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A Semantic Model for Cyber-physical production system inspired from Current developments

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Abstract – Cyber-Physical system (CPS) is a coupling of physical and cyber components with a networked intertwined connection. It involves computational elements able to operate on different scales and interact with each other when a change in context occurs. CPS applications for production are termed Cyber-physical production systems (CPPS). It is a new and foreseeable development, whose degrees of integration has reached a self-deciding function possible in production and reflects the industry 4.0 production paradigm. There is a need of modeling approaches to manage complexities, structural opacities and provide a common understanding of CPPS. This paper addresses the semantic understandings of CPPS inspired by the current developments; it classifies the involved entities and illustrates the relations on different aspects. This will serve as a foundation for CPPS, in particular, by helping to understand the structural ambiguity. The real LS2N-CPPS is a supporting use-case of this research work.

Keywords – Cyber-physical production system (CPPS), Semantic models, Smart machines and products.

1 INTRODUCTION

Industries rely on digital transformation and emergent technologies to have flexible and efficient processes. Cyber-Physical System (CPS) is an enabler for the revolution 4.0. CPS is a coupling of physical and cyber components with networked connections. It involves computational elements able to operate on different scales and interact with each other when a change in context occurs [Chen, 2017]. The main capabilities involve computation, communication, and control. CPS applications for production are termed Cyber-Physical production systems (CPPS). [Monostori et al., 2016] defined that the CPPS systems are autonomous and cooperative elements connecting in situation-dependent ways, on and across all production levels, from machines up to production and logistics networks. It enhances the decision-making processes, response to unforeseen conditions in real-time. The basic functionalities of CPPS are Connectedness, Responsiveness, and Intelligence [Cardin, 2019] (See figure 1).

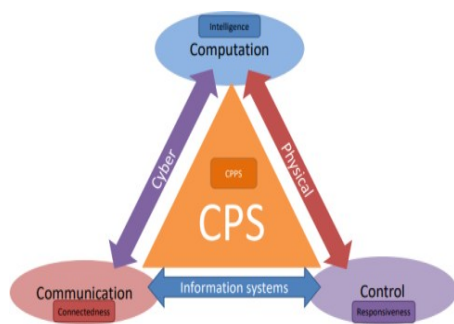


Fig.1 Capabilities of CPS and analogy to CPPS [Cardin, 2019]

The key characteristics of CPPS are modular, reconfigurable and networked system. It enhances the communication between the machines, people, and products in the ecosystem.

The key capabilities are, 1) Self-sensing: they are equipped to capture data and critical information from the environment involving product, quality, materials, machines etc. 2) Self-deciding: they can take data-driven decision in manufacturing, including the identification, collection, communication, analysis and learning the system by themselves. 3) Self-adapting: they adapt to changes in real market demands.

In addition, the system has modernized controlling capabilities, which are decentralized and centralized system [Weyrich et al., 2017]. The centralized level implies the availability of a single or few entities that have control over the entire network. It includes common PLC's, drive controllers, Industrial PC able to provide the highest performance on the top level. The decentralized level implies that single entities may control themselves. It includes plug and plays principles, HMI enable the decentralized control [Gronau et Theuer, 2016].

From the different dimensions of current developments, the CPPS learning system illustrates the smart production paradigm and thereby redefines numerous areas of modular production system.

From the previous CPPS studies, a lot of CPPS research challenges, capabilities, classification, and characteristics are discussed but there is a lack of studies on common understandings, their involved entities and relations. There is a need of semantic understandings on CPPS, their involved entities and the relations that enable them to address the system structural ambiguity and manage system complexity.

This paper is structured as follows: section 2 describes the

related works on CPPS and their current developments, section 3 describes the proposition: the identified entities and semantic models. Section 4 presents an application of semantic models on LS2N- Cyber-physical Production system, which is the use- case of this research work. Conclusions are drawn in section 5.

2 STATE OF THE ART

CPPS Semantic architectures related works and current developments are specified in this section. [Darwish et Hassani, 2018] specifies the key aspects of CPPS and architecture for CPPS. The study doesn't illustrate the entities and the interconnections. [Tomiyama et Moyon, 2018] presents a resilient architecture to handle the event-driven process. The architecture concerns only limited entities and their relationships. [Sánchez et al., 2016] presented a CPS-based process control solution for smart manufacturing by focusing on underlying architectures and services. The study does not stress all aspects involved in the system. [Agostino et al, 2018] develops CPPS architectures, which assist in integrating data collection and feedback systems. The study focuses on sensors and data processing elements leaving out the entities. [Gronau et Theuer, 2016] proposed a hybrid architecture approach to stimulate the various degree of autonomy of CPPS. They stress that common CPPS modeling approaches are necessary to depict a wide variety of production processes with different production. [Cardin, 2019], specified that current Cyber-physical production system (CPPS) applications are in different categories which include, 1) Cyber-Physical production (Learning) system 2) Lab XP and 3) Industrial CPPS system. Next section shows the identified involved elements of CPPS.

3 IDENTIFIED ELEMENTS AND PROPOSED SEMANTIC MODEL OF CPPS

3.1 Identified involved Elements

In this section, we showed the identified levels and elements of CPPS. [Zamfirescu et al, 2014] shows the distinguished guide and exclusive nature of cyber-physical system and their abstraction levels. The levels include "cyber", "physical" and "feedback computations". It poses an exclusive nature and structural view of the Cyber-Physical system. His Cyber-Physical system reference framework model helps us to differentiate abstract levels of the system. By using the current CPPS classification 1) CPPS- learning system, 2) Lab XP CPPS system, 3) Industrial CPPS System on structural basis, we classify each abstraction levels of CPPS [Puviyarasu S. A et al, 2020].

The different levels of abstraction include "cyber level", "physical level" and "link level" as a natural abstraction. This abstraction poses the standard structure and functionalities of the system. Furthermore, the system has its additional abstraction: humans intervene to make informed decisions and perform production tasks. So, we define the additional abstraction levels as "Human-machine agents" and "Operators". In addition, the CPPS system supports the external system to coordinate and influence the external system service to perform. So, we add the level "External system infrastructure". As of the currently developed systems, the CPPS is influenced directly or indirectly by other systems like transportation, miscellaneous activities etc. So, we define the abstraction

level "Support system". This abstraction is a supplement from the current development. These above abstraction levels are considered generic categories, which helps structure the CPPS and identify the entities involved in each level.

The next section shows the account of each of the 7 abstraction levels and their descriptions. Then, the relation between the identified entities and layers is illustrated.

3.2 Abstraction levels description

3.2.1 Cyber parts/layer

We define "Cyber part/layer" as the level that refers to intangible components. It encompasses the hardware, software that helps store data, analyze, process, collect, control, and actuate the information within the CPPS ecosystem. The Cyber layer acts as a central medium in the system that pushes each connected entity to enable the task. It connects people, product and production system.

Other authors may use "Cyber layer", "Cyber and network layer", "Cyber stack", "Cyber technologies", "Cyber components", "Virtual world", Network world", "Cyber world".

3.2.2 Physical parts/layer

The Physical Parts/layer refers to all tangible components that actively or passively participate in the production process to add value. In CPPS, the machine components and physical product components are referred to in the physical layer. It comprises raw materials and machines physical object that forms an integral part to produce tangible asset.

Other authors may use "Physical layer", "Physical Stack", "Physical components", "Real-world", "Physical part" [Bocciarelli et al, 2017].

3.2.3 Linking parts/layer

The Linking Parts/layer refers to the elements connecting or intersecting two things, in particular to combine the real and virtual world of production. Linking components, "Interfacing components", "combined layer", "Link layer" are the other terms used in the literature [Akanmu et al, 2012].

3.2.4 Human-machine agent parts/layer

Human-machine agent layer refers to the elements that enable operators to manage industrial and process control machinery via a computer-based user interface. From the current developments, the human-machine agents feature a component of a certain device, or software application that enables humans to engage and interact with machines [Weyrich et al., 2017].

3.2.5 Operator's layer

An operator is an individual who operates the equipment or machine in the factory in order to perform a global task. In currently developed systems, there is a need for human intervention to make decisions. We define this layer to encompass the human in the loop with production entities. There are three different modes of operation where the interaction between humans and the inner system (CPPS) occurs. The modes are centralized, decentralized, and hybrid scenarios. In current developments, this abstraction provides the necessary freedom to act in the ecosystem. In the next section, the semantic model for CPPS is illustrated.

3.2.6 Support system layer

The support system defines the system inside the system of interest (SOI) boundaries like transportation, miscellaneous system, etc., directly or indirectly influencing the CPPS.

3.2.7 External system and Infrastructure layer

External system and infrastructure layer specifies the external elements that interact with the Cyber-physical production system. As of the current developments, CPPS connects with external system such as other partner facility, ERP, transportation system and other Enabling system.

3.3 Proposed generic semantic model for CPPS

Semantics is the study of meaning in programming languages, formal logic, and semiotics. It focuses on the various representational theories of coherence and correspondence meaning [Lappin et Fox, 2015].

Semantic models are used to represent a knowledge model with the core content of the domain and set of relations. It contributes to understanding the whole problem of interest. It also supports the process of interrelating information and systems from diverse sources. It facilitates communication between the interested parties. The commonly used modeling languages are unified modeling language (UML), System Modelling Language (SYSML), XML, and Automation ML.

UML modeling is appropriate for modeling the structure of the system [Rumbaugh et al, 2000]. The class diagram is a container for many attributes, objects that share specific semantics, relations, and behaviors. In this work, UML model language is used to represent the semantics of the cyber-physical production system, involved entities, and their relations.

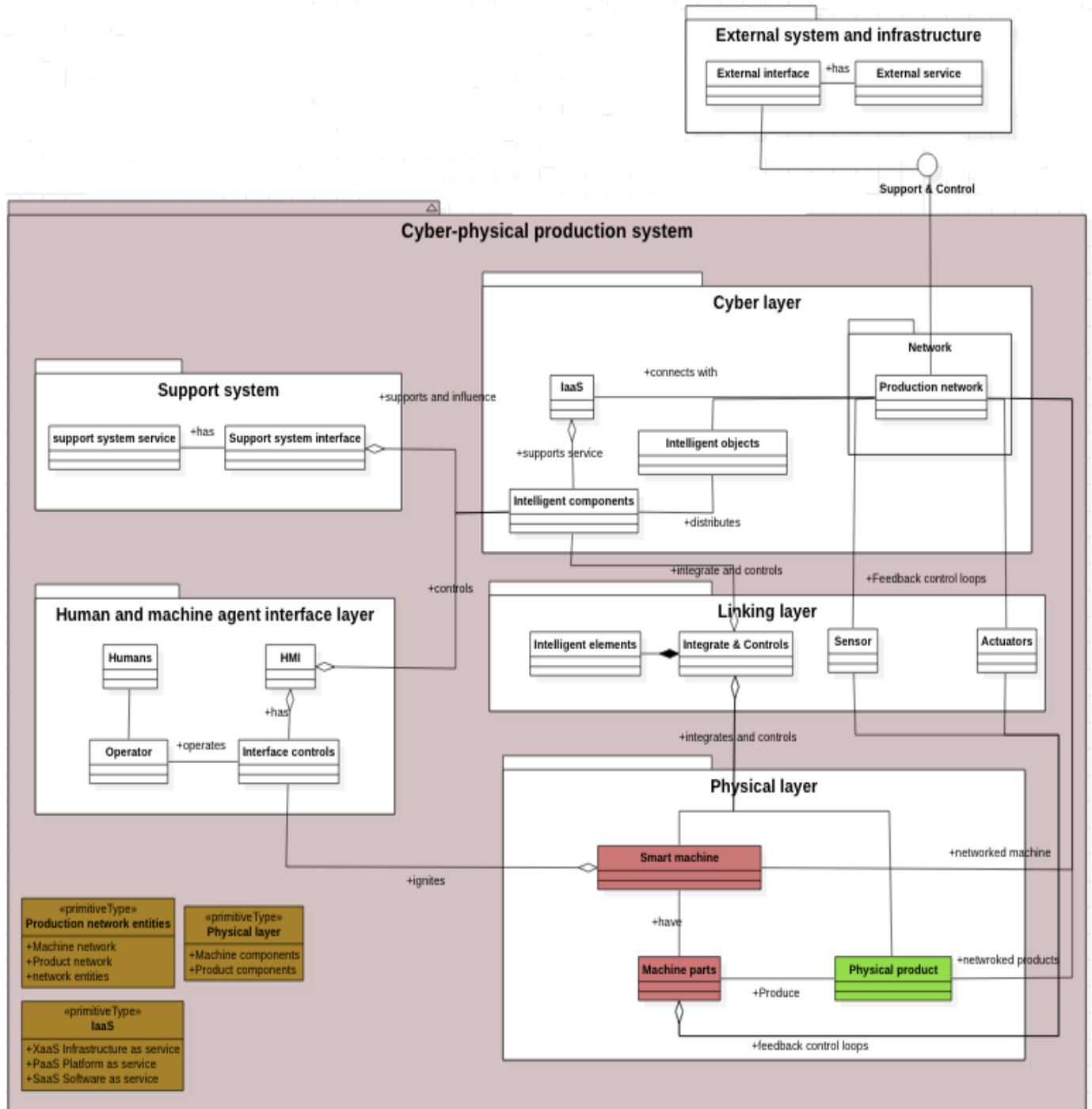


Fig.2. Proposed Generic Semantic model for CPPS

Figure 2 illustrates the generic semantic model of CPPS and their relations. The UML model is spitted into seven packaging syntax, using the previously presented layers (cf. section 3.2), the human layer is not represented in the figure. The Entities and their relations are specified in the classes' syntax.

Cyber layer- We define “intelligent object” and “Intelligent component” as a software system that makes its pre-cause in its capabilities. It controls, and adapts its environments concerning the operator’s need. It acts both autonomously and together with humans. It is a goal-oriented component; it has the capability of diagnosis and machine learning, where it enables adaptation of the changes in the Production environment. The intelligence is connected directly with the support system of HMI Agent and network entities in the ecosystem to perform a task.

“IaaS” (Infrastructure as a service) provides services, stores, access and controls the data through the internet to the system. The main services offered in the components are SaaS (Software as service), PaaS (Platform as service) and XaaS (Infrastructure as service). It assists in sharing services in large numbers in the ecosystem. IaaS has a parent-child relationship to “intelligent object” in the cyber layer to support service and has a direct association with the production network.

Network layer- “Production Network” defines the networking of hardware and software components of the system. It supports and communicates between the product, production and people in the eco-system. It includes the interactions with the operators, but it excludes the human-machine interface layers.

The “Production network” has the association link with different levels of the system. In the cyber level, “Intelligent objects” and “IaaS” have collaborative relations and enhance the communication between the software entities. In the linking level, the feedback control loop of cyber and physical layer has the networking communication through sensors and actuators. In physical level, the “smart through sensors and actuators. In physical level, the “Smart machine” and product component” have the networking connection and association with its entities.

In Human-machine agent layer we define the “Support system”, and “HMI” which helps to interact with the individuals. Such interaction comprises factory workers on a specific task and their applications with machine agents. It aggregates “intelligent component” of cyber level and “machine components” of physical level to have inbound services.

For Operator layer we define “individuals” as human workers whose intervention to make decisions on their desired modes whereas centralized, decentralized, and hybrid scenarios.

In Support system layer we define “system Assistance” which is a system of systems like transportation, miscellaneous system etc. which influences directly or indirectly the CPPS. This abstraction level is the supplement from the current development inside the CPPS ecosystem.

In External system and infrastructure layer, this layer's corresponds to external system. From the current developments, CPPS connects with external system and provides its support. The external system can be Partner facilities and other Enabling systems like Warehouse facilities, transportation system, etc. So, we define “External interface” and “External service” where the CPPS supports, control and shares their service directly or indirectly influenced to the external system.

4 APPLICATION SEMANTIC MODEL OF CPPS

In this section, we have applied the generic semantic model of CPPS on a specific example. We have chosen the Application magazine machine from the CPPS-Learning system of Laboratory of digital science of Nantes (LS2N), France. It clarifies the semantic understandings of Magazine machine, involved entities, and their relations aspects.

4.1 LS2N CPPS- Learning system

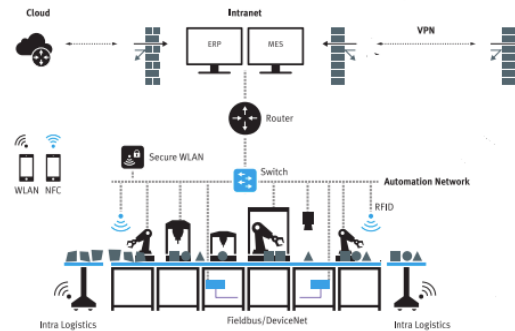


Fig.3 Schematic representation of LS2N-CPPS learning system [Festo-didactic, CP Factory, 2017]

LS2N test-bed is a CPP learning system (see fig. 3.), merging modernized ICT technologies with traditional industrial processes. It is an assembly production line.

This CPPS learning system assembles mobile phone cases from covers, PCB and fuses. The product portfolio is quite large; indeed aesthetic customization is possible: based on customer needs, covers' shapes and color can be modified.

The system has a centralized control with MES (Manufacturing Execution system) to plan the production. Once the customer order is launched, the assembly is product-driven: the workpiece support is equipped with an RFID (Radio-frequency Identification) tag containing the customized product routing. Each application machine can retrieve the order and execute the relevant processing jobs. Once the job is done, data about the executed operations is also written in the RFID and send to the MES. The states of the different machines are communicated to the MES using a local wi-fi network.

- The system has great edibility by combining different machine in different configuration. Each application machine has a standard interface which allows the modules to be interchanged in just few minutes.

- Material transportation is automated: a conveyor belt links nearby machines and an autonomous mobile robot transits between distant machines.

- Different modules enable warehousing: both for parts and finished products.

- Each module can act on manual mode (local control by a human through a HMI panel) or automatic mode (actions triggered by products' routings).

- The actual operations on the machine are controlled by OPC-UA.

4.2 Application magazine machine (LS2N)

The Application Magazine Machine (see fig 4) is a comprehensive modular and expandable system. It is used to store the top cover part in storage rack and assemble it on the mobile phone.



Fig 4.LS2N- Application Magazine machine (CPPS)

4.3 Semantic model of Application magazine machine-LS2N

In this section, we instantiate the generic model described in section 3 on the magazine machine (See figure. 5). In the cyber layer, the “IaaS” is a cyber-infrastructure component that provides the services in the cyber layer. Only the main cyber-infrastructure “IaaS” component is specified in this section. For Magazine machine, the main infrastructure component are

- 1) MES (Manufacturing execution system) software which provides the service of assembly machine to track and document the transformation of raw material to finished product.

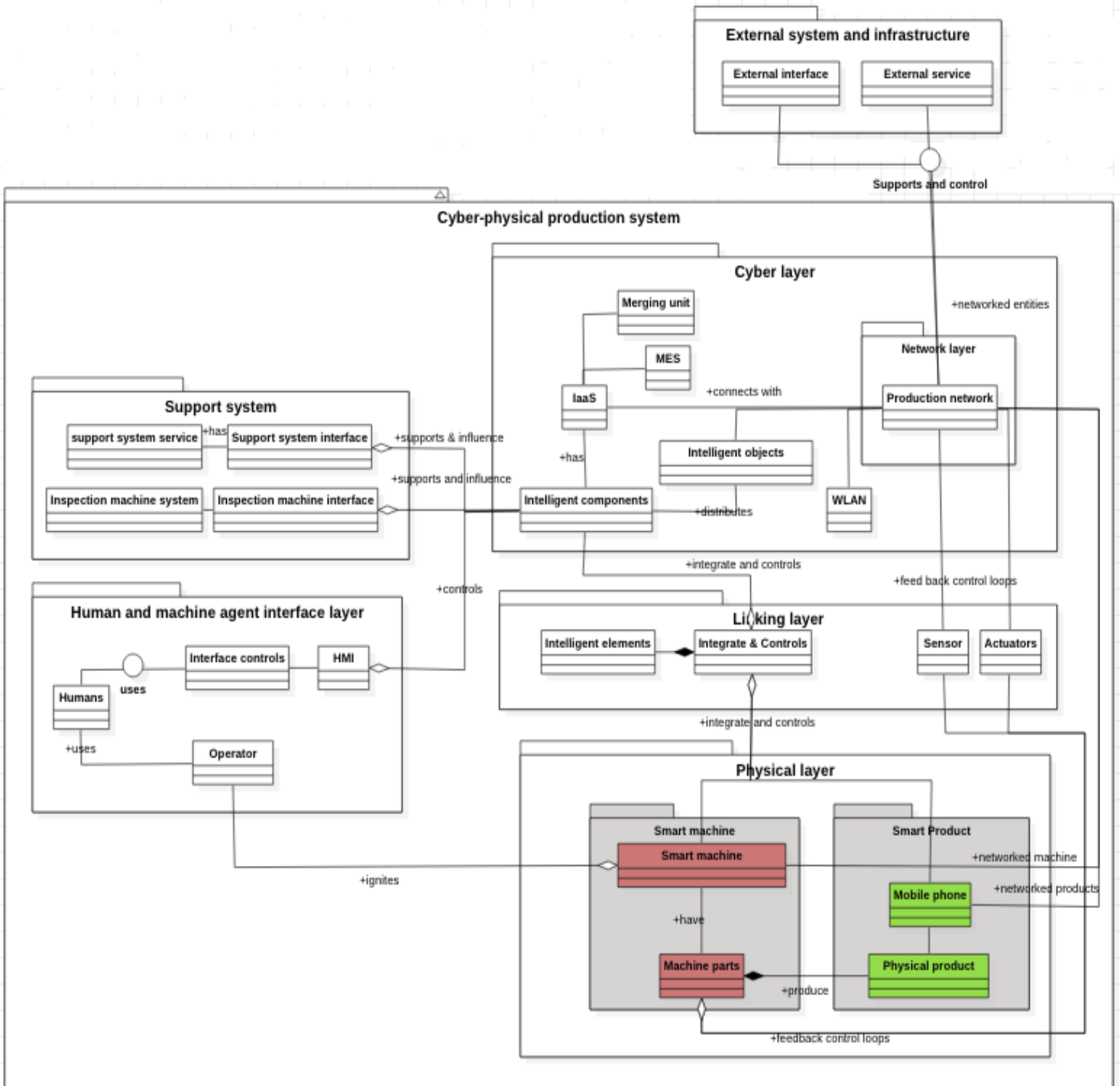


Fig 5. LS2N-Application magazine machine Semantic model (CPPS)

2) Cyber Merging Units- It is an integral unit in the cyber-infrastructure which is fulfilling the task of controlling and monitoring the top cover assembly part and collecting the data via the Ethernet network.

The Syslink connectors help to control its behavior and adapts to the changing environments. It acts both autonomously and together with humans.

The router defines the global networking of hardware and software components of the LS2N-CPP Learning system with help of WLAN automation network.

In the linking layer, the “intertwined magazine objects”- valve In/Op terminal, connect the real and virtual world of the magazine machine. It actuates the machine to perform a task based on magazine machine operation mode (manual or automatic).

In the physical layer, we find the physical tangible machine parts. In this layer is the RFID reader/writer tag which retrieves the information of the product and then writes the data describing the jobs done on each workpiece.

The Magazine Cylinders are “Machine parts” that help to store and separate the workpiece. Value terminal and magazine slot physical part help to assembly the “Top cover part”- Mobile phone. The Magazine machine transforms the semi-finished mobile phone into top-cover part assembled mobile phone.

The “machine parts” of magazine machine has a composition link with “Top cover part” workpiece.

The human-machine interface agent layer is composed of the control panel and power. When individual operators use the machine, they use power switches to ignite, and control panel to control and set the parameters of the Magazine machine.

The support system of the mobile assembly machine contains the transportation devices: the conveyor belt and a “mobile robot system”- which helps to transport the product from one station to another.

External system infrastructure layer- The external system of the Magazine machine is the Warehouse facilities –This Warehouse facilities allows the Assembled finished product to be stores. The Magazine machines provide the service of storing the top cover mobile case product directly to the external system.

5 CONCLUSION

The paper proposes a semantic model for the Cyber-Physical production system (CPPS) inspired by the current developments. It fills literature gaps. It clarifies the semantic understandings of CPPS, involved entities, and their relations aspects. The work lays a foundation for managing system complexity and understanding the structural ambiguity. The instantiation of the generic model on a real test-bed prove its applicability. Further research should consider application on industrial systems.

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