# Enabling Cyber-Physical Systems for Industry 4.0 operations: A Service Science Perspective

**Agostinho da Silva, Andreia Dionísio, Isabel Almeida**

***Abstract*: Based on the Internet of Things (IoT) and Smart Technologies, manufacturing industries are witnessing the fourth Industrial Revolution, the Industry 4.0 (I4.0), and digital transformation is a keystone in this change. Cyber-Physical Systems (CPS) are strategic in thoroughly digitalizing companies, and I4.0 operations depend on CPS efficiency. Digital plants are held by digital technologies that provide excellent tools for improving product security and supply chain security but requires structured information management to maintain the CPS in its highest level of efficiency. These systems are overly complex and hard to handle when several CPS need to be combined as in a large factory, where several machines must work together to achieve a common goal. This research addresses these issues, and we propose an information management framework of industrial CPS that, towards the industrial efficiency, affords an increase in value for all stakeholders. The framework structures the information through the introduction of two innovative value co-creation concepts: (i) Fingerprint (FP-I4.0), a virtual vehicle that can carry two types of structured information and (ii) Cockpit4.0, an interaction entity between the various service systems, applied from cradle-to-cradle. Validated through the Service Science Theory, we conclude that the proposed empirical framework may boost up CPS efficiency and, from it, I4.0 operations will be more effective.***

***Keywords*: Industry 4.0, Cyber-Physical Systems, Smart Objects, Service Science, Service System**

## I. INTRODUCTION

Industrial revolutions have always been characterized by features related to brand new technologies that rapidly change in a significant way the paradigm of industrial forms of production and cause economic and social phenomena that deeply and significantly change humanity. Some authors describe the fourth industrial revolution as the era of digitization or Industry 4.0 (I4.0). This paradigm shift is possible due firstly to the explosive growth of Industrial Technology and Information and Communications Technology (ICT) in recent decades and due to the continued work of industry to implement and promote them. The fourth industrial revolution combines physical systems, digital systems, and biological systems into an intelligent production network in which different components interact and work together, changing the way we look at the world.

IoT illustrates the digitization of Industrial Systems and Processes, Products, and Supply Chains [1]. It also addresses the inevitability of communications via the Internet – the Internet of Things (IoT) and Internet of Services (IS) – to achieve the best flexibility and individuality of production processes. Thus, I4.0 is the result of advanced technologies that make solutions flexible, intelligent, and completely independent.

The growing interconnection between the physical and the cyber world is becoming a central feature of the modern economy [2] nowadays. The term I4.0 has attracted the attention of several stakeholders: the ones related to the industry, as well as governments and academics [3]. It seems to identify a modern collaborative form of production [4], supported by the interconnection of digital technologies, such as the IoT, Big Data, additive production, artificial intelligence, among others technologies. This interconnection of systems is generally called a Cyber-Physical System (CPS). It is usually defined as transformative technologies that manage interconnected systems between their physical resources and computational skills [5]. Given recent developments that have led to an increase in the availability and accessibility of available sensors, data acquisition systems and machine networks, the cutthroat nature of today's industry forces more plants to move on the way to high-tech methodologies implementation. Therefore, the increasing use of sensors and machines in a network allows the continuous production of a large amount of data, the Big Data [6]. Against this backdrop, and to achieve the goal of intelligent, resilient, scalable, and self-adaptable machines, CPS can be further developed through an optimized machines network and improved Big Data management [7].

The incorporation of CPS into production, logistics and services in modern industrial procedures is generally perceived to operate correctly to transform today's factories into an "Industry 4.0" plant with substantial economic potential [8]. However, in a factory operating in I4.0 mode, the volume of information, complexity, and interpretation in real-time can reduce the efficiency of the Cyber-Physical System, and this is a problem that needs to be addressed. From this CPS efficiency reduction, the following research question arises: *What information management model must be adopted to increase the CPS effectiveness*?

Service Science (S|S) is an emerging and transdisciplinary scientific area that uses abstract entities, called Service Systems, as the object of study.

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Based on the description of the resources of the service systems entities, as well as their interactions and outcomes, S|S aims to find mechanisms that explain the evolution of interactions and their co-creation of value [9]. From the research problem stated above and supported by the Service Science Body of Knowledge, this research aims to conceptualize an empirical framework, for information management towards the Cyber-Physical System efficiency. With this framework it will be possible to achieve a higher CPS effectiveness, providing an increase in value for all stakeholders.

The remainder of the study is organized as follows: Section 2 describes the basic concepts related to the I4.0 mode of operation. Section 3 defines Service Science (S|S) concepts and principles. Section 4 details the I4.0 under the Service Science lens. The result of this review is presented an empirical model that improves the information management towards the Cyber-Physical System effectiveness, providing an increase in value for all stakeholders. Finally, Section 5 summarizes and describes the significance of the present study, presenting suggestions for future research.

## II. Basic Concepts

### A. Production in the Digital Age

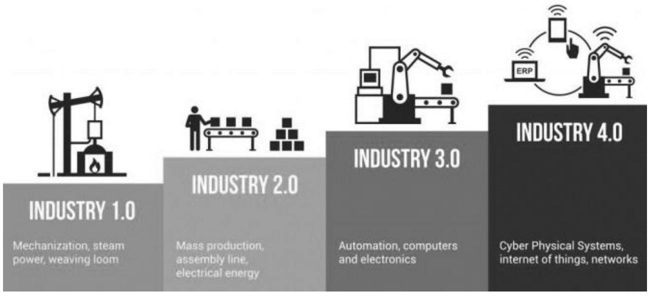


**Fig. 1. The four Industrial revolutions (Pouspourika, 2019).**

Today, we are witnessing an industry effort to produce customized goods, while at the same time, the lifespan gets shorter [3]. The increasing variability of industry capacity, with the consequent increase in market volatility, has led many observers, such as [10] to believe that Industry is on the Fourth Technological Paradigm, whose main characteristics are in (Table 1), presented hereafter. Nonetheless, the digitalization of production processes, combined with the widespread use of the Internet drives now this paradigm. A brief comparison between Industry 4.0 factories and the three previous industrial revolutions is presented in Fig. 1.

### B. Industry 4.0 Operations

**Table 1 – Dimensions of the Industrial Revolutions**

| INDUSTRIAL REVOLUTIONS | TECHNOLOGIC DRIVER | ECONOMY DIMENSION | MARKET DIMENSION | INDUSTRIAL DIMENSION | LANDSCAPE DIMENSION |
|---|---|---|---|---|---|
| 1st Industrial Revolution | Steam engine | Volume | Consumption habits | Mechanization | Mechanical workshops |
| 2nd Industrial Revolution | Electricity | Volume & Efficiency | Price | Production lines | Factories |
| 3rd Industrial Revolution | Computers & robots | Volume & Efficiency & Flexibility | Variety | Automatization | Industrial districts |
| 4th Industrial Revolution | Digital technologies | Volume & Efficiency & Flexibility & Collaboration | Personalization | Cyber-physical systems | Digital factories & Workshops |

The term I4.0 became popular among academics, practitioners and authorities as to the combination and integration of digital technologies such as advanced robotics, artificial intelligence, sensors, cloud computing, IoT, analysis and sorting of Big Data, augmented reality, additive production and mobile devices [11], among other digital technologies, into an interoperable and shareable global value chain, regardless of geographical space [12].

Most of these technologies have been available since the late 20th century, they have been created by manufacturers regardless of integration by users. A new purpose in I4.0 is, therefore, the interaction and communication of all these technologies with products resulting from their operations. [13]. Referring back to Kropotkin's (1902) experiments, for whom evolution depends on the level of collaboration [14], once digitally linked, these technologies bring the physical world and the virtual world together and enable the production and change of management from organizations worldwide.

In I4.0 mode, a Cyber-Physical System (CPS) merges the physical environment with the digital one [15]. Products begin as a kind of co-created "digital DNA" that transforms itself in intelligent objects and then becomes physical during the production process until they are sent to the consumer [16]. In this operations approach, product design and development tend to occur in virtual laboratories using customers as co-creators and move to digital manufacturing, where the products themselves are created through interaction with production methods. [17]. The network of machines which constitute the basis of the I4.0 factory floor will thus tend to become a "conscious" and flexible systems, responding quickly, not only to human commands but also to their perceptions transmitted through the interaction with the objects being manufactured. Analysing some practical cases [18], most companies focus on I4.0 to gain flexibility in production and to be able to adapt it for mass-produce customization.

Considering that we are transitioning to the Fourth Industrial Era, we can expect that as more companies gain competitiveness and sustainability in their businesses through I4.0, a mobilising effect will be seen not only in industry but also in services (Table 1).

Therefore, a new generation of factories is arising in which the CPSs are a support production. These are the so-called "Smart Factories of the Internet of Things" [17] also known as "digital factories" [19] whose objective is to maximize flexibility while maintaining efficiency [20]. For this new concept, called Smart Production, to be effective, some authors believe there must be performance simulation tools in upstream production, thus safeguarding the risk associated with physical experimentation in real-time [21]. The reorganization of the production processes resulting from this production concept will have different effects in each company, since each one has to interpret and adapt the specific profile and resources and adapt them to concepts related to I4.0, including IoT, CPSs and Big Data, among others.

While Big Data offers a ton of benefits, it comes with its own set of issues. The widespread use of sensory media, the expansion of wireless Internet networks and the development of increasingly smart robotic systems, as growing computing power becomes less expensive, causes a continual rise of information.

With a new set of sophisticated technologies and others still in the nascent stages of development and evolution, Data volumes are expected to be overwhelmed, thus transforming the production of goods in Europe and the rest of the world. From a holistic perspective, the I4.0 concept will incorporate many other concepts, that are sometimes difficult to describe individually. As an example, the smart object concept [22], or the sensory network associated with products and means of production, integrated into CPSs, as well as sending, receiving and processing of information, to make autonomous decisions based on digitalization and previous simulations of the product models [23].

## III. SERVICE SCIENCE (S|S)

From very early on, Service-Dominant Logic (SDL) [24] is identified as the philosophical foundation for Service Science (S|S). It is a transdisciplinary approach based on symbolic processes that adaptively compute the value of interactions between service-systems [25] as depicted in Fig. 2. Scientific discipline is a set of methods and standards, accepted and used by a community, to develop a Body of Knowledge that explains and typifies observable global phenomena. Thus, it was necessary to attribute to S|S the conceptual structures, theories, models, and laws that could not only be empirically tested but also applied for the benefit of society. In this context, the foremost advocates of S|S, [9], considered that S|S must be viewed as a scientific field under construction, for which the Body of Knowledge would emerge slowly but with the challenge of becoming genuinely interdisciplinary.

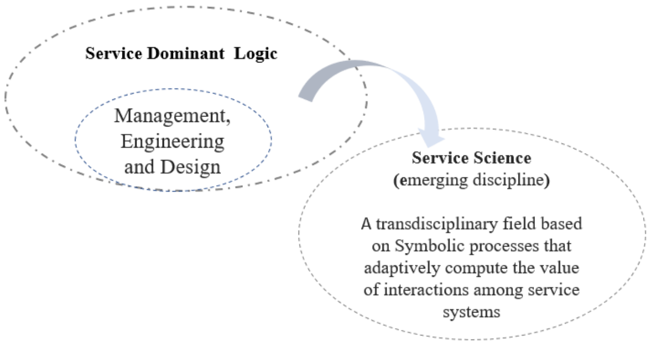


**Fig. 2. Service-Dominant Logic as the philosophical foundation for Service Science, with service-system as a basic theoretical construct.**

Considering SDL philosophical principles, Service Science places the Sustainability of the Planet as a cross-cutting concern that must be present in the exchange of services between stakeholders [26]. The symbolic processes that adaptively compute the value of interactions between service systems are the basis of Service Science [27], as shown in Fig. 2.

### A. The Fundamental Concepts of S|S

The literature review revealed that the process of creating the Theoretical Body of S|S has evolved from 2008 to the present day.

The literature review revealed that the process of creating the Theoretical Body of S|S has evolved from 2008 to the present day. By incorporating the SDL concepts – such as value co-creation and the integration of resources & services, that form the basis of all exchanges in the SDL mindset – for S|S, all economies have become service economies. At the same time, all companies nowadays being service companies belonging to service ecosystems [28]. This situation extends the scope of service-systems far beyond specific types of industries or services, concepts that no longer exist in SDL. S|S focus the value-creation process underlying all exchanges, finally abandoning the focus on physical resources such as natural resources, buildings, or others [29].

As in SDL, also for S|S the meaning of service cannot be confused with services, that traditionally relate to intangible goods [24]. Moreover, for S|S, the concept of service will become the provision of skills, trust, and knowledge, usable for the benefit of others and the necessary physical things, are seen as simple mechanisms of service provision [30]. This situation illustrates how S|S became the discipline that aims to categorize and explain the various types of service-systems, their interactions, and their effects on value creation. Since not all interactions co-create value, it urges to understand the reasons for these normative deviations [31]. In the case of activities related to the production of tangible goods (industry), increasingly supported by digital technologies common to intangible assets, S|S may become an exciting discipline at several levels. Thus, and particularly in digital plants, the need for new professional profiles is a reality[32]. Those skilful professionals can contribute to making the digital service innovation process more systematic and therefore a better choice of investment and business management [27], [33].

In this context, the following ten fundamental concepts of S|S were published in 2009, as part of its Body of Knowledge [34].

(i) Resources - anything that has a name and can be useful must be considered as a resource. Physical and non-physical things are potentially helpful [35] and framed in four primary types: people, technology, organizations, and shared information [36]; (ii) Service System Entities – the elemental unit of analysis [34] that refers to abstract entities arising from the configuration of people, technologies and other resources that interact with other entities to create mutual value; (iii) Access Rights – as part of a service-system, resources must be accessible to all in the system and allow interaction between two service-systems. Both will have to provide access, directly or indirectly, to the other's resources; (iv) Value-Co-creation Interactions – the mechanisms of value interactions are based on value propositions, intuitively the promises and contracts on which two or more entities agree because they believe that value will result for all entities [37]; (v) Governance Interactions - the notion of governance interactions and the development of more disputed resolution mechanisms is also a challenge for S|S Theory; (vi) Innovation Outcomes - are the result, whose normative or desired value is, of course, the co-creation of positive benefit for all actors [28]. When two or more service-systems interact, the outcome is judged by each stakeholder from their perspective; (vii) Stakeholder Concerns – at each step of the service process, the service-system proposing must put itself in the position of the other stakeholders, including itself, reasoning in terms of concerns about expectations and access to resources; (viii) Measurement - to measure the interests, for the presentation of results to be more coincident with this scientific discipline, the Key Indicators might no longer be referred to as Performance (KPI), to be referred to instead as Key Concern Indicators (KCI), continuing to be quantitative or qualitative and adopting clear names, measured throughout the service process as well as in traditional KPI, to measure their evolution in terms of Innovation Outcomes (IO); (ix) Service Networks - over time, i.e. throughout the co-operative process or service process, routine interactions can be transformed into long-term, mutually beneficial relationships, resulting in authentic service-system networks [27]. In these service-system networks, or only networks, there are also positive aspects from the S|S perspective, thus allowing the share of resources and increasing the capacity of, for example, the investment available to improve these resources [38]; (x) Ecology – the Sustainability of the Planet as well as people's well-being is a concern that must be present in every service-system interaction and therefore must be considered as a concern for all stakeholders when making and assessing a value proposal.

## B. The Principles of S|S

Following the SDL mindset, an economic entity can be a collection of resources – including people, technologies, organizations, and information - as well the service-system, the basic unit of analysis for S|S, with the following four principles:

(i) First S|S Principle – *The service-system entities dynamically configure four types of resources: people, technologies, organizations, and information.* The purpose of economic relations for the SDL mindset is the exchange of service among entities aiming for a reciprocal benefit [24], *i.e.*, for SDL *exchange service for service* [28]. This view of economics contrasts with the perspective of Adam Smith (1776), also referred to as Goods Dominant Logic. The SDL mindset, the products are not the fundamental basis of trade but rather the service, in the form of skills applied to benefit others [24], with each economic entity consisting of a set of operant and operand resources [30]. (ii) Second S|S Principle – *the service-system entities compute value given the concerns of multiple stakeholders.* The value propositions are the basis of relationships between service-systems which, from the S|S perspective, can be understood as a service-system request for another service-system to execute an action. Thus, a value proposition seems to be the primary relationship among service-systems, in the form of service exchange or service interactions [39]. (iii) Third S|S Principle - *the access rights associated with customer and provider resources are reconfigured by mutually agreed to value propositions.* In the traditional view (G-D Logic), the producer is the main actor who produces goods and services and consumers are secondary actors or passive recipients [40]. According to goods-dominant (G-D) logic, the producer is the source of knowledge and creativity, and therefore also the only source of product innovation [38]. (iv) Fourth S|S Principle - *service-system entities compute and coordinate actions with others through symbolic processes of valuing and symbolic methods of communicating* [39]. A symbol represents *a sign* which refers to what the object means by law, generally an association of general ideas, which operates to interpret the symbol as something referring to that object. To conceptualize the market as a system of signals, some authors draw attention to the linguistic conventions of signals (the rules of interpretation). They propose shared images, to constitute the meaning (interpretation) of material objects and realities (signs) in describing the process of communication and exchange of economic value, among actors, in consumption and marketing practices [41].

From the literature review, symbol-systems appear to play an essential role in the co-creation of value in S|S. However, the way symbols influence and are influenced by the adoption of practices in the digital economy, specifically in the I4.0 context, will require a more in-depth analysis starting from a discussion of the reasoned value-creation of SDL. Thus, and in the view of S|S ecosystems, it will be necessary to integrate symbol sets into dynamic ecosystems of service exchanges. In the digital economy, where IoT and I4.0 play an increasingly important role, it will become increasingly motivational to study and integrate the symbols used by cyber-actors. Thus, this will facilitate their understanding, skills, and competences, and develop tools that enable interpretation of cyber-practices, along with the various co-creative steps in which they participate.

# IV. RESULT AND DISCUSSION

## A. *Industry 4.0 through the lens of S|S Enabling a Cyber-Physical System Through S|S*

Applying the S|S Principles to the emergent paradigms of the Fourth Industrial Age, through digital technologies, the cyber-stakeholders (customers and providers) they become part of the Industry 4.0 ecosystem.

Regarding the Third Principle of [42], the stakeholders, when internally reconfigured to acquire capabilities, rights, limitations and responsibilities, may be considered as service-systems in I4.0. Their resources, once mapped by a tool such as service blueprinting, may be subdivided into three complementary groups, in permanent dynamic reconfiguration for value co-creation, as follows:

(i) CPS Front-Office Resource Group - consisting of people and interface technologies, which interact directly with other digital service-systems, providing specialized skills (knowledge and skills) through actions, processes and performance for the benefit of other entities;

(ii) CPS Back-Office Resource Group - consisting of people and technologies that interact directly with Front-Office resources, also providing specialized expertise through actions, processes and performance for the benefit of other entities;

(iii) CPS Support Resource Group - consisting of people, means of production, partners, company management, specific know-how, accounting, marketing, public and private entities, among others, that interact directly or indirectly with all available resources. The CPS supported group also provides specialized expertise through actions, processes, and performance for the benefit of the other entity (Fig. 3).

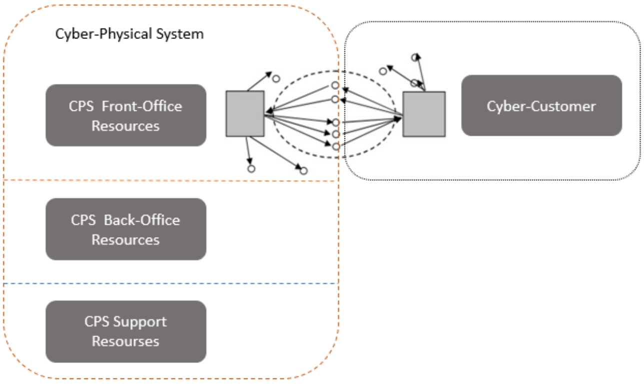


**Fig. 3. Service-system entities compute value given the concerns of multiple stakeholders**

Thus, in digital mode and according to the Third S|S Principle, it is the dynamic configuration of all physical and non-physical resources, with or without rights, that guarantees the existence of digital service interactions with other digital service-systems. This situation allows value co-creation interactions and thus constituting a service process [43], in which the formalization of continuous access rights to resources is one of S|S's purposes.

It is essential to keep in mind that innovation in the traditional concepts of the industry and service sectors is differentiated only by the typology of resources or schemes (norms and rules) or how they are combined. Whereas the fact that Industry 4.0 is related to digital production – supported by CPS as a co-creative innovation enabler of value propositions in the Industry 4.0 environment – we propose a set of approaches resulting from the S|S mindset to facilitate innovation in value propositions between service-systems.

## B. Fingerprint4.0 concept

As described above, in Industry 4.0 operation mode, products start as a single idea evolving into Smart Objects. From this stage, in the CPS, products take on the physical form until they are ready to be shipped to customers [16]. Therefore, to streamlining and transporting the co-created specifications related to the product, the introduction of a new concept, "the Fingerprint4.0" (FP4.0)", maybe considered: a vehicle to carry the value co-created by the service-systems' interaction (customer and provider), and from that into a *Smart Object*. Thus, FP4.0, once generated, may indeed be considered the *Global Outcome* of the service process Phase 1, that is, the phase of product design and deal conclusion (Fig. 4).

The roadmap consisting of successive and co-creative steps during Phase 1 of the service process leads to co-creation of the object's FP4.0. Along the way, this may mean, in some stages of the process, the uploading of specific applications, such as drawing particular geometries of the artefact or others, and in parallel, involving traditional technical-commercial assistance through conventional technologies such as phone or email, to achieve FP4.0 in full.

Fingerprint 4.0 will thus be a kind of cargo vehicle with two compartments for complementary but different contents: (i) the first compartment carries the descriptive content of the specifications of the co-created product, which may include comments, notes, remarks, or other relevant information. (ii) the second compartment, FP4.0 carries the IFC/XML code, as exported by the CPS post-processor, and interpreted by the CPS, from which the Smart Object will be generated.

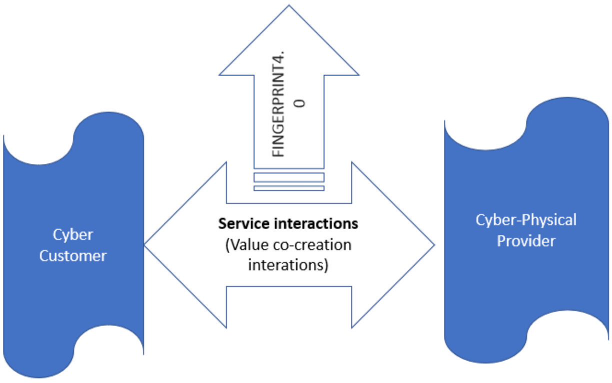


**Fig. 4. Digital Operations Interactions - Fingerprint 4.0 Outcome**

Before accepting the value proposition, the CPS will make the contents of both compartments of FP4.0 available to the customer. It includes the specifications co-created, additional information about the product, such as its ecological footprint, recycling process, associated compliance and any other relevant information for the customer, provider, and authorities. Once the value proposition has been evaluated and confirmed by the customer, CPS will generate the product's Smart Object file.

## C. Cockpit 4.0 concept

According to some authors [44], Smart Objects can be generated automatically, without any human intervention. The feasibility of this level of automation must not be pointed out in simple cases, such as the additive production.

In complex processes, this would make the production process probably too rigid, and thus, contrary to the main objectives of I4.0 operations mode, inhibiting the advantage of providing flexibility to digital production [23].

Is increasing the use of artificial intelligence and algorithms as cognitive assistants, and they are considered essentials in service-systems. However, they are legally unpunishable machines having no rights and duties, so, they cannot, on their own, and for that reason, be considered as service-systems according to S|S. To overcome this limitation, we propose an interface feature within the CPS itself - "Cockpit 4.0" that must be specified: as a humanized interface, Cockpit incorporates resources with rights, and thus acquires the service-system classification through the lens of S|S Theory. With relative autonomy inside the CPS, Cockpit will thus perform the double role of dialogue and interface entity, between the CPS and the cyber client and, on the other hand, the function of dialogue interface entity with the CPS Body as well as with the organization's support resources, such as the company's management. The Cockpit will thus be a virtual feature of the Industry 4.0 operations mode, which will be an integral and fundamental set of resources to enable a Cyber-Physical System to facilitate the innovation of value propositions with cyber-customers.

**D.** *Industry 4.0 Resources*

In the digital market, five complementary and interdependent groups embrace cyber-customer resources:

(i) Frontage Resources - Internet-connected cyber buyer; (ii) Backstage Resources - experts in different fields, from whom the cyber buyer can get advice whenever it seems necessary; (iii) Administration Resources - investor, construction directors, among others; (iv) Partnership Resources - public and private entities related to cyber buyer activity or the company responsible for it; (v) Know-How and Shareable Information Resources | knowledge such as patents, technology transfer, cross-fertilization processes, temporary innovation initiatives, benchmarking information from multiple competitors, other shareable details or documents, among others, related to cyber buyer activity.

In Industry 4.0 operations, resources can be split into interdependent groups such as Cockpit4.0, the CPS Body, Management and Marketing, Support & Partnerships, Know-How & Shareable Information, and Support Technology resources group, among others. Although Cockpit4.0 operates as the CPS front-end, it is not the provider itself, but only a Provider resource, within which there will be people, and for that reason, includes physical resources with rights [27]. When a cyber-physical system provider goes into availability mode to provide a product or a service to a cyber-customer, it becomes a service-system [45] whose resources may be divided into the following ten complementary and interdependent groups:

(i) *Cockpit4.0 Front-Office Human Resources*: physical-with-rights, which include the human resources that interact and collaborate directly with the cyber-customer, such as experts, sales staff and other resources; (ii) *Cockpit4.0 Front-Office Cyber Resources*: not-physical-with-no-rights resources which include cyber media that interact directly with the provider, such as dialogue interface cyber-customer, web-libraries, websites, email, phone and others; (iii) *Cockpit 4.0 Back-Office Human Resources*: human resources that interact and collaborate indirectly with the cyber-customer, including experts in Industry 4.0 & Smart-Objects, which means physical-with-rights; (iv) *Cockpit 4.0 Back-Office Cyber-Physical Resources*: with-no-rights, which include cyber-physical means and therefore end up interacting though indirectly with the cyber-customer, such as the central server, cognitive assistant algorithms, smart object generation algorithms and others; (v) *CPS Body Human Resources*: physical-with-rights resources, maintenance and control of all means of production and logistics of the CPS including operators, technicians and others; (vi) *CPS Body Cyber-Physical Resources*: physical-with-no-rights that support the physical activity of CPS which includes manufacturing equipment and devices; (vii) *Support Partnerships Resources*: not-physical-with-rights resources including public or private entities outside the company, with which it collaborates on a permanent or occasional basis; (viii*) Know-How and Shareable Information Resources*: not-physical-with-no-rights, including specific knowledge that can bring competitive advantages when the value-creation proposal is evaluated, such as patents, technology transfer, cross-fertilization projects, pilot projects, temporary innovation initiatives and other resources; (ix) *Support Technology Resources*: physical-with-no-rights resources including technologies that although traditional are essential to the company's operation; (x) *Management and Marketing*: physical-with-rights including human resources related to the company's managing directors, legacy staff, accounting staff, marketing staff and other resources. The Fig. 5 presents the above ten complementary and interdependent groups in which the service-system resources are classified, concerning S|S and I4.0 operations.

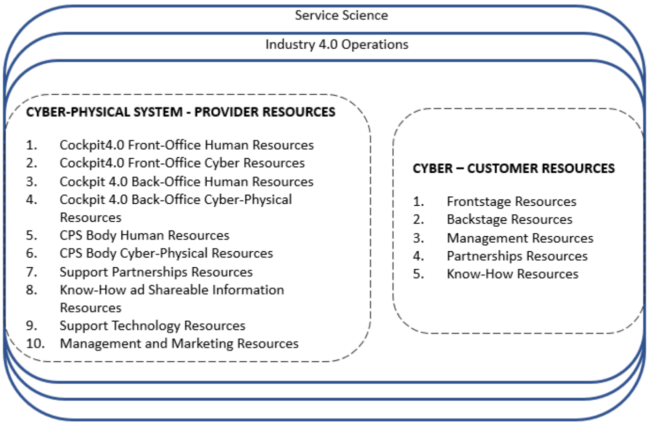


**Fig. 5: Industry 4.0 conceptualization of stakeholders' resources: A S|S perspective**

**E. Enabling a Cyber-Physical System Through S|S**

Through Cockpit4.0, it is possible to guarantee permanent and co-creative interaction with the customer along the entire service process. From the moment the customer intends to buy until the product is recycled, Cockpit resources are also responsible for FP4.0 transforming into a Smart Object. Additionally, both Fingerprint4.0 and Cockpit4.0 are part of the Economical 4.0 value co-creation scenario, namely: (i) Fingerprint4.0 related to information organization and (ii) Cockpit4.0 related to resources organization, enabling in this way the Cyber-Physical System to allow the innovation of value propositions with their cyber-customers.

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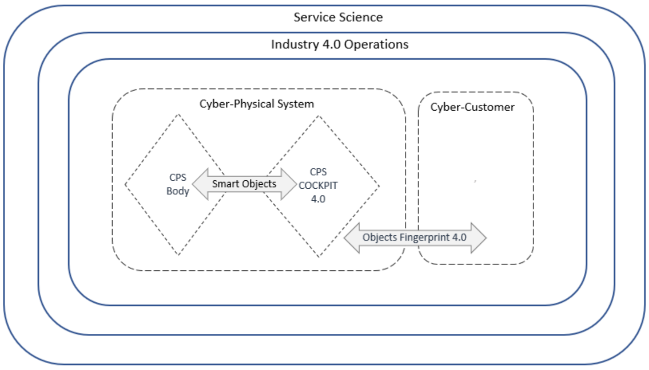


**Fig. 6. Resources and information to enable a CPS**

Moreover, Cockpit4.0 is also the CPS interface resource that interacts with the cyber customer, from the start of FP-I4.0 co-creation until the product-recycling stage (Fig. 6).

## V. CONCLUSIONS

Industry 4.0 mainly consists of two main factors: CPS and the IoT & Services, and the real value of the IoT for manufacturers will be in the analytics arising from cyber-physical models of machines and systems. The companies that are switching to Industry 4.0 to achieve better process efficiency and competitiveness need to be aware of the influences in operational aspects arising with this change, and what the main implications are, as well as the innovation opportunities. A CPS is a smart system that integrates computational and physical systems to manage and recognize the changing state of real-world variables (NIST, 2013). The introduction of CPS in today's factories offers various improvements, particularly in three areas:

- Components (where occurs the conversion of sensory information about critical components into data);
- Machines (extended machine data, such as control parameters, are combined with component information to monitor the status and form cybernetics for each particular machine);
- Production systems (the collected information about components and information at the machine level offers self-configurability and factory maintenance).

However, attention is paid to the successful implementation of the CPS, as: (i) it depends on the existing internet infrastructure of the factories; (ii) is based on a network of reliable, secure sensors and communication technologies; and (iii) depends on the number of machines that must work together to achieve a common goal.

Moreover, producers' competitiveness increasingly depends on the level of collaboration with their (cyber)-clients, leading many of them to migrate the operation of their operations to Industry 4.0 mode.

Supported by Service Science Theory, a model for information management of a Cyber-Physical System is conceptualized in this research, through two new empirical concepts: Cockpit4.0 and Fingerprint4.0 (FP-I4.0):

(1) Cockpit 4.0 - is an entity that interacts with the various service systems throughout the entire service process, i.e., from the beginning of the customer-supplier relationship to the recycling of the product at the end of its service life.

(2) Fingerprint4.0, is a virtual vehicle, with two compartments, for transporting different types of structured information: (i) in the first compartment it carries the descriptive part of the co-created objects, clearly representing the customer's expectations, i.e., what the customer expects to receive from other stakeholders, namely from the supplier, and (ii) the second compartment carries the co-created object code, i.e., the information in a technical format, compatible with the Cyber-Physical System in an open file format. It is from FP-I4.0 that the CPS generates Smart Objects, essential elements to operate in Industry 4.0 mode.

This empirical framework, validated through Service Science Theory, leads us to conclude that once applied to an organization operating in I4.0 mode, it may contribute to its Cyber-Physical System efficiency, thus resulting in increased value for all stakeholders involved in operational terms, during the co-creative process and before the customers accept the value proposition, Cockpit4.0 will generate drafts of FP-I4.0, making them available to the customer. It includes the co-created specifications and concepts, as well as additional information related to product dimensions such as the ecological footprint, the final recycling process, legal aspects and other relevant information for the customer.

Through this innovative framework supported by Service Science, FP-I4.0 becomes the bearer of the collaborative result of the actions between CPS resources and the resources of the cyber-client. The product is elaborated in the fabric floor and from here, Cockpit4.0 sends a Smart-Object, once finished, that will reach the customer. It is expected that each stakeholder makes a different assessment of the value generated. Thus, the concerns of the various stakeholders, in the model presented here, are defined in terms of Indicators of Main Concerns with which it is possible to measure the evolution of the particular concerns (qualitative and quantitative) presented in the form of Innovation Outcomes, as recommended by Service Science.

Addressing the research problem presented in the introduction section, as well as the research question, we can conclude that the use of Cockpit4.0 and Fingerprint4.0 seems to be a useful information management model to increase CPS efficiency.

The research proposed in this article is, therefore, of academic and practical interest. With the choice for Service Science approach provides the Theory and a decisive contribution to the understanding of the value co-creation interactions between actors, the stakeholders, from which we can propose as research a sequential approach, usable for empirical case studies in the context of the digital market. Validated through the Service Science Theory, we assume that the empirical model resulting from this research, when applied to a factory operating in I4.0 mode, can make Cyber-Physical System more efficient, making the operations more effective. Thus, we believe that the objective proposed for this investigation (to design an information management framework of industrial CPS that, allowing a higher CPS efficiency, affords an increase in value for all stakeholders), is successfully reached. The result of this research suggests a practical validation of the model. Thus, as an insight for al for future work, we propose to test of this empirical model in a real case study. The implementation of our model in a real-world situation is also desirable to evaluate the techniques introduced in real-life operational contexts, to refine, improve and determine the practical applicability of the proposal presented in this article.

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