to achieve efficiency and flexibility, and, by adopting advanced technologies, new concepts or scientific approaches, it is subject to continuous evolution, [1].

Industrial automation is possible by integrating devices that allow detection, measurement, monitoring and control of manufacturing processes. These are distributed throughout the manufacturing system and consist of the sensor system, (to convert physical process variables into electrical signals), actuators (to transform an electrical signal into a physical process variable), programmable logic controllers (to gather information and apply control signals), human-machine interfaces, and IT&C system (which allows data acquisition and processing and communication).

Over the time, the advanced production technologies have evolved and have been adopted, witch lead to superior manufacturing automation systems, and the integration of IT&C technologies allows the smart manufacturing, a new and superior integrated manufacturing processes management concept, [2]. This new system is based on the communications technologies capabilities to increase flexibility, and standardization of the IT environment. This concept is known as Industry 4.0, [3].

According to this concept, the Industry 4.0 manufacturing system have cognitive capabilities, and allows a fully automated, digitized and self-configurable production, in which the value chain is decentralized, and its elements are autonomous.

## 2. INDUSTRY 4.0 SMART AUTOMATION

To become applicable, the Industry 4.0 system must vitrualized its components. To do this, the physical assets must have communication skills. The digital correspondent of a production asset is defined as an application, called the Asset Administration Shell (AAS), witch is a data container that includes the virtual representation and the functions it performs. The digital assets can be integrated into complex modules who depict a complex physical or digital manufacturing structure. All AASs, and the relationships between them, form the cyber-physical system (CPS), witch is considered the main technology of Industry 4.0 integrated systems, which incorporates advanced computing capabilities in order to achieve the intelligence level, reliability, flexibility and self-adaptability. From industrial automation point of view, the main concern is to integrate different subsystems, and to maintain the functionality, while system complexity is increasing.

Transforming an existing manufacturing system into an Industry 4.0 manufacturing system is a process, in which each production asset, process or subsystem has to go through different updating stages, until to reach the technological, functional and cognitive integration level required by concept. The assessed of current manufacturing system consider the advanced manufacturing technologies, automation and integration of components, the complexity of distributed control system, as well as the automation of manufacturing processes, [4].

The digital integration of a physical production system is doing by defining a digital twin that describes the physical components, their properties and their functionalities. Digital twin is a virtual representation of the physical production system. Both are directly connected, interacts and exchanges data and information. This data is used to assure functionality, to evaluate performance, to design, analyze, or simulate processes, or to define manufacturing services.

CPS is an integration of physical processes with cyber capabilities. The aim is to achieve the autonomy, intelligent real time monitoring and control of the physical manufacturing system. The implementation of CPS aims to transform the existing automatised manufacturing system into a digitaly integrated automatised manufacturing system, which allows reconfiguration and self-organization, and it is oriented to services.

By doing this, the CPS architecture becomes dynamic, can define different manufacturing solutions, acording to the type of product produced or to the required manufacturing situation. CPS design begins with defining and implementing agents. Agents are hardware or software components who behave autonomously, and interact with their environment, or with other agents [5]. The multi-agent system allows collaborative automation between dispersed subsystems or between heterogeneous systems. Through his capabilities, an agent allows implementing sensors, actuators or regulators network, which leads to physical system holonic architecture, and through virtualization leads the way to the cyber-physical manufacturing system (figure 1) [5].

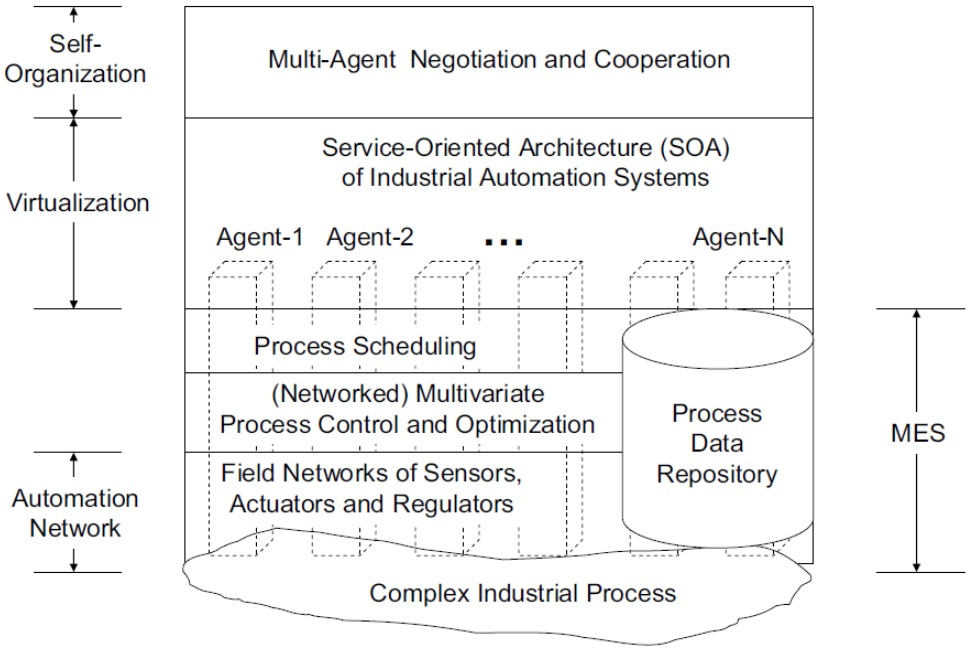


Fig. 1. New framework of re-configurable industrial automation [5]

## 3. HOLONIC SYSTEM AUTOMATION

The holon systems have a higher level of internal organization than agent systems and have a high adaptability. The difference between the agent system and the holonic system is given by the quality of connection between the command and control system with the physical production system. While the agent system acts independently, the holon structure includes the physical structure, to which it is connected by function blocks. The function block is an application programming of the logic controller (PLC) or distributed control system (DSC), through which a function is applied to the input variable, resulting in an output variable. In this way, the holon can embed functions or algorithms that are applicable to the physical production system components, and become an intelligent and adaptable manufacturing solution.

CPS is the result of the manufacturing system upgrading process, which retains the automation main features, to which are added the digital cognitive capabilities. The architecture of the CPS system consists of the physical manufacturing subsystem, the cybernetic subsystem and the IT&C infrastructure (figure 2).

In order to be virtualized, both the physical components and the manufacturing processes must have communication and interaction abilities. It is given that a manufacturing system is the result of an evolution, in which machines or equipment are designed and developed under different technologies, or have been successively adopted. The upgrade to Industry 4.0 manufacturing system must ensure the compatibility and requirements of existing technologies to the future manufacturing system, whose main features are self-configurable, self-managing and service-oriented automatisation.

This is done by updating physical manufacturing assets with equipment and component systems that allow reconfiguration of manufacturing cells, and at the cybernetic level with new automatisation processes requirements, implementation of algorithms, communication capabilities, and integration of command and control functions.

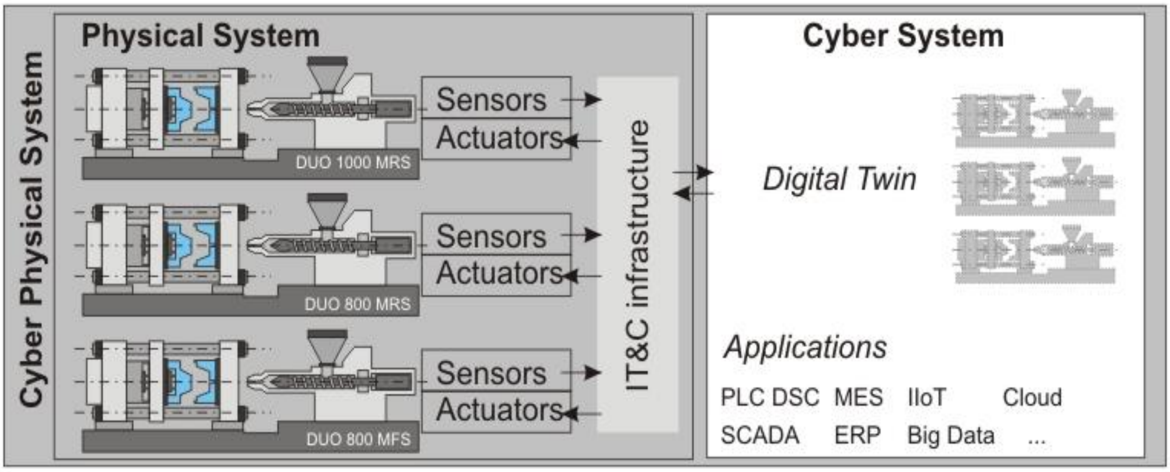


Fig. 2. The architecture of the Cyber Physical System

By fulfilling these requests, the physical manufacturing system is prepared for integration with the cybernetic system, the architecture offering solutions for reconfiguration and self-organization. Its behavior is specific to holonic systems, which can be assembled and disassembled at the manufacturing cell level and the coresponding processes it will be implemented (figure 3), and the holons can be defined in the form of manufacturing services.

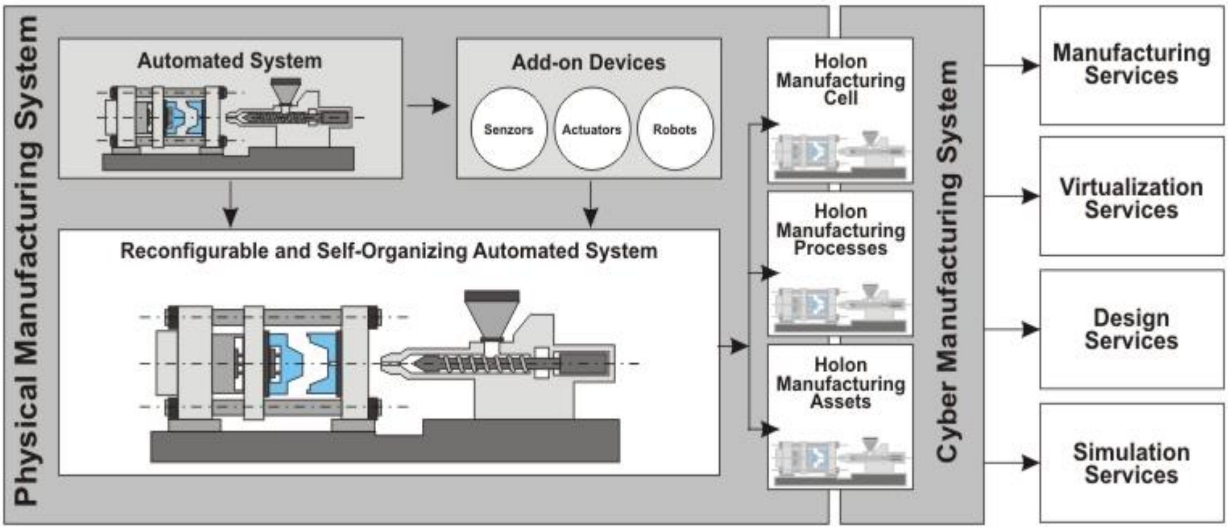


Fig. 3. Defining Holons in Industry 4.0 Manufacturing System

Cybersubsystem host the digital copy of the physical manufacturing system, automatisation digital models, and the manufacturing digital processes. Also, here the products and services are designed. At this level, the manufacturing system digital integration model is established and cyber security is ensured. The objective of the cyber subsystem is to add to the physical subsystem the capabilities incorporated by communication and computing technologies. The main challange is to achieve superior capabilities to collect, storage and processing data, and also to attain higher process control and management. Depending on the final purpose of collected data, it is divided into synchronous data and asynchronous data of the manufacturing processes (figure 4).

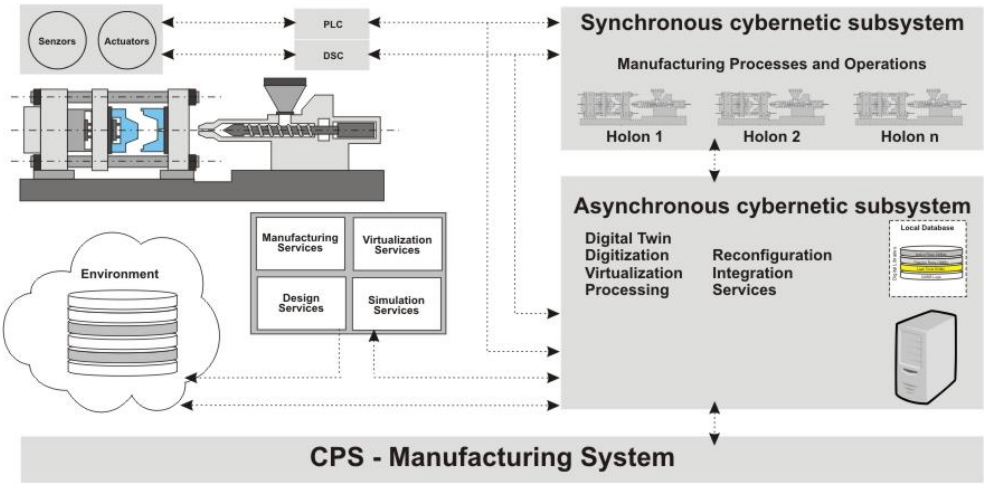


Fig. 4. Cyber Physical System – Synchronous and Asynchronous Subsystems

Synchronous data covers the needs to ensure a constant data flow between the physical and cybernetic subsystems to provide rapid adjustment to environmental factors, process continuity, managing of physical manufacturing assets, to correct occured errors, and at the level of the cyber subsystem to allow real-time data processing, structuring information, providing feedback, and archiving this information.

For asynchronous data point of view, the cybernetic system must provide a superior processing platform, mainly due to their purpose. Asynchronous data is used to define the digital twin, to virtualize manufacturing processes, to increase the efficiency and quality of automatisation, or to configurate holons. The results of asynchronous data processing allow the manufacturing system evolution, the service-orientation, to achieve synergies between the manufacturing systems and the value chain collaborative systems, as well as the connection with the external world.

## 4. CYBER PHYSICAL HOLONIC SYSTEM

From Digital Twin perspectives, AAS depict the capabilities, features, functionalities, and attributes of the represented object. AAS consists of a header, which contains unique identification data, and a body, which includes all object relevant data and information, the type of information provided, and communication specifications. Operational operating data are organized into submodels [6], so that are individually accessed, also to embed applications or references to other computer components.

The AAS module is a reference to an attribute, function, or component of the represented object. Different AASs can be nested in the form of complex AASs (named Meta-AAS), capable of applying different manufacturing scenarios and processes. The sum of Meta-AAS defines the cyber manufacturing holonic system. Through virtualization, the structure employed achieves a coherent level, which manages the properties of the assets, the relationships between the components and the resources involved. This structure, together with the manufacturing scenario described by the Meta-AAS, defines a cyber physical holon (HCF) of the Industry 4.0 manufacturing system (figure 5).

Through CPS, the automatisated manufacturing system incorporates advanced technologies, and accesses a higher level of internal organization, in order to better adapt to the manufacturing environment. Specific processes, which are not synchronous with the manufacturing flow, asynchronous CPS subsystem manage operations that are different than physical product manufacturing, but impact their execution upstream - by adopting and integrating superior capabilities which increase the performance of the execution, during the execution - by formulate decisions for superior control of variations and manufacturing environment, and later - by increasing the adaptability, predictability, and integrating value chain or the products life cycle.

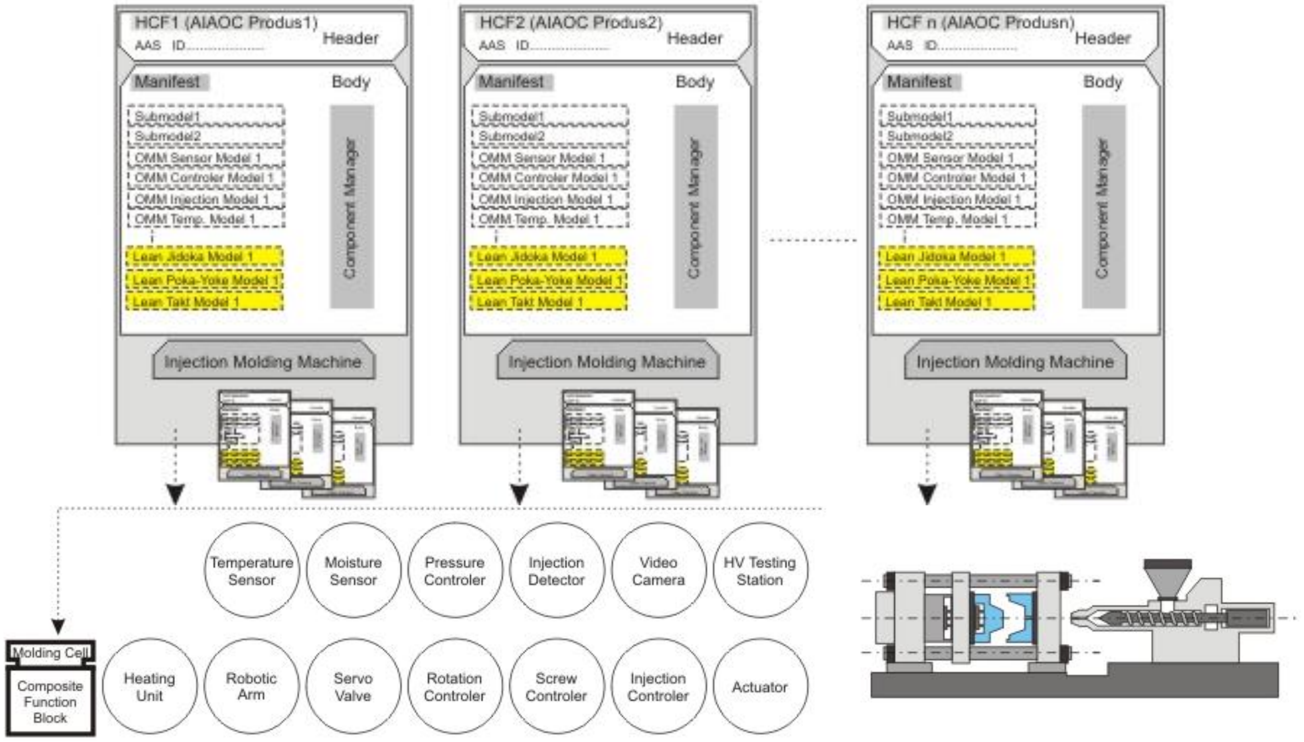


Fig. 5. Defining Cyber Physical Holonic System

## 5. LEAN 4.0 MANUFACTURING SYSTEM

The Lean production system is built around the philosophy of increasing performance using fewer resources, by eliminating waste (activities or processes that do not bring value), increasing efficiency, flexibility and profitability. This concept is seen as a solution to reduce automatisation complexity. Lean Automation has opened the perspective of integrating the Industry 4.0 concept at the manufacturing system level and the orientation towards decentralized, transparent, flexible structures, with low complexity [7]. According to Lean theory, there is a set of specific tools who identify and eliminate waste. A set of fundamental Industry 4.0 technologies have been identified through which waste are identified and managed. Also, there is a correspondence between Lean tools and Industry 4.0 technologies, [8].

The Lean 4.0 is an autonomous, self-configurable manufacturing system, who run processes completely automated. The applicable Lean tools are digitized, benefit from the advanced capabilities of Industry 4.0 technologies, and their implementation aims to comply with the principles of flexible manufacturing. The transformation of an automated and adaptable manufacturing system into an automated, adaptable, flexible, intelligent and computer-integrated manufacturing system Lean 4.0 is achieved by separating the physical assets actively involved in manufacturing processes from the passive ones, which do not change when switching from a manufacturing scenario to another and which ensures the support or continuity of the processes. This is an effective strategy for identifying digitized Lean tools, specific to each manufacturing scenario.

The Lean 4.0 tools, involved in the manufacturing process, collect the information at the physical system level and process it at the level of the manufacturing cybernetic synchronous system, and the decisions are applied at the Meta-AAS level, which apply the manufacturing scenario. The Lean 4.0 tool is defined as AAS, whose modules integrate the interactions, supervise parameters for each manufacturing asset, as well as the decision-making structure applicable to the actuator system, through function blocks. Within CPS, Lean 4.0 tools are grouped as a layer between the physical manufacturing system and the cyber system and individualize each stage of the manufacturing process [10]. The design of Lean 4.0 tools as AASs ensures the coherence of the manufacturing holon and the implementation of the tool. Thus, the two digital entities are connected, communicate with each other data and status information, and progress of ongoing processes. In this way CPS becomes CPS Lean 4.0 (CPSL), each Lean 4.0 tool is connected to the Meta-AAS defined at the synchronous cybernetic level of the manufacturing system. Lean 4.0 tools will evaluate the evolution and send in real time commands to the physical system level, which will be applied through the function blocks or distributed control system.

Moreover, the Lean 4.0 manufacturing system will intervene at the entire physical manufacturing system,

by supervision of CPS and HCS and initializing the corresponding Lean 4.0 digital tools, [11].
The two cyber structures, Meta-AAS and Meta-LeanAAS, allow tu build an adaptive manufacturing system, capable to supervise physical processes, and to apply corrections at HCF level. As subsystem, the Meta-LeanAAS is positioned in a HCF coordination level, and manage it through selected Lean 4.0 instrument modules. In this Lean 4.0 architecture, the selected tools are individualized and distributed for each HCF. Also, placing within the synchronous cyber subsystem offers the possibility to supervise and intervene in real time in the development of the specific manufacturing scenario (figure 6).

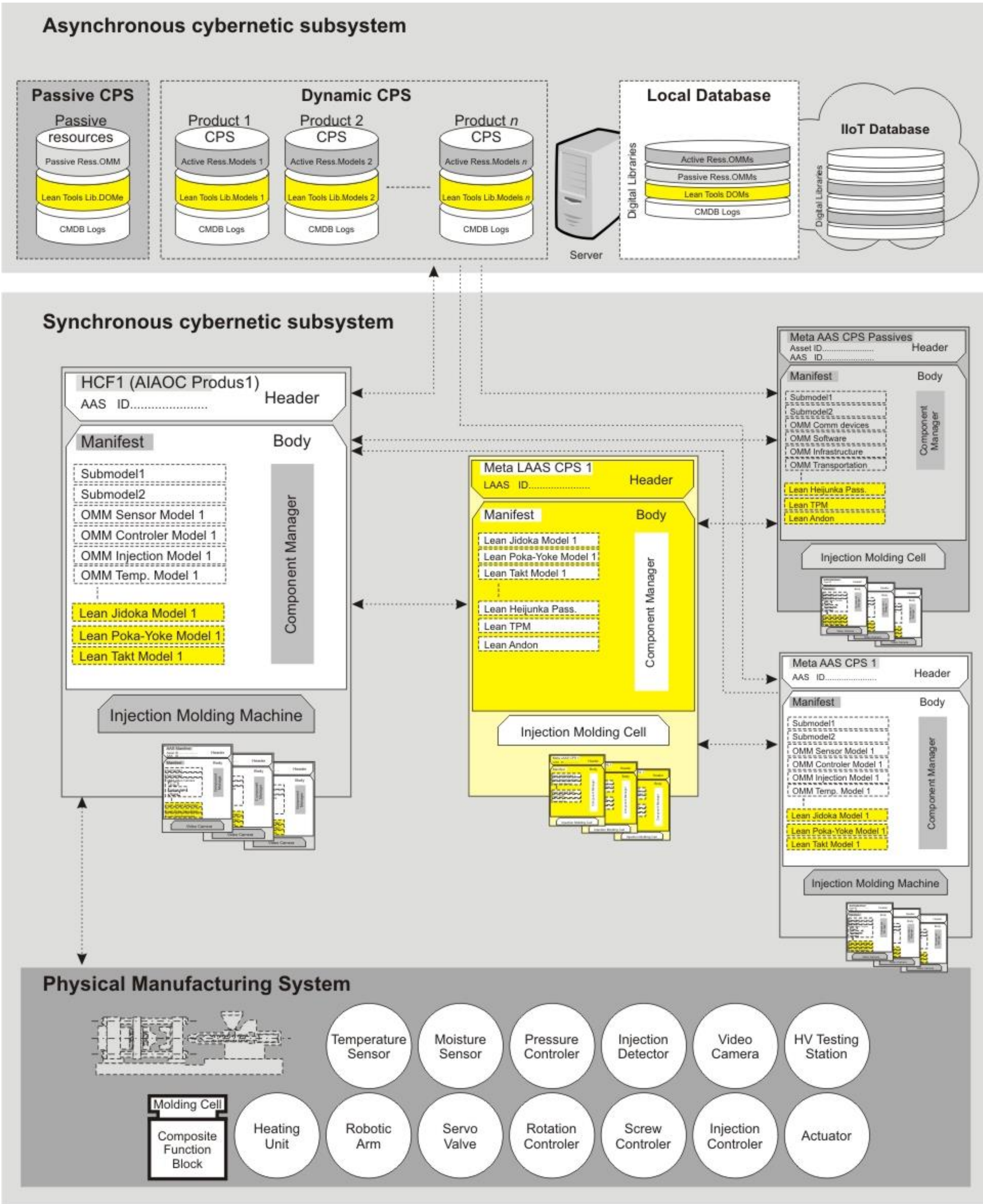


Fig. 6. Lean 4.0 Cyber Physical System

## 6. CONCLUSIONS

For the transformation of an automated manufacturing system into an intelligent, self-configurable, self-managing and service-oriented manufacturing system, the main challenge is that the manufacturing system is the result of the technology evolution over time. This, requires to split the cybernetic system into two subsystems, depending on the destination of the data collected at the physical level, one synchronous and the second asynchronous to the manufacturing processes.

While the synchronous cybernetic system is limited by the attributes of physical assets and the capabilities of the physical manufacturing system, the asynchronous cybernetic system has a versatile architecture that allows system organization / reorganization, scalability, horizontal integration, connection to the external environment of the production system. This selection provides an effective strategy for defining manufacturing holons, implementing the Lean 4.0 concept, and identifying the Lean tools for each manufacturing scenario.

By defining the Lean instruments as Meta-AAS and positioning as a coordinating level the cyber-physical holon, both the Industry 4.0 and Lean 4.0 concepts become applicable at the manufacturing cell level.

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