Comparison of Agent Oriented Software Methodologies to Apply in Cyber Physical Production Systems

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***Abstract*— Cyber-Physical Systems (CPS) could be the most modern electronic development as yet, thanks to the integration of information and communication technology (ICT). CPS has associated with computer systems (cyber part) which are closely related to the real-world processes (physical part). A CPS is supported by the newest and foreseeable further advances of computer science, data and communication equipment on the one hand, and of manufacturing science and tools, on the other. On the contrary, within the multiple applications, there are CPS for manufacturing systems, called CPPS (Cyber-Physical Production Systems). The fourth industrial revolution regularly distinguished as I4.0 is based on CPPS. Considerable numbers of authors agree that paradigms agent-based as Multi-Agent Systems (MAS) converge or they make up some parts to apply CPPS. In general, this paper emphasizes that there are different important approaches in CPPS implementation which point near, in particular to MAS. The objective of this article is to provide general and specific concepts associated CPPS implementation through agents, considering the current multiples approaches and methods. A key result is that Agent-Oriented Software Engineering (AOSE) methodologies have been a highlight to comparisons leading benefits to apply in CPPS.**

Keywords*— *Agent Oriented Software Engineering (AOSE), Cyber-Physical Production Systems (CPPS), Multiagent Systems, Industrial Automation, Industry 4.0.

I. Introduction

The flexibility and re-configurability along with the robustness and operational efficiency of manufacturing systems can be substantially improved by applying new and advanced information and communications technology (ICT). Recent trends in IT are regularly associated with of the Internet of Things (IoT). High impact academic institutions, industries, and governments all over the world develop plans and strategies for their long-term evolution around those terms [1].

Under this agreement, Industry, 4.0 (I4.0) was initialized in Germany and extended to Europe, aiming at the expansion of the fourth industrial revolution. Leading prospect of I4.0 and other related concepts are mass customization and flexibility of production systems, based on Cyber-Physical Systems (CPS).

Substantial changes are required in the manufacturing systems for I4.0, which should include the new technologies such as reconfigurable machines and more intelligent robots which are principally different in appearance and functionalities; nevertheless, they follow a similar pattern among them in their communication and interaction behavior.

Based on [2], the evolution of systems could include the industrial type of IoT or IIoT/I^{2}oT, as shown by from Fig. 1. First, the demand to develop specific tasks and real-time computing creates the *Embedded Systems*. Second, systems, products, services are generated and evolved through the application of interconnected networks and systems, or communication from Machine to Machine (M2M).

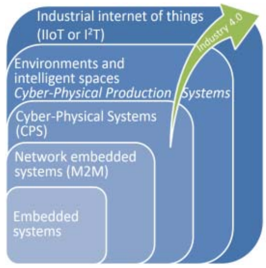

Fig. 1. Evolution from Embedded Systems to the IIoT [2].

Different approaches can be modified or adapted to develop CPS, in particular for the consideration of industrial automation systems for manufacturing or CPPS (Cyber-Physical Production Systems). The main contribution of this paper is to classify existing agent-based approaches as a technological basis to realize CPPS and to identify benefits of Agent Oriented Software Engineering (AOSE) as a useful strategy for CPPS development.

Therefore, first, this paper shows related applications of currently CPPS projects and their approaches (Section II). Second, the next section explains ten requirements relevant for the apply Multi-Agent Systems (MAS) for CPPS (Section III). Compendium and comparison of primary MAS methodologies are given in the last section (Section IV). The paper is concluded with a summary and outlook of future work.

II. Impact of Cyber-Physical Production System in Industrial Automation

Nowadays, a significant amount of manufacturing information is already generated. There is a great need for a new generation of systems to design and realize more than networking, ICT, and knowledge being integrated into physical things [3]. Hence, with the recent advent of Information Technology (IT), it is possible to apply computers to store data, analyze statistics, recover records, transmit signals, and manipulate general information for the production environment. IT evolution generated the Cyber-Physical Systems terminology.

978-1-5386-0837-1/17/$31.00 ©2017 IEEE

CPS concept consists of a virtual part (software) and a real part (hardware). CPS have a trend towards more flexible cooperative distributed systems, and they will introduce new communication concepts [4]. The primary benefit of the CPS in automation is smooth integration of software components at runtime so that its operability, especially productivity for manufacturing is not hindered as much as possible.

Thanks for primary integration benefit, there are a lot of applications for CPS such as autonomous cars, robotic surgery, smart buildings, smart grid, medical implant devices and smart manufacturing and they are just some of the examples since they are in permanent extension [2].

CPS for manufacturing systems has also generated Cyber-Physical Production Systems concept. CPPS are intended to develop the necessary contributions to obtain the *Smart Factory* [1]. CPPS could be done more practical thanks to the advance of newly available devices for the future of automation through IIoT [5]. A reported landscape of works with CPPS and their proposals are enlisted through Table I.

TABLE I. SELECTED CPPS PROJECTS PROPOSALS

Project	Proposal
myJoghurt [1], [6]	Implementing examples for CPPS through prototypical MAS-based evaluating and using the production scenario from different German chairs
IDAPS [7]	Perceiving as a microgrid is intelligent, having a built-in multi-agent functionality in the context of Intelligent Distributed Autonomous Power Systems
ENIAC JU E2SG [7]	Developing methods for detecting and controlling energy flows in the grid with information transmitted over the grid itself
Socrades [7], [8]	Exploring application of service orientation and web services using formalisms for modeling, analysis, and execution for next generation of industrial automation
GRID4EU & SGAM [7]	Testing innovative concepts and technologies in real-size environments, to highlight and help remove barriers to the deployment of Smart Grids in Europe
IMC-AESOP [7], [8]	Proposing a Service-Oriented Architecture (SOA) for very large-scale distributed systems in batch and process control applications
Grace [9]	Developing a modular, intelligent, and distributed control system that integrates process and quality control using the MAS principles
IDEAS [7], [10]	Enabling fast deployment of mechatronic modules based on eEAS paradigm, advocating the use of process-oriented and associating interacting agents
Pabadis Promise [7]	Distributing manufacturing execution systems and bringing flexibility features to the control systems using software agents and plug-and participate technology
iSiKon [1]	Increasing ding flexibility in heterogeneous material flow systems based on intelligent software in self-configuring modules
SmartFactory[KL] [11]	Working on new concepts, standards, and solutions to form the basis for highly flexible automation technology and manufacturer-independent *Industrie 4.0* plant
HySociaTea [12]	Establishing the basis for production environment of the future with a team of humans closely collaborating with robots and virtual agents
It's OWL [13]	Focusing is in the fields of self-optimization, human-machine interaction, intelligent networking, energy efficiency and systems engineering
uPlant [14]	Testing facility for methods from the areas of monitoring, modeling, control and optimization of modern and future automation technologies
PhyNetLab [15]	Developing of ultra-low power WSN for decentralized control of materials handling facility

Selected projects from Table I are several large-scale R&D initiatives, which were conducted over the years to research the use of CPS in industrial applications. These projects have demonstrated crucial challenges, such as safety, security, and interoperability and have become a reality especially manufacturing systems [7]. Furthermore, these projects have also been covered by industrial partners as well as academic experts. Therefore, the parallel development of academic and industrial approach has been possible.

There are many different definitions for CPPS. One in [4] says, "Cyber-Physical Production Systems (CPPS) are Cyber-Physical Systems as applied in the domain of manufacturing/production, in Germany the term *Industrie 4.0* is used". Other authors in [16] mentioned that "Cyber-physical systems (CPS) are systems of collaborating computational entities which are in intensive connection with the surrounding physical world and its on-going processes, providing and using, at the same time, data-accessing and data-processing services available on the Internet."

A preview summary could be that CPPS as the previous generation for Intelligent Manufacturing Systems (IMS) and future automation [2], [5]. Thus recent works show that the most significant contributions of CPPS are the following [1], [6], [7], [16]–[18]:

- Vertical and horizontal integration through value and smart networks.
- Manufacturing devices are intelligent to acquiring information from their environs and act autonomously (smartness).
- Cooperation and collaboration will be some inherited skills to use connections to the other system actors (including *human beings).*
- Reaction properties towards internal and external changes or failures (robustness).
- Optimal decision making for energy and resource efficiency.

Along last decade, in the selected projects from Table I, classified in Table II, they have been developed *CPPS demonstrators*, *Smart manufacturing* approaches, *Electric Grid applications* or *Architectures* installed in industrial environments. The Table II also categorizes these selected CPPS projects agreeing to ISA 95 standard levels. As surveyed in [17], the ISA 95 levels could be classified according to *Device Level* (L1); *Supervisory Control And Data Acquisition* or SCADA Level (L2); *Manufacturing Operations Management* or MOM Level (L4); and the *Enterprise* or ERP Level (L4).

TABLE II. CATEGORIZATION OF SELECTED CPPS PROJECTS

	CPPS type				ISA 95 Level			
Project	CPPS demonstrator	Smart Manufacturing	Electric Grid Application	Architecture development	Device	SCADA	MOM	Enterprise
myJoghurt	X	X	-	-	X	X	X	-
IDAPS	-	-	X	X	X	X	-	-
ENIAC JU E2SG	-	-	X		X	X	-	-
Socrades	X	X	-	-	X	X	X	X
GRID4EU & SGAM	X	-	X	X	X	X	X	X
IMC-AESOP	-	X	-	X	X	X	X	X
Grace	-	X	-	-	X	X	-	-
IDEAS	-	X	-	X	X	X	-	-
Pabadis'promise	-	X	-	-	X	X	X	-
iSiKon	-	X	-	-	X	X	-	-
SmartFactoryKL	X	X	-	X	X	X	X	X
HySociaTea	X	X	-	-	X	X	X	-
It's OWL	X	X	-	-	X	X	X	X
uPlant	X	X	-	-	X	X	X	-
PhyNetLab	X	X	-	-	X	X	X	-

III. APPROACHES REVIEW FOR CPPS

After the first classification of existing CPPS projects, in the previous section, manufacturing concepts, CPPS approaches, and its general characteristics are discussed in this chapter.

A. Concepts of Architecture, Methodology, and Standard in Manufacturing Approaches

For this paper, an *approach* is defined as a set of *architectures*, *methodologies* and/or *standards* that follow a common scheme. In the case of *architectures*, they are considered only as structures of static modeling systems. Most of these are frameworks patented by their authors and often do not have the procedural information to carry out their implementation (methodology). A *methodology* determines a series of steps to be taken to improve productivity in development and quality systems (generally for engineering software). It also indicates how it will perform the process in a systematic, predictable and repeatable way. Both an architecture and the methodology can be endorsed by international institutions which generate *standards*. Depending on the nature of the organization, a standard in manufacturing may be a private or open type.

In the ideal case, architecture can be promoted by its methodology to carry out its implementation, and they both can be standardized. However, in the reviewed authors' academic literature (e.g. [7], [10], [17]), architectures, methodologies, and standards are mutually exclusive characteristics. In fact, not all architectures, nor methodologies in manufacturing systems are supported by international standards.

In summary, a manufacturing approach is a collection of architectures, methodologies, or standards that are part of a similar paradigm but do not maintain the same structural, dynamic, and procedural properties.

B. Manufacturing Approaches for CPPS

This section will give an overview of traditional manufacturing approaches and their particularly comprised points. After that, agents based schemes will be introduced with their characteristics.

1) Traditional Hierarchical Approach

Most of the traditional manufacturing systems belong to this classification. These are implemented using centralized and staggered control techniques, and present good responses regarding outputs due to their optimization capability. Such methods typically follow a rigid multilevel structure, which prevents them from reacting agilely to possible variations.

Hierarchical architectures are similar to that pyramid Computer Integrated Manufacturing (CIM). In this, the different levels cannot take the initiative; therefore, the system is vulnerable to disturbances and autonomy, and its reactions to disturbances are weak. This rigidity increases the costs of its development produces a system problematic to maintain [5].

A significant example is a norm applied to batch processes, called ISA-88, which corresponds to hierarchical schemes due to its centralized nature. This standard does not present a solution to the automation system, but it refers to an ordered method for thinking, working and communicating. It has a hierarchy characteristic between control levels of devices and equipment. It also contains models and terminology that allow analyzing the organization.

2) Heterarchical Approach based on Multiagent System

Heterarchical manufacturing techniques introduce a proper response to the requirements of flexibility and agility. These designs provide an excellent performance against changes and can be continuously adapted to their environment. Systems are fragmentations of small and completely autonomous units.

The independent components, called agents, are the main part of this architecture, and they obtain cooperation skill through negotiation protocols structures. Multi-agent system (MAS) approach prohibits all types of hierarchy to give all the power to the necessary modules. By eliminating hierarchical relationships in the system, the modules cooperate as equals, generating a flat architecture rather than assigning subordination and supervisory relationships.

Gaia is a particular example tailored to the analysis and design of MAS [8]. Gaia is a general methodology that supports both levels of the individual agent structure and the agent society in the MAS development process [9]. In this methodology, MAS looks like a system constituted of a conglomeration of autonomous interactive agents that exist in an organized society in which each agent plays one or more specific roles. Gaia structures MAS regarding a role model, based on the roles that agents have to play within the heterarchy and the interacting protocols between such different characters. Functions include the following attributes: responsibilities, permissions, activities, and protocols.

3) Hybrid Approach Based on Hybrid Systems

Another main approach similar to MAS is a holonic (or holon based) manufacturing system (HMS) by P. Leitão, H. Van Brussel, and P. Valckenaers [8], which consists of autonomous, intelligent, flexible, distributed, co-operative holons. Multiagent systems (MAS) and holonic MAS (HMAS) may comprise complex systems. Getting started with such hybrid architectures can be challenging to implement CPS.

The design enables the product cases to drive their production; consequently, coordination through holons can be completely decentralized. In contrast to many decentralized setups, the manufacturing based on holarchies (levels of holons) predicts future behaviors and proactively uses actions to prevent impending difficulties from occurring.

Hence, one of the most hopeful features of HMS is that they symbolize a transition between fully hierarchical and heterarchical systems. Review literature of HMS indicates that the ADACOR (ADAptive holonic COntrol aRchitecture for distributed manufacturing systems) is one of the most remarkable for HMSs. ADACOR architecture identifies four types of basic holons: *Product holon* (PH), *Task holon* (TH), *Operational holon* (OH), and *Supervisor holon* (SH) [8]. It is a holonic design that offers an adaptive manufacturing control approach scales from a stationary state to a transient state, in typical and unexpected conditions, respectively, combining the benefits of hierarchical and heterarchical control structures applying some adaptive elements.

Finally, a classification of the approaches is provided, to identify levels of ISA 95 (y-axis Fig. 2) and on the Z-axis real time requirements for important works in CPPS. Also, Fig. 2 shows the classification into hierarchical, heterarchical and hybrid on the x-axis and arranges a selected *Architectures*, *Methodologies,* and *Standards,* which could be applied in the development of CPPS according to the proposed classification.

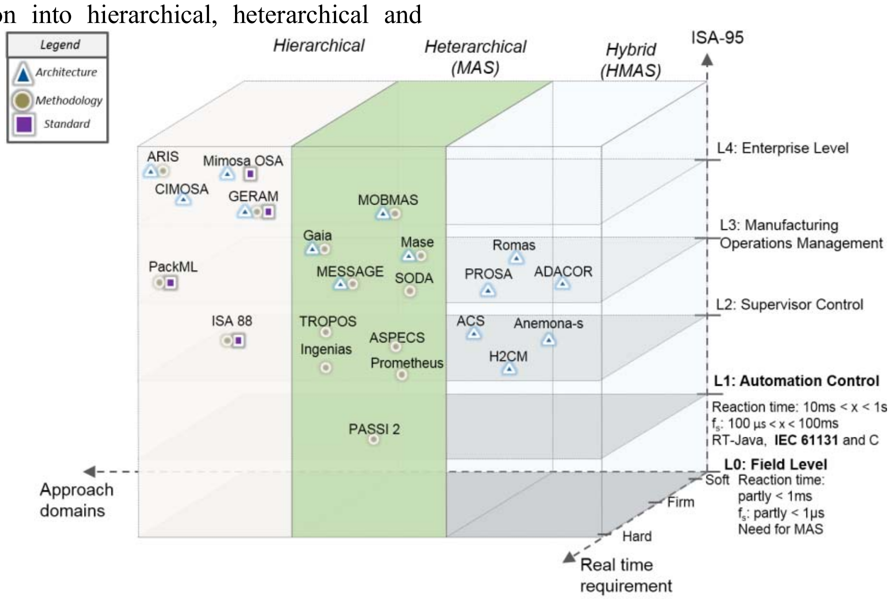

Fig.2. Classification of agent-oriented architectures, methodologies, and standards for CPPS approaches

IV. Requirements for CPPS

Main requirements need to be satisfied before obtaining the vision of integration and convergence of the IIoT, and in this way, all its benefits can be achieved [4], [6]. In particular, it is important to consider that even in highly developed countries there are asymmetries on the degree of digitalization of manufacturing, and even within the same organization, there are areas which have been highlighted on automation from others [7]. To overcome these challenges and to homogenize a comparison, in this section, requirements for future manufacturing architectures and CPPS necessities are derived.

A. CPPS Minimal Conditions (Requirement 1)

Some studies have been conducted to investigate the conditions to discover the necessary technical characteristics for CPPS, realizing a CPS architecture that could couple various industrial production facilities [6]. Consequently, several fundamental properties of a CPPS were recognized that could be summarized into four main groups of following elements:

1) Independence architecture model (R1.1)

Modules could be simple to integrate with open architecture and platform independent implementation. From the numerous varieties of automation system items that need to be able to play in CPPS, network requirements concerning the computing devices for which a necessary examination arises. For example, Programmable Logic Controllers (PLC) are frequently used in industry. Thus, these devices need to be considered as one platform type to integrate into the agent-based CPPS. Nevertheless, independence of architecture means that CPPS is not limited to this class of devices. However, expanding the different platform should always be possible to maintain data transfer for more multiple kinds of applications.

2) Open communication protocol for IIoT (R1.2)

This requirement is related to standardization and is pointed out by the industry as a major distinctive for the manufacturing acceptance of any technology (open architecture). There could be easy and quick abilities to switch between open protocols for IIoT (e.g. OPC-UA). Due to the importance of the communication in this ubiquitous networking era, many kinds of components, layers, and protocols are required to have OPC-UA standard features in a manufacturing control systems.

3) Levels of automation are enabled from ISA 95(R1.3)

All levels of automation are allowed (ISA 95) depending on the scenario in which the CPPS is applied. Various parts of a manufacturing system may have to be connected to the network. It means, in a simple automation system, only overall production equipment, and their respective information element systems need to be linked to the CPPS network. Then, to be applicable in several different scenarios, a CPPS should not be limited to a particular hierarchy level of a manufacturing system. For this, the connection of random system components should be feasible independently of their locations in a plant hierarchy or global context of ISA level.

4) Easy to adapt the system to future products (R1.4)

It will be necessary to have easy adaptation the system to future products (Smart products). According to that information and the knowledge regarding their techniques, the production facilities can reason about circumstances for executing the processes and, based on results, return the product with either an offer or rejection.

Behind a pure syntactical correspondence of the received operation report and the models that describe production capabilities, the application of semantic technologies enables a semantic checking and hence enhanced possibilities of uniting the different entities of a CPPS. The communication necessary for switching the request, offers or refusals, is realized by information that is either published by global data inside of the CPPS or sent directly to the other entities of the system in a Machine to Machine (M2M) communication manner.

B. Intelligent Characteristics Attributes (Requirement 2)

1) Autonomy (R2.1)

Autonomy could be achieved by deducing behaviors of the CPPS on agents from its experience, and processes. Agent-based approaches support the success, called Plug and Work production systems, where various elements are joined to a complete production system without hand-operated configuration efforts. The primary goal of these developments is the creation of a basically soft agent platform that presents guidelines and facilitates a fast, platform-neutral implementation of the agent technology.

2) Communication and ontology (R2.2)

Communication is necessary to speak same languages and common agent ontology. In general cases, agents may communicate to achieve goals or due to selected event. Considerations of inter-agent communication include which protocol to use, how to define a domain –in terms an agent from another field can understand– and how competent could be the communication technique.

3) Cooperation (R2.3)

Cooperation is crucial to enable developing mutually acceptable goals. Cooperative skills for CPPS offer necessary elements and subsystems to connect an intelligent network. CPPS networks will be based on the context within and across all levels of production, from processes through machines up to ERP systems.

Manufacturing control systems require autonomous entities to be classified in hierarchical and heterarchical structures for cooperation. Cooperation requirement is related to the kind of behavior that the control unit at factory level should exhibit. Manufacturing control based agent are regularly handling a high number of duplicated events, which are known but random. This flow of events should be processed in an efficient manner with temporal constraints and agent collaboration.

The administration of the agent events can consequently be determined apriori by routines, while the beginning and execution of these routines should be performed in a real-time collaboration technique. The size of the event set and their activity patterns increase over time.

4) Pro-activity (R2.4)

The agent is capable of achieving his assigned goal. It means that MAS must have skills to take the initiative not solely motivated by events, also adapt itself generating "rational" actions to succeed goals. This suggests some degree of Pro-activeness (e.g. it tracks its' own agenda). For CPPS researchers, this is a defining attribute of an agent.

C. Formalized Modeling Terms (Requirement 3)

Innovative approaches to abstractions (formalisms) and architectures are necessary to enable control, communication and computing integration. CPPS implementation implies the rapid design and to be developed. They should admit the combination and interoperability of heterogeneous systems that formed the CPSs in a modular, practical and hardy manner.

1) Using standard language (R3.1)

The models for CPPS require internationals standards which are the base for the expansion of standard lines between SCADA, MES and ERP levels systems. Formalism such as the Unified Modeling Language (UML) helps to structure and comprehend information from manufacturing architectures through understandable models.

Other modeling languages have been proposed to model a CPS in [18], called Systems Modeling Language (SysML). SysML has been established in automation systems based on UML to support Model-Based Systems Engineering (MBSE). A related semantic is Automation Markup Language (AutomationML), and it is one of the imminent upcoming open standard series (IEC 62714) for the description of production plants and their components. For *Plug and Work* concept, AutomationML defines the contents, which is exchanged between the parties and systems complex.

It requirement helps to model plants and plant components with their skills, topology, interfaces, and relations to others, geometry, dynamics and even logic and behavior.

2) Level of abstraction for overview (R3.2)

There could be a different degree of abstraction for applying the model in CPPS. The conventional approaches and methods for manufacturing system modeling, such as CIM, are mainly based on a top-down scheme. The user's requirements and the general conceptual design constitute the whole set of modeling limitations. With these approaches, very rigid hierarchical architectures are built.

Other non-traditional designs were differentiated as being bottom-up structure. Nonetheless, in line with the order of the complexity of the distributed system made up by a network of smart entities, IMS modeling requires several development methods. It includes bottom-up and top-down integration, depending on the level being formed. It is not mandatory to define the whole set of constraints at the origin. A mixed construction process allows the generation of reconfigurable and scalable structures.

3) IDE coverage and complexity (R3.3)

The model must provide details to facilitate the implementation in Integrated Development Environment (IDE) and platforms. In traditional automation systems, there are only a few languages including the languages defined in IEC 61131-3. These languages were developed for IDE with a focus on automation systems. Depending on a proper runtime, tools could be often programmed in C or assembly language. With the increase of mobile devices, such as smartphones or tablet PCs playing an important part in CPPS, the range of different languages and platforms gets even wider. Every platform uses its runtime, and again even the various programming languages.

For example, instance applications for Android applications use a Java framework; hence, they have to be written in Java language. Another example is Firefox OS, which is in progress and it uses JavaScript language in combination with Hyper Text Markup Language (HTML) for mobile applications. could be required to find devices with this IDE to apply CPPS there soon.

D. Systems and Human Integration Needs (Requirement 4)

1) Open systems to different systems domain (R4.1)

It is open to different kind of systems area (e.g. energy, manufacturing, or process). Due to the broad diversity of industrial process systems, the development custom or tailored solutions has to be reduced. On the contrary, an architecture for agent-based CPPS should apply to a variety of situations, i.e. different kind of products and processes. For this reason, the MAS architecture, protocols, and messages for CPPS should be independent of a particular application.

2) Hybrid topologies (R4.2)

It is necessary to include hybrid topologies to enlarge and downsize the production system because many different architectures can be present in a CPS. It means that various manufacturers may integrate several designs. A specialized engineering or development tool is established for every element in a CPS. The developers are used to their respective devices and have their skill in its approach. It should be possible to continue developing in the similar languages. Because of this, devices with different runtime systems have to be mixed into a CPS.

3) Social norms considering human factors (R4.3)

CPPS must provide social norms to execute MAS considering human factors. Also, if all data and information available concerning a CPPS and its products, production facilities, and architecture is modeled and semantically represented, the preparation of this knowledge for human personnel or customers remains an essential issue. It must include concepts that support the engineering of CPPS and their system entities (e.g. intelligent products and production facilities) as well as mechanisms to preprocess the relevant process data during production for human operators, support personnel and even for the customers of the produced goods. This information will provide opportunities for individual arrangements (e.g. age or user level distinguished visualization and interaction mechanisms) as well as integrations with regularly used especially mobile devices and humans [6].

V. AOSE Strengths to Implement CPPS

MAS or Agent-based approaches signify a natural method of realizing CPPS [6]–[8], [17]. The important concept of MAS is Agent Oriented Software Engineering, and there are several AOSE methodologies, which are at least ten years old [5]. Indeed, the decision of an AOSE methodology depends on the MAS demands, in this case, CPPS requirements expressed in section III.

Considering requirements from part III, this article will now examine the different methodologies of reported in the dedicated literature of AOSE. The goal of this revision is to determine to what extend these procedures into account the requirements for implementing CPPS. Firstly, this section presents a brief summary of the various methods (more details can be found in [8], [9]). Finally, this chapter will make a comparison discussion based on the requirements it has cited in Chapter III.

A. Main Agent Oriented Software Engineering (AOSE)

Previously selected ones of AOSE for the CPS event-driven multi-agent model, a comparison should be performed based on the following evaluation criteria, grouped into four main categories: CPPS Minimal Conditions, Intelligent Characteristics Attributes, Systems and Human Integration Needs. Table III presents the comparison between AOSE approaches that could be used in a real CPPS implementation.

Table III. Main AOSE Strengths Ordering

Main AOSE	R1- CPPS minimal attributes				R2- Intelligent characteristics				R3- Formalized modeling			R4- Systems and Human Integration		
	R1.1	R1.2	R1.3	R1.4	R2.4	R2.5	R2.6	R2.7	R3.1	R3.2	R3.3	R4.1	R4.2	R4.3
Gaia	+	+	~	+	~	+	~	+	+	~	~	-	+	-
MaSE	+	+	+	+	+	+	+	-	-	-	~	+	-	-
MESSAGE	+	~	-	+	+	+	+	+	+	~	+	+	+	~
TROPOS	+	-	-	+	~	~	~	-	+	-	~	+	+	-
Prometheus	+	~	+	~	~	-	+	-	+	-	~	+	-	-
INGENIAS	+	+	~	+	+	+	~	+	+	~	+	+	+	~
SODA	+	-	-	~	+	+	+	-	+	-	-	+	-	-
PASSI 2	+	~	-	~	+	+	~	-	-	~	~	~	-	-
ASPECS	+	-	-	+	~	+	~	-	+	-	+	+	-	+
MOBMAS	+	-	-	~	+	~	+	-	+	-	-	+	-	-

Notation: + High; ~ Medium; - Low

B. Discussion

The analysis of Table III allows extracting some important conclusions related to the adoption of AOSE to develop CPPS. In the *CPPS Minimal Attributes* (R1), the area of interest covered by the Independence architecture model requirement (R1.1) is entirely covered. However, on the same item, there is a little coverage of the *ISA 95 Levels* for vertical integration automation (R1.3). It means that AOSE methodologies must help to increment integration of separate system components regardless of their location in a plant hierarchy (or global context of ISA level).

The second general distinctive is that *Intelligent Characteristics* requirement (R2) has coverage satisfactorily. However, *Pro-activity* requirement (R2.4) is not available for many AOSE yet. It is necessary to consider improving AOSE technologies to have skills with more initiatives achieving their assigned goal.

In the same line, there is good coverage in the *Formalized Modeling Terms* requirement (R3) for AOSE methodologies. Conversely, there is low *Level of Abstraction for an Overview* element (R3.2); then, AOSE requires a different development formal method, bottom-up and top-down depending on the degree being formed.

Another observation is that *Systems and Human Integration Needs* (R4) are the least covered because main parts of this specification are not included yet. In fact, both *Hybrid Topologies* (R4.2) and the *Social Norms Considering Human Factors* needs (R4.3) are weak in the selected AOSE methodologies. That can be given by the complexity of human behavior and its corresponding integration into the manufacturing system in a predictable way.

At last, an essential issue when reviewing the selected AOSE methodologies for CPPS is that the majority group show at least 50% coverage of the requirements (R1-R4), on average. Nevertheless, there are some requirements (R1.3, R3.2, and R4.3) that need urgent attention since they are not considered by most of the AOSE methodologies.

In summary, it is important to note from Table III that we can conclude the adoption of AOSE to apply CPPS combined with other approaches with different architectures, methodologies, and international standards could improve all the coverage of requirements from section III.

VI. CONCLUSION AND ROADMAP

The comparison reported in this paper analyzes the combined strength of approaches for implementing CPS in manufacturing. As contained in the context, a CPPS could be considered as a system of multiple agents with a precise technique called MAS or hybrid HMAS. CPPS would have better flexibility, adaptability, and proactivity due to agent-based negotiation and holarchies. In the MAS approach, essential issues to be applied on CPPS are AOSE methodologies. Future work could address the main AOSE benefits and problems for CPPS and extend this to evaluate results through metrics. Metrics are crucial to obtain benefits with clearness and to compare offers from different CPPS providers. For example, flexibility is one of the upper goals of CPPS, and it will require metrics to estimate reliable results.

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