PART III

12

Building an Automation Software Ecosystem on the Top of IEC 61499

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The adoption of Cyber Physical System (CPS) technologies at European level is constrained by a still emerging value chain and by the challenging transformation of manufacturing processes and business ecosystems that their deployment requires. This issue becomes even more challenging when the concept of CPS is exploited to propose cyber-physical machines and manufacturing systems, where the complexity of the controlling intelligence and of the digital counterpart explodes. As a matter of fact, the market behind CPS has a potential that is still scarcely supported by methodologies and tools able to foster the rise of a solid ecosystem required for a relevant market uptake. Multi-sided platforms (MSPs) have demonstrated to play the pivotal role of providing the environments and the technological infrastructures able to match make the needs of manifold user insisting on them. The manufacturing sector did not remain untouched by this trend and moves its first step towards the integration of platform logics across value networks: the CPS business ecosystem is one of those.

In this chapter, beyond an analysis of the current state of the automation value network, the design and implementation of a multi-sided platform for CPS deployment within the automation sector are described. The proposed platform can provide the infrastructure to incentivize CPS adoption, creating the technological and value drivers supporting the transition towards new paradigms for the development of the software components of a mechatronic system. Developing an infrastructure on the top of which the CPS value network can be instantiated and orchestrated, the proposed platform provides the technical means to incentivize the creation of an ecosystem able to support especially SMEs in their transition towards Industry 4.0.

12.1 Introduction

Technological innovation is the main engine behind economic development that aims at supporting companies in adapting to the rhythm of the market dictated by globalization [1, 2]. According to Stal [3], innovation is the development of new methods, devices or machines that could change the way in which things happen. The fourth industrial revolution, pursuing the extensive adoption of innovative technologies and systems, increasingly impact almost every industry. According to Bharadwaj et al. [4], "digital technologies (viewed as combinations of information, computing, communication, and connectivity technologies) are fundamentally transforming business strategies, business processes, firm capabilities, products and services, and key interfirm relationships in extended business networks".

The automation industry has historically a leading role in experimenting and pushing this transformation, with technological and process-related innovation being assimilated all-inclusively across the whole value network [5]. However, the characteristics that the automation market acquired in the last decades, where complex value networks support standard-based technologies relying on legacy systems, make purely technological advancements no more enough to satisfy the need of innovation expressed by the market. As proposed in the Technology-Organization-Environment Framework [6], the propensity of companies towards the adoption of innovations is indeed not only dependent on the technology per se, but it is influenced by the technological context, the organizational context, and the environmental context. The technological context includes the internal and external technologies that are relevant to the firm. The organizational context refers to the characteristics and resources of the firm. The environmental context includes the size and structure of the industry, the firm's competitors, the macroeconomic context, and the regulatory environment [6–8]. These three elements present both constraints and opportunities for technological innovation and influence the way a firm sees the need for, searches for, and adopts new technology [9].

In this context, the European initiative Daedalus supports companies in facing opportunities and challenges of Industry 4.0 starting from the overcoming of the rigid hierarchical levels of the automation pyramid. This is done by supporting CPS orchestration in real time through the IEC-61499 automation language, to achieve complex and optimized behaviors impossible with other current technologies. To do so, it proposes a methodology and the related supporting technologies that, integrated within an "Industry platform[1]" and brought to the market by means of a Digital Marketplace, are meant to foster the evolution of the automation value network. The desired evolution is expected not only to impact on how companies manage their production systems, providing extended functionalities and greater flexibility across the automation pyramid, but also to broadly impact the automation ecosystem, creating and/or improving connections, relationships and value drivers among the automation stakeholders.

In the following sections, the principal characteristics of the current automation domain are analysed by focussing on the stakeholders (hereinafter complementors) that populate the ecosystem and on the structure of the relationships among them. The Daedalus platform is therefore presented by highlighting, beyond technological aspects described in Chapter 5, the value exchanges managed by the digital marketplace. The impact that the creation of such ecosystem has on the complementors is eventually discussed through an analysis of the to-be business networks.

12.2 An Outlook of the Automation Value Network

The automation industry is an interdisciplinary field, which involves a wide variety of tasks, product portfolios (machinery, control, equipment, small elements, etc.), technologies (robotics, software, etc.), standards and services, serving different sectors, with distinct requirements and needs. This environment is populated by many stakeholders, which, through complex and articulated value chains, collaborate to develop complete automation solutions. This section aims to provide an overview of this complex domain,

[1]An industry platform is defined as: foundation technologies or services that are essential for a broader, interdependent ecosystem of businesses [17, 18].

describing its characteristics, its players and the relation that they have established over time.

12.2.1 Characteristics of the Automation Ecosystem Stakeholders

The automation environment is currently populated by several different players, which can be grouped into five macro-categories:

- Component suppliers (CSs);
- Automation solutions providers (ASPs);
- Equipment and machines builders (E&MBs);
- System integrators (SIs);
- Plant owners (POs).

These macro-categories are the most relevant entities concurring in the design and development of industrial automation solutions in which different hardware & software elements, characterized by a high granularity of functionalities and complexity are integrated into the building of complex mechatronic systems. In Figure 12.1, connections, flows, and relationships among those of the automation domain have been thus summarized by providing a general

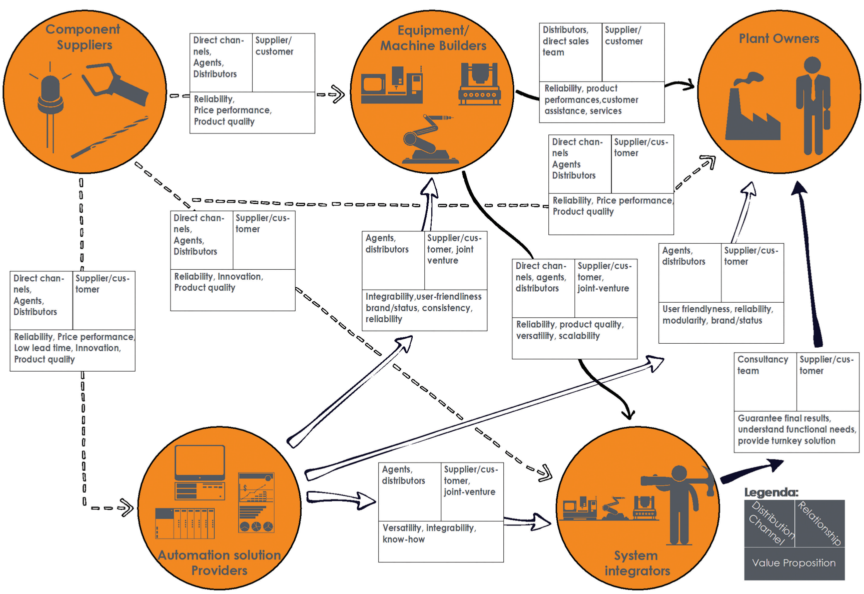

Figure 12.1 Automation value network general representation.

overview of the current automation value chains with a particular focus on: (i) Type of relation, (ii) Distribution Channels and (iii) Value-proposition. These elements drawn in boxes among complementors are intended to be univocal: for example, the value proposition of one player can vary a lot in accordance to the customer he serves.

The main interactions that can exist among the automation players are here presented with the aim of not covering all the possible interactions (biggest players frequently group under their umbrella more than one of the proposed stakeholders' functions; similarly, it is frequent that companies establish partnerships exposing a unique contact point with the customer), but describing the most common ones. The resulting schema highlights the linearity of the current automation ecosystem, where automation solutions, i.e. manufacturing lines, are the result of a "chronological" (even if very complex) interaction among players that goes from the granularity of low intelligence components, to the high integration and desired smartness of full manufacturing lines.

In the existing value chains, the automation solution to be purchased is still selected merely considering its hardware elements. Despite the great commitment exerted in software development to create integrated and versatile automation solutions, resulting in high impacts the software has in terms of costs and implementation efforts, but still it is not a primary decision-making parameter. The decision between a solution or another one depends first on the hardware (the component, the control system, the machine, the equipment, the production line) and, only in second instance, the software to integrate, coordinate, and/or use the entire system is selected. To this end, in the schema, it is not underlined in the relevance of the software, being considered a player in the background.

12.2.1.1 Automation solution providers

The automation solution provider (ASP) produces controllers for automation, such as PLC's, servo-drivers, HIM, safety devices and a wide variety of products. Companies such as Siemens, Allen-Bradley, Turk, Omron, Phoenix Contact, Rexroth, Mitsubishi and Schneider/Modic provide the hardware components of the control solution, the software to develop the programs and the standards on which the logic controls are based.

The choice between the different automation solution brands is based on several parameters including integrability, flexibility, scalability and reliability.

Controllers have a relevant impact on the realization of an automation solution. Developing a plant totally based on one single brand guarantees reliability and easy integration. Nevertheless, this decision involves a strong dependency, which can bring disadvantages in terms of costs, flexibility and change opportunities.

ASPs have usually a strict relation with machine builders. Depending on the adopted business model, it may happen that the automation element is directly provided by the equipment & machine builder (E&MB), which is an ASP itself (e.g. ABB and Yaskawa). In other cases, E&MBs develop some kind of drivers within their products, allowing to work with different automation solutions. For example, they may create a special driver for communication with profibus for Siemens, or Etherner/IP for Allen Bradley or just leave an open port of communication like MODBUS, to work with any other device. In many cases, an E&MB proposes to its customer automation solutions that are compliant with its machines. The customer decides which one to implement.

Customers have a relevant role for the ASP's business and their relationship can be resumed in two categories:

- Self-service: customers have a limited interaction with automation solution providers' employees. The main relation channel is often the website, where self-help resources such as white papers, case studies, videos and answers to frequently asked questions are available. There is often the possibility to use also a personal assistance in the form of phone and e-mail support (e.g. ABB).
- Consulting: direct sales forces consult the costumer to ensure that all the needs are met. The main objective is to establish a long-term relationship. Technical support is provided through personal and on-site assistance, but also through phone or online resources.

ASPs can offer consultancy services either directly or through the support of system integrators. Some system integrators (SIs) prefer to remain completely independent from ASPs, while others choose to form alliances, which take the form of membership in an ASP's program. This provides to its program members a wide number of benefits including training, advertising, marketing assistance, beta product trials, free product samples and more [5].

12.2.1.2 Components suppliers

Components supplier (CS) produces devices not executing, on their own, complex functionalities (i.e. influencing alone a whole production process).

Their main customers are E&MBs, and sensors, drives, panels, I/O clamps, etc. are typical "deliverables". Production is usually oriented towards a make-to-stock approach in large numbers, aiming at a wide application scope. Their business model mainly focuses on the premium segment and/or on the customization, where it is possible to obtain the largest profits, with a strong emphasis on their home country [10]. CSs usually try to grow through joint ventures and cooperation, exploring adjacent businesses also with horizontal integration.

12.2.1.3 Equipment and machines builders

In the current automation environment, the main business of an equipment & machine builder (E&MB) is the design and production of equipment and machines, through the assembly of different simple components, including low-level controllers and their logic control, in order to obtain more complex and functional systems. The integration and configuration of HMI, PLC, CNC, other accessories and tools depend on the business model of the player. In some cases, these activities are developed in-house, and in others, they are developed by SIs or directly by customers. E&MB is usually characterized by a strong level of internationalization that it intensifies through local value creation and shorter time to market. E&MBs are, with ASPs, the most advanced player from the technological point of view.

Considering their supply chain, the dependency of an E&MB on external suppliers is heavy in the case of high-value added elements such as numerical controls, drives, linear guides, spindles, clamps or specific/custom automation components. Some of these are bought on the market from multinational companies (typical examples are NC, drives and PLC), others are produced by specialized companies working closely with E&MBs (e.g. clamps and tooling).

In some cases, machines and the equipment are sold without the integration of the automation control. It is directly the customer or an SI that implements the automation. Who produces machines usually provides a list of compliant automation solutions, without expressing specific recommendations. It is the ASP that has to promote its products and be able to influence the buyer to install it. In the same way, the ASP does not suggest any E&MB. E&MB's business model has a particular impact on the relation with customers. Sometimes, the E&MBs rely on distributors partners, which sell and implement the basic configuration of their products based on customer needs. In other cases, in particular when the E&MBs is a big company, there is a direct relation, where consultants or agents interact with the customers.

It is necessary to consider also that customers can be both plant owners, who directly purchase the machines and equipment, and the SIs, who purchase it for a third party. Another element, which is influenced by E&MBs, is the machines integration. Some E&MBs provide this service, while others provide only the product and leave the integration to a third-party actor or to the customer. Depending on its needs and the type of equipment and machine, builders can produce basic, highly standardized and high-volume machines or customized ones, involving the customer in the development with a strict collaboration between customer and supplier.

12.2.1.4 System integrators

The main business of system integrators (SIs) focuses on assembly and integration of combined machinery systems, lines and equipment. SI has usually vertical competences in a specific sector (e.g. food and beverage, wood, textile, packing etc.), due to the need of having a deep knowledge of available technologies.

The SI starts from customer's functional needs to design, propose and implement turnkey solutions. These are developed through the combination of existent and new resources. In many cases, SI develops codes in different languages, providing low-level SW (application, libraries, algorithms) to connect, integrate or add basic functionalities to machines, lines and plants. SI can provide support also for request-for-proposal and after-sale maintenance.

Usually, every SI has its main, trusty and reliable suppliers they select among on the basis of specific customer requirements. If it has not specific brand needs, the system integrator appeals on well-known or partner suppliers. SI usually purchases components from different vendors, depending on which integration it is working on and on the customer requirements. The relationship with components suppliers, which is often intermediated by the distributors, is driven by different elements, such as personal relationship and past relationships/experience. In many cases, the system integrator prefers known suppliers, with a long time, inter-personal relationship, which guarantee a service that goes beyond a simple buyer–supplier relationship (e.g. delivery outside the working time). Price is also a relevant aspect, especially when the customer is directly involved in the choice. If the customer has no specific requirements about the automation controllers, HMI, software, etc., the SI adopts the technology he knows better. If the employee knows specific languages and software and there is not the need to change them, then the relative automation solution will be adopted.

12.2.2 Beyond Business Interactions: Limitations and Complexities of the Existing Automation Market

Adopting and using automation solutions requires the involvement of experienced and skilled employees, whose competences are developed during time and cover all the value and supply chain steps. Being able to maintain a sustainable value chain, where all the members have the proper revenue seems to be therefore the winning factor fostering continuity, customer loyalty and product familiarity. For this reason, in particular from the final user point of view, consistency, time continuity and familiarity of the supplier/solution are often more relevant than innovation itself. Also, price and services are relevant aspects to be considered for an automation solution, but if they are aligned between competitors, the personal relationships and the known modus operandi have a higher impact.

Actually, the automation environment is very conservative and slow to make changes: evolutions and innovations are often seen more as concerns than as opportunities of improvement. Automation solution providers, whose main products are PLCs and control systems, are the main rulers. Current PLC technologies, which impact the deployment of industrial automation applications, are a legacy of the 1980s, unsuited for sustaining complex systems composed of intelligent devices. The current control systems, which have at the base the IEC-61131 standard, are outdated from a software engineering point of view. Moreover, they have been implemented by each vendor through specific "dialects" that prevent real interoperability and they are strictly dependent on the hardware on which they run. Therefore, the automation solution brand is considered by the customer as a relevant aspect. If a company wants to access a specific market, it has to adapt its product to that context specificities. For example, in Germany, if a machine does not have Siemens PLC, probably it will not be sold. The low inclination to changes of this sector, due to the strong dependency on reliability and on well-established know-how, does not push the actors towards innovative changes (not even ones pulled by the Industry 4.0 principles).

In addition to the previously mentioned domain's issues, there are different technological limits that should be included to obtain a wide representation. Obsolescence of automation systems has a relevant impact on the all automation solution life cycle. In order to be compliant to the 4th industrial revolution principles, the access to data related to an equipment, a machine, a line, a plant and a factory should be available at any level of the supervisory and management hierarchical architecture. On the contrary, constraints and limits imposed by HMI or SCADA systems, designed and implemented to fulfill the requirements identified at the design stage restrict the access to data. Moreover, should additional information requirements emerge not included/considered in the initial design (e.g. for monitoring performance improvement purposes), existing legacy systems require a modification of the PLCs and a reconfiguration of the SCADA system (and/or HMIs). This upgrading of the system becomes expensive and risky, in particular, if applied to many controllers. In addition, flexibility and optimization of the manufacturing plants do not merely ask to access the raw data available on controllers (like status variables and/or sensors data), but also to computation and/or smart functionalities offered by the increasingly embedded intelligence. The software tools composing the ICT infrastructure of a factory could take advantage of the equipment/machine-embedded computation capabilities with the application of the appropriate functionalities. In classical automation systems, all these kinds of interactions, data elaborations and data delivery are defined at the design stage of the automation software, considering the requirements available in that step. When changes of those specifications should be considered after the automation system is implemented, there could be the need to modify the automation software on many controllers and this requires to be aware of the details about how the systems were implemented. These kinds of modifications are rarely applicable in real productive scenarios and this affects the upgrading and revamping of legacy systems, actually dampening innovation.

12.3 A Digital Marketplace to Support Value Networks Reconfiguration in the Automation Domain

As highlighted in the previous chapter, a classic value chain, characterized by processes linked together in support of a value network is not typical of the automation industry. In fact, the influence of the upstream companies is relevant on the final product, be it a machine, an entire line or a plant. For this reason, value creation in the interdisciplinary automation industry cannot be represented as a chain: it is a value network where the same company can act both as a supplier and as a consumer of products and solutions. In this value network, services along the process steps are becoming more and more important, in particular when offered in connection with a physical product [5] (the so-called "product-related services").

Digital platforms have been widely adopted in the last decade as instruments to support the diffusion of product-related services, reducing transaction costs and facilitating exchanges that otherwise would not have occurred [11]. The main value that the platforms create is the reduction of the barriers of use for their customers and suppliers. A platform encourages producers and suppliers to provide contents, removing hurdles and constraints that are part of the traditional businesses. As for suppliers and producers, platforms create significant value also for consumers, providing ways to access to products and services that they have not even been imagined before. Platforms allow users to trust in strangers, allowing them to enter in their rooms (Airbnb), renting their cars (Uber) and using their applications (Phone and PC marketplaces). Platforms provide and guarantee for users' reliability and quality. New sources of supply can cause undesirable contents, if not filtered, while thanks to the reliability and quality mechanisms that platforms integrate, this issue becomes not relevant.

The platform developed within the Daedalus project follows this trend by extending platform logics to the automation domain. This is done exploiting as a foundation the new evolution of the IEC-61499 standard that envisages the technology on the top of which additional value drivers for the automation complementors can be set up. The Standard allows: (i) the design and modelling of distributed control systems and application execution on distributed resources (not necessarily PLC), (ii) the creation of portable and interchangeable data and models and the re-utilization of the code, (iii) the seamless management of the communication between the different function blocks of an application (independently from the hardware resource they run on) and (iv) the decoupling of the elements of the CPS (its behavioral models) from the physical devices and reside (designed, used and updated) in-Cloud, within the "cyber-world", where all the other software tools of the virtualized automation pyramid can access them and exploit their functionalities.

Among the others, code modularity, reusability and reconfigurability of systems are the main features that are advertised as practical benefits of applying this Standard [12]. The final result is the ability of designing more flexible and competitive automation systems by providing the functionality to combine hardware components and software tools of different vendors within one system as well as the reuse of code [13, 14].

The Daedalus platform is therefore meant to bring together automation complementors and give them the infrastructural support to technologies, services and skills essential for systems improvement through CPS integration and orchestration [15]. This is done by opportunely adapting the functional model already implemented successfully within the IT world for mobile applications developing a digital place (i.e. a marketplace), where automation-related applications and services will be shared among platform users. The digital infrastructure will allow also machine, equipment and components manufacturers to exploit a common platform where to share updates and extended functionalities of their systems.

12.3.1 Architectural Characteristics of the Digital Marketplace

The Digital Marketplace represents the reference interface to be adopted by developers/manufacturers of IEC 61499-compliant CPS(s), interested to sell their products via a multi-sided marketplace and able to match-make product offer with plant owners, equipment manufacturers or system integrators needing their solutions.

The proposed digital infrastructure takes advantage of the faceted nature of a CPS (aggregation of hardware, software and digital twin), to make the decoupling between the mechatronic system, the control application and the digital twin the lever to support the integration of third-party developers and service providers. Thanks to the nature of the IEC 61499, the platform relies on CPS(s), and mechatronic systems may be indeed controlled by different intelligences, potentially made by different developers, which represents a big opportunity for developers who want to create their own control application. Therefore, the Digital Marketplace is not only a repository of CPS, but it provides a set of services enabling developers and manufacturers to test and validate their own products. The Digital Twin is used in this case as the instrument to simulate the mechatronic system in a well-known and certified simulation environment, providing a digital way to validate the cyber part of a CPS.

The Digital Marketplace is a Web-based application that exposes a set of Web services that allow external components, such as portals, IDE, applications, etc. to be connected with the Digital Marketplace and exploit its provided functionalities. At the architectural level, the marketplace is composed of the software components, exposed interfaces and interaction flows proposed in 0, whose main elements are (Figure 12.2):

- The *Persistency Layer:* it is the fundamental layer on which the rest of the architecture is based, and is divided into two main components: the *Repository* and the *Persistency Manager*. The first one represents the knowledge base of the Marketplace and it is composed of the hosted CPS(s), the *Economic Data Model*, meant to describe all economic aspects of the products (pricing strategies, fees, etc.) and the *Semantic Data Model* meant to characterize the submitted product in order

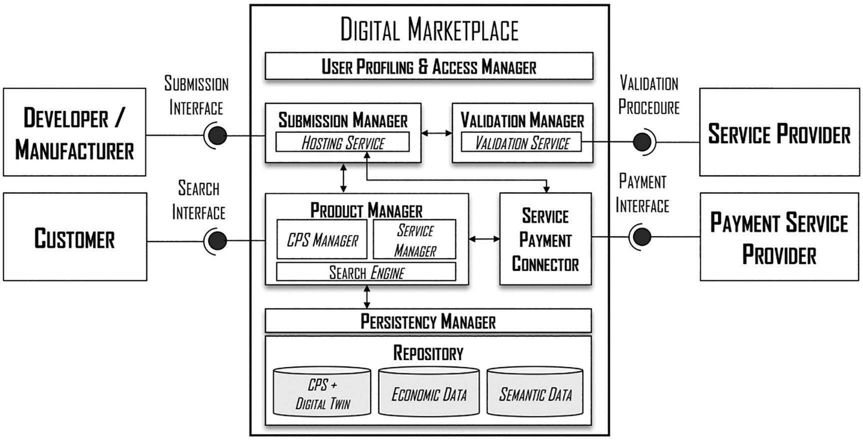

Figure 12.2 Digital Marketplace Architecture.

to be accurately searched and identified. The *Semantic Data Model* is managed by the *Product Manager* component which is also in charge of providing discovery functionalities of the hosted products. In particular, once the CPS has been successfully submitted and validated, it becomes available to customers who want to buy and use it. For this purpose, the Digital Marketplace provides a search engine mechanism based on a set of algorithms meant to result the best possible answer to a search query. The aim of this semantic search is to improve search accuracy by understanding the customer's intent and the contextual meaning of terms as they appear in the searchable dataspace, within the system, to generate more relevant results. Semantic search systems consider various points including context of search, intent, variation of words, synonyms, meaning, generalized and specialized queries, concept matching and natural language queries to provide relevant search results. The semantic search will produce a result containing the list of suggested products, whose characteristics answer the customer's needs.

- The *Submission Manager* is the software component in charge of regulating the CPS submissions process starting from the request, passing through the validation, to the payments. Both the payment service connector and the validation manager are directly connected with the product manager.

  The submission manager exposes a submission interface, which allows to describe the submitted product in terms of: general description of the product, set of functionalities provided by the CPS, set of compatibilities with existing mechatronic systems and pricing strategies by which the marketplace will manage contracts of the products' usage between the marketplace itself and the customers.

- The *Validation Manager* has the aim to validate all the submitted products in terms of provided functionalities. This component is in charge of managing the validation process that requires to simulate or test the Digital Twin of the submitted CPS into a simulation/testing environment, properly built by the certifier, where both the context of execution and the CPS' operations are replicated. The validation process follows a well-defined protocol based on the objective criteria, aimed to verify if the CPS specifications/functionalities, under certain conditions, are satisfied or not. In order to guarantee the tests repeatability, the CPS tester must publish, into the Digital Marketplace, the testing results accompanied by the applied testing protocol.
- The high-level component belonging to the Digital Marketplace is the User Profiling Manager, which is in charge of managing the user profiling in terms of roles, authentication and authorization.

In order to transform the described Architecture in a functional marketplace, an overall data model, encompassing both the digital integration of all technological elements of the project and the definition of revenue creation mechanisms has been therefore developed. The basic idea of this model is to provide a set of technical functional specifications (by using UML diagrams) aimed to cover the design of all needed mechanisms meant to guarantee the economic and technical aspects behind the Digital Marketplace.

The *Digital Marketplace data model* (Figure 12.3) aimed to cover, on the one hand, all the economic aspects of the products in terms of prices, contracts, etc. and, on the other hand, a detailed description of the hosted CPS.

The *Digital Marketplace data model* not only aims to describe the automation application in terms of "what a certain automation application does" but also how it does something. The design of the data model has the aim to fully characterize a product of the ecosystem in order to be accurately searched and identified. For that reason, the creation of such data model considered aspects like exposed functionalities, compatibilities, specifications, meaning of the application I/O, application extensibilities, description of the logics that the automation application wants to provide and the openness of its source code.

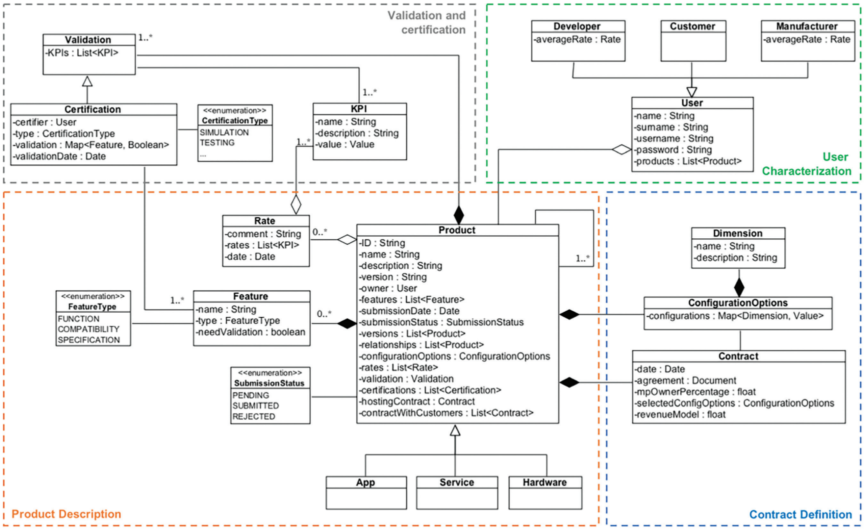

Figure 12.3 Digital Marketplace Data Model.

The designed data model has been divided into five sections, each respective to one of the five packages of the structure presented in the figure above:

1. ***User Characterization package***: it contains all data entities related to the user description and characterization. This part of the data model deals with the representation of the User, being it a developer (Developer class) or a manufacturer (Manufacturer class) or a customer (Customer class), and all the related information.
2. ***Product Description package***: it contains the data objects needed to describe the products (hardware, application and services) hosted by the Marketplace. This package groups the set of entities needed to formalize the data structure for describing the hosted products in terms of features, possible relationships with other products, product contract configurability, product validation and certification.
3. ***Contract Definition package***: this package contains all entities needed to formalize all possible configuration options of the contract that regulate the economic aspects between the Marketplace and the customers about the use of the products.
4. ***Validation and Certification package***: this part of the data model is dedicated to formalize those entities meant to support the validation of the submitted product and the optional product certification.

The validation phase has to be intended as part of the product submission process, where, according to the terms of the contract between the developer/manufacturer and the Marketplace, the submitted product undergoes a validation of the provided features. In particular, a validation has to be considered as a more specific validation service provided by the Marketplace and released by a validation service provider.

12.3.2 Value Exchange between the Digital Platform and Its Complementors

If the marketplace described in the previous chapter is the technological infrastructure supporting the exchange of value (products, money, services) among automation stakeholders, the data model underpinning it provides the logical constructs enabling to deploy the rules running ecosystems exchanges. The business model characterizing the Digital Marketplace instantiation is eventually the description of how these rules are managed and how the cost/revenue structure of the marketplace is arranged [16]. The entity of the cost/revenue structure behind value exchange among platform complementors is strictly dependent on the specific implementation scenario that the marketplace will assume (type of platform owner, network of existent suppliers involved, approach to system integrators, etc.). Therefore, the economic dimensions required to assure the profitability of the whole ecosystem have to be defined on a case-by-case basis, in accordance with the specific implementation scenario and the specific business case. The marketplace dynamics driving exchange of value among complementors and more in general, the type of transactions that it can enable can be generalized and discussed without referring to a specific business case.

Four sources of value are at the base of the marketplace dynamics:

1. *Money and credits:* this is the most common form of value that is exchanged by customers and suppliers in return for goods and services delivered. As normally happens, on these transactions, the Marketplace builds its profitability.
2. *Goods and services:* as anticipated in §0, the Marketplace supports the trading of IEC 61499-compliant CPS (aggregation of hardware, software and digital twin), exploiting the independent nature of each CPS component to extend the number of elements that can be traded. Goods and services are therefore hardware components, the related software control part (developed by the company or by application developers), software applications that can support the integration of hardware components

across lines and/or the integration of CPS with IT components of higher levels of the automation pyramid and services provided by third parties related to the deployment of CPS (e.g. integration of simulation services supporting software applications testing and validation).

3. *Information:* the Marketplace is expected to host supporting material for companies/system integrators intended to integrate IEC 61499 technologies in their business and for developers approaching IEC 61499 programming, together with the related software development kit (SDK) supporting software development.
4. *Intangible value*: in order to support customers in selecting hardware and/or software components and services to be deployed, the marketplace supports the delivery of intangible value across each transaction in the form of evaluations of delivered products/services. The customer can therefore rely on a set of credentials of the supplier represented by the evaluation of its work provided by other customers.

In Figure 12.4, for each complementor, the main exchanges supported by the marketplace have been therefore highlighted by representing through arrows the forms of value described above. The direction of the arrow shows whether the value is taken form the platform, delivered to it or both. The diagram also summarizes the impact on the value proposition that the platform supports (further discussed in §12.3.3).

To describe the main interactions occurring among marketplace and Complementors, the complementors have been grouped into four categories of stakeholders (Table 12.1): Customers, Application developers, Service providers and Hardware developers. In the following table, the mapping among the proposed categories and the overall Marketplace complementors is presented. Some of them can play the role of both providers of product/services delivered by the marketplace as well as customers.

12.3.2.1 Customers

The main relationships that customers have with the marketplace are: the purchase of product/services, agreements with product/service providers mediated by the marketplace and rating of the delivered product services. To this end, customers are meant to start the interaction with the marketplace by performing a registration that allows them to store and retrieve data related to their buying experience. By browsing the hardware and software catalogues, customers can select the product/service they are interested in and visualize the software/hardware products or services associated to the selected product.

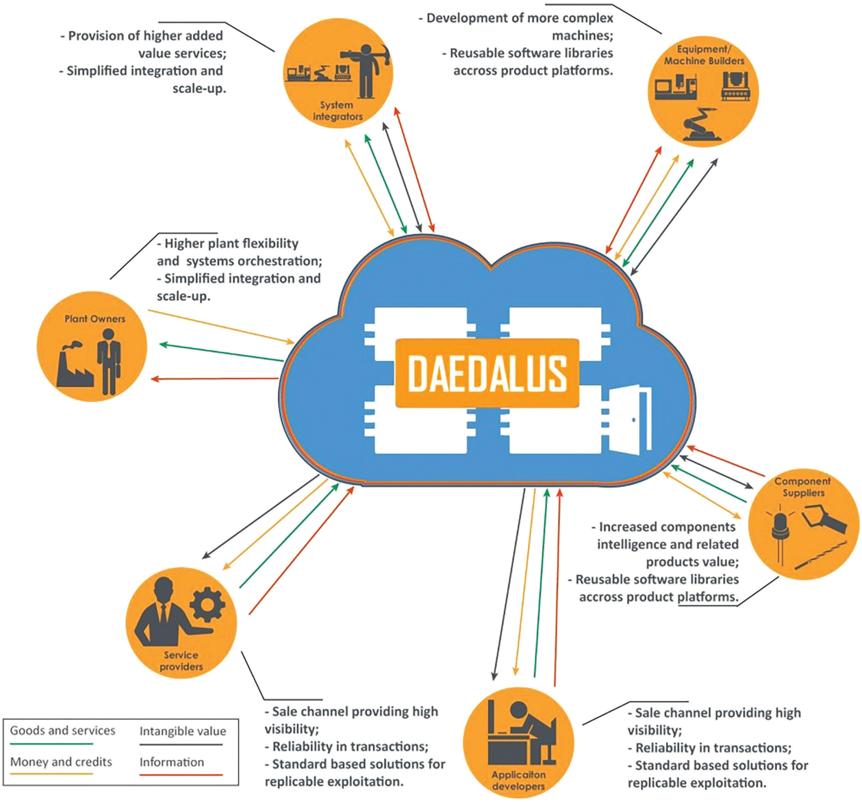

Figure 12.4 High-level definition of marketplace interactions with main Daedalus stakeholders.

Table 12.1 Mapping of stakeholders on Marketplace ecosystem

Type of Stakeholder	Mapping on Marketplace Ecosystem
Customer	Plant owners; system integrators; equipment/machine developers; component suppliers
Application developer	Application developers; system integrators; equipment machine developers
Service providers	Service providers
Hardware developers	Equipment/machine developers; component suppliers

Each product is indeed connected with specific software/hardware/services that can operate together (i.e. if browsing a sensor, then the marketplace suggests the applications supported by the hardware itself and the services of integration supported).

The selection of one product enables the customer to access the contractual area, where the contract among the customer and the marketplace is agreed, and recall the payment service. In its interactions with the marketplace, the customer is not charged for the services provided: it is always the product/service provider that pays a percentage fee.

Once completed the purchase, the customer can exit the marketplace. He will then receive the products/services according to the modalities agreed within the contract. Customer will receive notifications with respect to software updates in order to improve the customer experience and support the maintenance of updated hardware/software functionalities.

12.3.2.2 Hardware developers

Hardware developers are a category of marketplace end-users very important to its deployment; indeed, it is expected that in the first stages of marketplace life, hardware developers will provide both hardware and software applications to run on it. To this end, they will be the first category of stakeholders providing contents of the marketplace.

If maintaining the perspective on the sole hardware, then the marketplace will give hardware manufacturers the possibility to store product catalogues, giving the facilities to define characteristics, specification and costs of their products. As for customers, the first access will require a registration giving them the access to a dedicated page where they will be able to set up the characteristics of their account. In parallel, the marketplace will also provide the infrastructure for the definition of the contracts with customers, leaving manufacturers the freedom, among certain constraints set by the marketplace, to configure the contracts setting the relationship with the customer (i.e. cost of product, type of business model, purchase/product as a service, etc.).

The hardware manufacturer will be billed by the marketplace at two levels: on a first tier, paying a fixed cost for the hosting of the products catalogue and, on a second level, with a percentage fee on each transaction with customers. The economical dimensions of both the fixed cost and the transaction fee will be decided according with the specificity of instantiation of the marketplace.

12.3.2.3 Application developers

Application developers will find on the marketplace the infrastructure to host their applications and sell them. Similarly, to hardware developers, the marketplace will give them the facilities to define characteristics, specification and costs of their products. Moreover, considering the type of product sold, the marketplace will also provide specific contracts templates supporting characteristics of an application sale (in-app purchase, period-based licence, etc.).

The marketplace will be also the place where developers will be able to find, accessing dedicated spaces, the quality procedures and SDK required to develop applications compliant with the ecosystem. These services are provided without additional costs to the developers.

12.3.2.4 Service providers

Service providers are meant to benefit from the marketplace by increasing the visibility of the provided services. Similarly, to other stakeholders, the marketplace gives them the facilities to describe and host their services and set up contracts related to service provision. In exchange, the marketplace charges them a percentage fee for the services sold. The marketplace also make revenues by giving priority advertise for those service providers paying an additional fee.

12.3.3 Opportunities of Exploitation of an Automation Platform

As already mentioned in the previous sections, the creation of a platform-based automation ecosystem is expected to have a relevant impact on the way that automation complementors manage their business. A platform relying on IEC 61499, to support transactions in a complex ecosystem as that of automation, should guarantee to be completely open and hardware-independent, enabling full interoperability and much-deeper portability and reusability of application developments. The specific deployment of technologies and ecosystem should be first targeted to the most innovative and pioneering SMEs and large enterprises in Europe, already oriented to accepting a decentralized approach to automation. These will be the first players that can adapt their business model, in order to be successful in a platform-based automation ecosystem. In the transition toward such ecosystem, opportunities and challenges are clearly generated for all the automation stakeholders. For each of them, a brief description of the expected challenges is provided hereinafter.

12.3.3.1 Opportunities for system integrators

Among the automation players, System Integrators (SIs) are one of the stakeholders closest to the customers. Considering their active role in understanding customers' functional requirements to propose ready-to-use solution, they have a direct vision on their main needs. In this context, SIs are realizing, more than any other automation player, that customers are requiring more flexible and reconfigurable solutions, capable of increasing production performance and providing more advanced functionalities.

On the other hand, in the current automation environment, SIs have a marginal role in adding value for customers and have low technological competences. They usually integrate different components, equipment and machines to provide functional and ready-to-use solutions. They mainly perform the operative part, which does not only allow to cover customer needs, but only to satisfy their functional requirements.

Adhering to a platform-based ecosystem, SIs will no longer be a simple assembler, but they will have the opportunity to add relevant value to the automation solution. This could be done by developing SW for their customers and proposing dedicated solutions, which add functionalities, improve performances and manage orchestration and distributed architecture between the different factory levels. SIs have therefore the opportunity not only to deliver functional solutions meeting customer requirements but also to add functionalities to the systems, increasing the value of the overall proposed solution. Moreover, thanks to reduced hardware dependence, code re-usability and modularity achieved through the adoption of IEC 61499 logics, SW use could be extended in different contexts, for different customers application.

The first opportunity for SIs will be the update of existing legacy automation systems. For the first adoption of platform principles, CPS-izers (systems that are meant to act as an adapter among legacy and IEC 61499 technologies) develop a fundamental role, allowing SIs to transform solutions tied to old legacies to compliant ones. The higher integrability of components, equipment and machines will allow SIs to reduce the effort to provide ready-to-use solutions and to ease the integration of new functionalities by developing dedicated SW. This becomes a relevant activity that is expected to be mainly internalized by SIs. Thanks to the platform and the related marketplace, they will have the opportunity to re-use libraries and algorithms developed by third-party developers to improve or speed up the development of their SW solutions.

All these elements are meant to increase the value proposed to customers, allowing to extend solutions' functionalities and enabling to dedicate more resources to the development of high-level applications and SW, while reducing efforts and resources for components, equipment and machines integration and basic functions programming.

It is necessary to consider that SIs are the players that can achieve the highest benefits from platform-based automation ecosystem, but to which are also required the main transition efforts. In this kind of domain, SI becomes a more advanced player, to which are required more technological competences. It is no more a simple consultant, but it also a product (SW) developer. It is expected that SIs expand their know-how and competences from low operative level to higher, with the objective to provide more added value to its customers, not only through integration, but also through the improvement of performance and functionalities, maintaining them during the whole solution's life cycle.

12.3.3.2 Opportunities for equipment and machines builders

E&MBs, adhering at the ecosystem and adopting the related technologies, have the opportunity to release more advanced products, able to work in flexible and orchestrated production systems. E&MBs can produce complex manufacturing systems as aggregation of CPS, focusing their effort on the assembling and orchestration of the automation tasks of these composing elements. The adoption of platform technologies can allow an E&MB to develop products that can take advantage of all the components (control software, applications and services) IEC-61499 compliant.

For E&MBs, the platform will become a relevant resource, being one of the structural technologies on which its products will be designed and produced. The management of this resource should be performed with particular attention, in order to spread out all the possible benefits and to maximize products' performances.

12.3.3.3 Opportunities for components suppliers

The platform-based ecosystem generates opportunities also to CSs. They have to become capable of releasing more functional, intelligent and independent components. Components can be designed and developed as more complex elements (such as CPS), already equipped with on-board distributed intelligence. A CS should not be focused only on reliability, quality, price and lead time. It should innovate its products adding functionalities. Therefore, CSs will have the opportunity to provide not only hardware, but also SW, adding value to their solutions and increasing the revenue opportunities, creating a closer relation with their customers.

12.3.3.4 Opportunities for automation solutions providers

Thanks to the extended functionalities that it brings by, the IEC 61499 standard can have the potentiality to affirm as a competing standard to the

IEC 61131, currently largely adopted by Programmable Logic Controllers. If this situation actually happens, ASPs are expected to have two behaviors: (i) they can adopt the IEC-61499 standard, implementing their own "dialect" and tools, to create their own IEC-61499 automation ecosystem and (ii) they can try to stop its adoption, taking advantages of their position of strength which ties customer to their legacy solutions.

12.3.3.5 Opportunities for new players

The platform-based ecosystem and in particular the marketplace create the opportunities to all those ICT companies and software developers that aim to make business in the automation market. Application developers (AD) will be a new player of this environment that arises through thanks to the transition to platform-based business model.

These players will have the opportunity to develop compliant software for general-purpose usage scenarios, customizable by CSs, E&MBs, SIs and/or customers for their specific projects. Through the distributed intelligence, software will acquire a more relevant role, through which customers can increase functionalities and performances of equipment, machines, lines and plants, obtain data and/or perform analysis. Added value is provided by guaranteeing special functionalities based on specific competence, quality of implementation and performance achieved.

12.3.3.6 Service providers

SP provides services and support to POs and SIs. Exploiting the IEC-61499 benefits the possibility to develop an extended amount of new services with the aim of creating a digital representation of the system, perform simulation, analysis, test application, and/or store data. The described platform can become the environment where these services are made visible and brought to the market. In this sense, their business model is similar to AD's, but instead of providing SW, SP provides services to be integrated in manufacturing lines design and deployment.

12.4 Conclusions

In the last decades, the automation domain has been characterized by an ecosystem ruled by legacy technologies, where the dominant role of the chosen hardware solutions strongly constrains reusability, upgradability and orchestration of manufacturing systems. This situation led to the rise of important barriers to the shift towards competing or optimized solutions, limiting the potentialities of upgrade and flexibility of the systems.

In this context, the digital platform developed within the DAEDALUS project, relying on the extended functionalities provided by the upgrade and deployment of IEC 61499 in the CPS domain, stands out as a ground-breaking platform able to revolutionize the whole approach to how automation systems are conceived, designed and set up. The infrastructure developed is therefore the first step to achieve the challenge of developing a platform able to foster the creation and deployment of more efficient, flexible and orchestrated production systems, easy to be integrated, monitored and updated. The proposed platform is able to widely manage CPS in their multifaceted sense (HW, SW, Digital Twin), reaching different (even complementary) customers and offering new opportunities to developers in terms of possibility to create own(ed) control applications and of exploiting validation services thanks to the hosted digital twin. As a consequence, the platform drives a reconfiguration of the automation value network, with the aim of releasing the main issues currently faced by the sector and extending the value drivers that characterize their interactions.

Next steps to be carried out in order to create a digital platform meeting the needs of the current industrial markets (customers) are envisaged in (i) the creation of specific mechanisms and procedures, software interfaces, and incentivizing system, all supporting the large adoption of the platform, (ii) further elaborating methodologies and outcomes of processes and services supporting CPS validation, (iii) integrating in the platform value added services for customers (e.g. performances assessment of the machines, management of manufacturing systems, manufacturing data elaboration for predictive maintenance forecasting) and (iv) implementing a business development strategy intended to actually deploy in the market the logics proposed by the Digital Marketplace.

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