

# The IEC 61499 Function Block Standard: Launch and Takeoff

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## ABSTRACT

In economic terms, the adoption of new technologies for industrial automation and control is characterized by strong “network effects” where the value of a technology increases as more users and vendors adopt it. Because of these effects, and the long life cycle of industrial equipment, the adoption of new technologies in this domain is much slower than in the consumer market with its shorter product life cycles. Nonetheless, the existence of these effects causes a positive feedback loop such that, if the needs of early adopters can be met, the adoption of the technology follows the well-known S-shaped “logistic curve” characterized by a *Launch* phase populated by innovators, a *Takeoff* phase populated by early adopters and a *Maturity* phase populated by late adopters. This paper utilizes information presented at the “IEC 61499 Day” at SPS/IPC/Drives in Nuremberg last November<sup>1</sup> to show that IEC 61499 is currently in the Launch phase, and to identify application domains where “killer apps” are most likely to emerge that will boost IEC 61499 adoption into the Takeoff phase. The characteristics of probable early adopters are described, and the advantages likely to accrue to them during and after takeoff are identified. Finally, this paper identifies the means to ensure the presence of those factors necessary to ensure a successful takeoff of this technology.

## I. INTRODUCTION

The IEC 61499 Standard<sup>2</sup> project began as an effort to provide a common reference architecture for the standardized programming, reuse and deployment of software objects known as *Function Blocks* (FB) in

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<sup>1</sup> See <http://vyatkin.org/iec61499day/index.html> for presentation slides.

<sup>2</sup> IEC 61499-1, *Function Blocks: Part 1 - Architecture*; IEC 61499-2, *Function Blocks: Part 2 - Software tool requirements*; IEC 61499-4, *Function Blocks: Part 4 - Rules for compliance profiles* (all published by International Electrotechnical Commission, Geneva, 2005).

Programmable Controllers (“PLCs”)<sup>3</sup> and Distributed Control Systems (“DCS”)<sup>4</sup>. However, this soon evolved into a comprehensive architecture encompassing all aspects of distributed industrial automation, including (1) an event-driven execution model that adequately represents distributed nodes communicating via message passing; (2) a management interface capable of basic (re-)configuration services; (3) an application-centered modeling methodology; and (4) support for the distribution of control programs to different control/field devices. The Second Edition of IEC 61499, to be published in late 2012 will be a clear, unambiguous, and industrially useful specification for the use of FBs in distributed, embedded devices and systems<sup>5</sup>.

As previously noted,<sup>6</sup> the successful introduction of new system architectures such as IEC 61499 is characterized by strong "network effects" where the value of a technology increases as more users and vendors adopt it. This produces a positive feedback loop such that the adoption of the technology follows the well-known S-shaped "logistic curve", which is characterized by Shapiro and Varian<sup>7</sup> as comprising three major phases: *Launch*, *Takeoff* and *Maturity*. These phases can also be characterized by the major players in each phase, namely *Innovators*, *Early Adopters*, and *Late Adopters*, respectively.

In this paper we first present an overview of some of the innovative applications of IEC 61499 that have been made in the Launch phase. From these we develop a profile of the most likely early adopters during the Takeoff phase, and describe the benefits that the IEC 61499 architecture can provide them. Finally, we identify those factors that will be critical for a successful transition from the Launch to the Takeoff phase.

## II. LAUNCH PHASE: INNOVATIVE APPLICATIONS

In this section we describe four innovative applications of the IEC 61499 Standard in the application domains of Smart Grids, Smart Material Handling, Smart Buildings, and Smart Factories. While this is by no means an exhaustive list, it serves to illustrate the major features of such innovative systems.

### SMART GRIDS

The Smart Grid is characterized by the U.S. Department of Energy as follows:

*...smart grid means “computerizing” the electric utility grid. It includes adding two-way digital communication technology to devices associated with the grid. Each device on the network can be given sensors to gather data (power meters, voltage sensors, fault detectors, etc.), plus two-way digital communication between the device in the field and the utility’s network operations center. A key feature of the smart grid is automation technology that lets the utility adjust and control each individual device or millions of devices from a central location.... The number of applications that can be used on the smart grid once the data communications technology is deployed is growing as fast as inventive companies can create and produce them. Benefits include enhanced cyber-security,*

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<sup>3</sup> IEC 61131-3, *Programmable controllers - Part 3: Programming languages*, 2<sup>nd</sup> Edition, International Electrotechnical Commission, Geneva, 2003.

<sup>4</sup> IEC 61804-2, *Function blocks (FB) for process control - Part 2: Specification of FB concept*, International Electrotechnical Commission, Geneva, 2006.

<sup>5</sup> J. Christensen, T. Strasser, A. Valentini, V. Vyatkin, A. Zoitl, “The IEC 61499 Function Block Standard: Overview of the Second Edition,” ISA Automation Week 2012.

<sup>6</sup> *ibid.*

<sup>7</sup> C. Shapiro and H.R. Varian, *Information Rules*, Harvard Business School Press, 1999, p. 13.

*handling sources of electricity like wind and solar power and even integrating electric vehicles onto the grid.*<sup>8</sup>

In contrast to traditional systems, active control at the consumer (load) side plays an important role in the Smart Grids area. Demand Side Management (DSM)/Demand Response (DR) is an appropriate method in order to improve the quality of the power and energy system as well as to reduce energy consumption<sup>9, 10</sup>. It is common understanding, in both research and industrial communities, that traditional hierarchical automation design approaches are not going to work for the Smart Grid. The control architecture of the Smart Grid is seen by many researchers as a heterogeneous network of controllers communicating in a peer-to-peer manner<sup>10</sup>. Given the large number of heterogeneous hardware elements present in Smart Grids, standards for the design and implementation of their automation, communication and control systems are indispensable. Several standardisation bodies (IEEE, ISO, IEC, ITU, etc.) are working on this topic. A very important approach for communication and interoperability is the IEC 61850 standard<sup>11</sup>, which is referenced extensively in the *NIST Framework and Roadmap for Smart Grid Interoperability Standards*<sup>12</sup>.

IEC 61850 aims to harmonize the information and data used in power utility automation in order to simplify the interoperability between heterogeneous devices from different vendors. The standard consists of ten different parts covering the topics of modelling, configuration, and communication, using object-oriented data modeling. One of the core elements are the so called *Logical Nodes* (LN) for the modelling of devices and functions of the power system (e.g., circuit breaker, voltage controller). LN properties are usually represented in tabular format; however, the *System Configuration description Language* (SCL) – based on XML – has been introduced into IEC 61850 to enable the modelling of a complete configuration of a power utility system. Since the IEC 61850 standard mainly addresses the interoperability of power system utilities, additional standards are required in order to account for the implementation of their functionalities (e.g., interlocking functions, voltage control functions, ancillary services). Promising approaches to be applied are for example the IEC 61131-3 programming languages and/or the IEC 61499 reference model<sup>13</sup>. There are many advantages using the IEC 61499 approach for Smart Grid applications, including its object-based component orientation, reusability, interoperability, and system-level view. For instance, IEC 61499 technology can be used for:

- **System level design and simulation:** Due to the provision of the system model as well as the availability of executable models the IEC 61499 is a very good choice to get a system level view of a distributed Smart Grid application as well as to use it for system level simulations<sup>14</sup>.

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<sup>8</sup> <http://energy.gov/oe/technology-development/smart-grid>

<sup>9</sup> S. Bogosyan, “Recent advances in renewable energy employment,” *Industrial Electronics Mag.*, IEEE, Sep. 2009, pp.54-55.

<sup>10</sup> P. Palensky and D. Dietrich, “Demand Side Management: Demand Response, Intelligent Energy Systems, and Smart Loads,” *IEEE Transactions on Industrial Informatics*, Aug. 2011, pp.381-388.

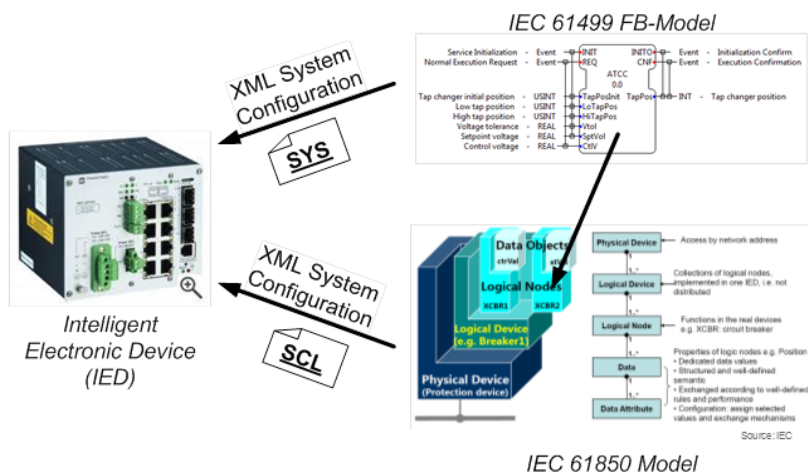
<sup>11</sup> IEC 61850, *Communication networks and systems for power utility automation*, Parts 1 - 10, International Electrotechnical Commission, 2010.

<sup>12</sup> [http://www.nist.gov/smartgrid/upload/NIST\\_Framework\\_Release\\_2-0\\_corr.pdf](http://www.nist.gov/smartgrid/upload/NIST_Framework_Release_2-0_corr.pdf)

<sup>13</sup> N. Higgins, V. Vyatkin, N. Nair and K. Schwarz, “Intelligent Decentralised Power Distribution Automation with IEC 61850, IEC 61499 and Holonic Control”, *IEEE Transactions on Systems, Machine and Cybernetics, Part C*, 41(1), 2011, pp.81-92

<sup>14</sup> T. Strasser, M. Stifter, F. Andr n, D. Burnier de Castro, and W. Hribernik, “Applying open standards and open source software for smart grid applications: Simulation of distributed intelligent control of power systems,” *IEEE Power and Energy Society General Meeting*, 24-29 July 2011, pp.1-8.

- **Implementation of IEC 61850 LN in Intelligent Electronic Devices (IED)**<sup>15</sup>: Figure 1 shows the use of IEC 61499 FBs for the standard-compliant implementation of LN in IEDs. Through its object-based nature the IEC 61499 approach is a perfect extension of the IEC 61850 capabilities.



**Figure 1** - Example of the implementation of IEC 61850 Logical Nodes (LN) via IEC 61499

## SMART CONVEYORS

Airport Baggage Handling Systems (BHS) are a classic example of complex automation systems combining requirements for modularity and distribution with high performance, reliability, and flexibility. Using smart modules with embedded intelligence is a possible and very promising approach for the realisation of BHS. Such modules will integrate sensors, actuators, and embedded control devices with open software architecture, allowing for easy plug-and-play integration with other modules and machines into complex self-configurable systems. Each machine will be controlled by an intelligent agent – the software that combines traditional low level control functions with communication and collaboration with related devices<sup>16</sup>.

Using the IEC 61499 reference model for the realisation of the corresponding control architecture is very promising. In a first realisation an IEC 61499 application for the complete automation of a small airport BHS has been created. It consists of dozens of identical FBs – one per conveyor section. Each FB is internally structured according to the Layered Model-View-Control (MVC) design pattern for IEC 61499<sup>17</sup>. An overview of the resulting IEC 61499 control application is depicted in Figure 2.

To test the feasibility of distributed control implementation deployed on a network of embedded control devices, a testbed consisting of more than 50 networked control nodes has been constructed, corresponding in complexity to a medium-sized airport<sup>18</sup>. The hardware is heterogeneous, comprising platforms from four

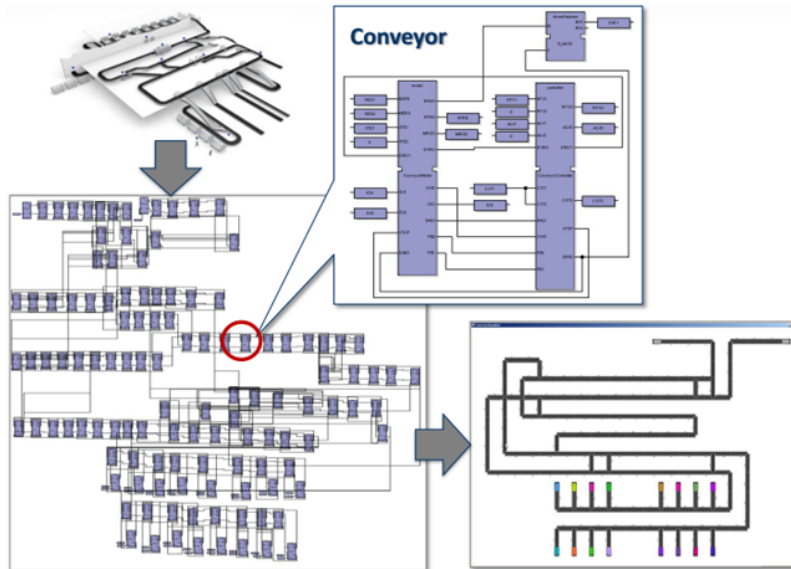
<sup>15</sup> G. Zhabelova and V. Vyatkin, "Intelligent Logical Nodes of IEC 61850 and IEC61499 for Multi-agent Smart Grid Automation", *IEEE Transactions on Industrial Electronics*, 2012, 59(5), pp. 2351 - 2362.

<sup>16</sup> G. Black and V. Vyatkin, "Intelligent Component-Based Automation of Baggage Handling Systems with IEC 61499," *IEEE Transactions on Automation Science and Engineering*, April 2010, pp.337-351.

<sup>17</sup> <http://www.holobloc.com/doc/despats/mvc/index.htm>

<sup>18</sup> Y. Yan and V. Vyatkin, "Distributed execution and cyber-physical design of Baggage Handling automation with IEC

different vendors and including 48 lightweight IEC 61499-based modules<sup>19</sup>, each of which could be embedded into a conveyor or a motor drive.



**Figure 2** - Application of IEC 61499 to an airport Baggage Handling System

Various simulations and experiments with the testbed have shown the ability of the IEC 61499 approach to meet the required levels of modularity, distribution, reliability and flexibility. Runtime flexibility has been achieved through the use of agent-based control that includes dynamic distributed routing of every piece of baggage. This imparts active fault tolerance to the BHS, whereby it is capable of continued operation even in case of breakdowns in some conveyor sections. This study has demonstrated the feasibility of implementing a variety of BHS control functions in a truly distributed manner, and has illustrated a systematic pattern for structuring agent-based control and deploying it onto a distributed network of IEC 61499 devices.

## SMART BUILDINGS

The distributed nature of the building automation domain, and its need for distributed intelligence, make it a natural fit for the application of IEC 61499 technology. The Austrian company *nxtControl*<sup>20</sup>, a software vendor for IEC 61499 based systems, is actively involved in several projects in building automation for office buildings, hotels, and shopping malls as well as data centers. The following challenges for the implementation of a building control system were similar in almost all of these projects:

- The hardware setup of the building automation system has a distributed nature in which various controllers, sometimes from different vendors, are in use.
- Different communication protocols have to be used, for example KNX<sup>21</sup>, DALI<sup>22</sup>, ENOCAN<sup>23</sup>.

61499,” *IEEE International Conference on Industrial Informatics (INDIN)*, 26-29 July 2011 , pp.573-578.

<sup>19</sup> [http://www.isagraf.com/get/ETFA07\\_SS1\\_Final17Oct2007.pdf](http://www.isagraf.com/get/ETFA07_SS1_Final17Oct2007.pdf)

<sup>20</sup> <http://www.nxtcontrol.com/en.html>

<sup>21</sup> <http://www.knx.org/>



- The control engineers have to deal with weak or often changing requirements, and the reality at the building site is often very different from that envisioned during the design and planning phase.
- Cost pressures and a very tight time frame are challenges for the control engineers during the design and implementation of the control system.

These challenges demand a very flexible software architecture for the building automation system. Therefore, in order to offer the greatest impact for system integrators and control engineers, the vendor has developed an IEC 61499-based *component library* of the most-used devices and functions in commercial buildings. For missing devices and functions, the vendor and customers together are continuously working on additional specifications in order to extend the existing IEC 61499 building automation library. This library consists of *software objects* including not only control logic but also visualization, I/O connection and documentation, which are very important aspects for the realization of control solutions. The vendor has therefore introduced a so-called *Composite Automation Type (CAT)* which includes all these elements, on the basis of the IEC 61499 FB model. Once all the objects are available the engineering and commissioning of the automation for the buildings can be done very quickly. It is simple drag-and-drop engineering. The engineer makes an instance of a library element (CAT), drags it in the IEC 61499-compliant editor, connects the different objects as needed, and the same instance is then dropped in the HMI editor. This combined approach drastically speeds up the design and development procedure in the building domain. For example, a distributed control solution for a training center with 140 cells (i.e., office rooms) on 4 floors has been implemented in a very short time. The automation solution comprises the control of the heating, ventilation, air-conditioning, lighting, electrical distribution system, and the monitoring of the fire smoke exhaustion system as well as the integration of a web-based visualization system of the training center building. In total, 12 embedded controllers equipped with an IEC 61499 runtime system connected to about 1200 I/Os are used for the control solution.

## SMART FACTORIES

Mass customization of footwear is characterized by very dynamic and heterogeneous demand for products whose features are customized to user requests, and by generally high production volumes, thus justifying the adoption of highly automated production systems. The high number of product variants and possible customizations, together with the need to match evolving production requirements and market trends, can be accomplished only by relying on extremely agile and reconfigurable production solutions. A production system has been developed to meet the challenging requirements of this market. The resulting modular and reconfigurable system architecture<sup>24</sup>, illustrated in Figure 3, comprises a number of production islands connected by a flexible transport system. This system was named the European Best Practice in mass customization in 2009. The production system architecture is composed of the following main production phases: (1) cutting of shoe components, (2) stitching of the shoe upper components, (3) last milling, (4) shoe assembly and roughing, (5) sole application, (6) shoe finishing, and (7) packaging. In order to match the

<sup>22</sup> [http://en.wikipedia.org/wiki/Digital\\_Addressable\\_Lighting\\_Interface](http://en.wikipedia.org/wiki/Digital_Addressable_Lighting_Interface)

<sup>23</sup> <http://www.enocean-alliance.org/home/>

<sup>24</sup> E. Carpanzano and F. Jovane, “Advanced Automation Solutions for Future Adaptive Factories”, *CIRP Annals - Manufacturing Technology*, 56(1), 2007, pp.435–438.

evolving production requirements, the production system has been conceived with two major characteristics:

1. **Flexible transport system:** Different shoe production cycles require the product to visit different production stations – within each phase – according to specific sequences of operations . This results in a high number of alternative routings across the shop floor depending on the production process to be executed. As a result, the transportation system has been designed as a scalable line composed of a number of standalone mechatronic modules. In turn, each module is composed of two transport and dispatching units, the table and the manipulator and a buffering island, serving specific machines disposed it. This mechanism enables each item to reach equally well any operation unit of the shop-floor coherently with the process plan.
2. **Flexible and reconfigurable machines:** Machines have also been conceived with reconfigurable and flexible fixturing and tooling systems, to match frequent changes of product geometric and technological features. As example, within the robotized roughing cell, flexibility has been exploited with reference to (i) dedicated multifunctional tools for differentiated shoe roughing and gluing, (ii) a flexible gripper for fixturing and handling of items with extremely different shapes and dimensions, and (iii) variable geometry tool path generation.



**Figure 3** - Views of the mass-customization shoe factory

Agility and reconfigurability requirements necessitate complex and flexible automation infrastructure, characterized by different hierarchical levels covering several control tasks – from the single control loop to the supervision, coordination, and scheduling activities.

With specific focus on the control system, a distributed and modular architecture has been designed coherently with the standard IEC 61499. The adoption of this standard has been driven by two major advantages. On the one hand, it supports the *control software development across its lifecycle* from the control specification, the architecture and functional design, the algorithm development until the implementation, verification and validation up to the final deployment of the control software into the real target. In addition, the development of a control software solution for a reconfigurable manufacturing system requires very high levels of software *modularity, integrability, diagnosis, customization, and convertibility*. Compared to traditional control solutions characterized by monolithic, rigid and loosely-coupled architectures, the development of IEC 61499 based control software is conceived to enable efficient control modifications without a major overhaul of the entire software so to accomplish the integration and/or substitution of portion

of the control software driven by system reconfigurations or adaptations.

The shop floor control system solution relying on IEC 61499 standard has been implemented in ISaGRAF 5.2 workbench<sup>25</sup>. Specific Function Blocks of the implemented control system incorporate a set of control algorithms devoted to ruling single controlled mechatronic components, as well as module optimization policies whose goal is to compare the actual and nominal behaviors of components and executing an adaptation if necessary. Full modularity and reconfigurability of single modules is thus supported, both from hardware and from software point of view. In fact, twofold automation reconfigurability<sup>26</sup> has been incorporated in the control Function Blocks, facing both forecasted and unforeseen events:

- **Off-line predictive reconfiguration:** The control system comprises some latent Function Blocks, coupled with forecasted system physical reconfigurations so that as soon as the physical reconfiguration will occur, the correspondent control modules are activated by Function Block events.
- **On-line dynamic reconfiguration:** When a new intelligent unit is introduced in the system, it openly shares its functional description, process capabilities, and requirements. The recognition phase involves the comprehension of the entity features to be exploited within the production environment so to enable the integration of the new entity (new Function Blocks,) within the control infrastructure.

Both the off-line and the on-line control reconfiguration policies require – beside the control module integration at shop-floor – an adaptation of the dispatching process. For each single product, it ensures the understanding of the mapping of tasks-to-be-performed vs. resources, dynamic step by step building of consequent product routing, and resulting distribution of tasks across (new) available resources. The deployment of such a solution evidences how the IEC 61499 approach extends not only “horizontally” (i.e., at shop-floor level), but also *vertically*, involving *supervisory and control management levels*.

An example of off-line control reconfiguration is related to the roughing and cementing robotic cell. The robotic cell control has been implemented by considering a set of production cases, with each representing the sequence of operations to be performed for the specific part type. Together with the production cases related to the actual part types to be processed, there is a number of cases related to parts types which are not at the moment under production but are expected to be included in the future. As a result, when the new part type will be introduced in the product portfolio, the control will be robust in the reaction so that it will be automatically capable of recognizing the part type and associating it to one of the existing specific cases.

### III. TAKEOFF PHASE

In this section, we utilize the lessons learned in the IEC 61499 Launch phase to identify:

- The application domains most likely to deliver significant returns to early adopters;
- the characteristics of early adopters most likely to realize significant returns; and
- critical factors necessary for the success of these early adopters.

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<sup>25</sup> [http://www.isagraf.com/pages/products/Isagraf/appworkbench\\_detail.htm](http://www.isagraf.com/pages/products/Isagraf/appworkbench_detail.htm)

<sup>26</sup> A. Valente and E. Carpanzano, “Development of multi-level adaptive control and scheduling solutions for shop-floor automation in Reconfigurable Manufacturing Systems“, *CIRP Annals - Manufacturing Technology*, 60(1), 2011, pp.449-452.



## APPLICATION DOMAINS

Using the lessons learned from the Launch phase, the following common characteristics can be identified for those application domains most likely to deliver significant returns to early adopters of IEC 61499 technology:

1. The application requires **functional distribution** of automation and control, due to one or more of the following factors:
  - a. The system may be **geographically distributed**, as in the case of the Smart Grid.
  - b. **Local** (manual) as well as **global** control may be required, as in Building Automation.
  - c. Local as well as global **automation** may be required for **robustness** against fault conditions.
  - d. Local as well as global control may be required to **reduce overall system complexity**.
2. The application presents a **high level of functional replication**.
3. The application may require high levels of **distributed intelligence** such as software agent architectures, which may require the encapsulation and reuse of data and algorithms in high-level languages such as Java and C++, rather than the lower-level languages typical of programmable controllers (PLCs) or the configuration-based architecture of typical distributed process control systems (DCSs).
4. The application may require **frequent reconfiguration**.
5. The application cannot be addressed effectively and economically with existing technologies such as PLCs, DCSs or personal computers (PCs).

Applying these criteria to surveys of the field<sup>27, 28</sup> in addition to the examples shown in Section II, the following application domains can be identified as presenting significant potential returns for early adopters of IEC 61499 technology: (i) high value-added manufacturing processes requiring frequent reconfiguration (e.g., semiconductors, consumer electronics, pharmaceuticals, or fashion); (ii) machines and processing equipment containing high value-added intellectual property (IP), (iii) flexible material handling systems, (iv) building automation, (v) energy management systems, and (vi) smart grids.

## EARLY ADOPTERS

The position of early adopters can be best understood by reference to the “industrial automation value-added chain”<sup>29</sup>. In this chain, each player can add value by encapsulating its Intellectual Property (IP) in reusable and deployable form according to the IEC 61499 architecture.

1. A significant number of **Tool/Service Vendors**, and an increasing number of **Device Vendors**, have

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<sup>27</sup> I. Terzic, A. Zoitl, B. Favre, and T. Strasser, “A survey of distributed intelligence in automation in European industry, research and market,” *IEEE Conference on Emerging Technologies and Factory Automation (ETFA)*, 15-18 Sept. 2008, pp.221-228.

<sup>28</sup> V.Vyatkin, “IEC 61499 as Enabler of Distributed and Intelligent Automation: State-of-the-Art Review”, *IEEE Trans. on Industrial Informatics*, vol. 7, no. 4 (Nov 2011), pp. 768-781.

<sup>29</sup> J.H.Christensen, T.Strasser, A.Valentini, V.Vyatkin, and A.Zoitl, “The IEC 61499 Function Block Standard: Software Tools and Runtime Platforms”, *ISA Automation Week 2012*.

- already become early adopters and are offering products into the marketplace<sup>30</sup>.
2. **Machine Vendors** can use the solutions provided by the Tool/Service and Device Vendors and encapsulate their machine know-how into intelligent machines.
  3. **System Integrators** are now able to develop whole system solutions for **Industrial Enterprises** using hardware and software components offered by the Tool/Service, Device, and Machine Vendors and add value via system- and enterprise-specific extensions using the elements provided by IEC 61499.

## ADVANTAGES FOR EARLY ADOPTERS

The **architecture** defined in IEC 61499-1, combined with appropriate **software tools** as defined in 61499-2 and the **open system** attributes of software *portability*, device *configurability* and *interoperability*<sup>31</sup> achieved through **Compliance Profiles** as prescribed in 61499-4 will enable early adopters to meet the unique requirements imposed by high value-added application domains.

1. The **functional distribution** of automation and control is enabled by:
  - a. **Application-centric design** through the construction of *applications* as interconnected *function blocks* and *subapplications*.
  - b. A **system-level view** through the construction of systems as interconnected *devices*, each of which may contain multiple *resources* configured internally as networks of interconnected *function blocks*.
  - c. A **mapping** mechanism for the distribution of the elements of applications into resources of the system's devices.
  - d. Compliance Profiles can specify standardized means for software tools to perform the necessary **configuration tasks** to accomplish the specified functional distribution.
2. **Functional replication** is enabled by:
  - a. **Functional encapsulation** in the form of IEC 61499 Library Elements (*classes* in object-oriented programming terminology), including *data types*, *FB types*, *device types*, *resource types*, *subapplication types*, and communication network *segment types*.
  - b. **Reuse** through the population of applications and systems with *instances* of classes from **software libraries**, as well as the population of *composite FB types* with instances of existing FB types.
  - c. **Hardware abstraction** through the use of Service Interface FBs (SIFBs) to segregate hardware dependencies from the functionality of reusable and deployable FB types, thus simplifying their deployment to heterogeneous hardware platforms.
3. IEC 61499 software tools and runtime platforms can enable **distributed intelligence** through the programming and reuse of data and algorithms in high-level languages such as Java and C++.
4. Flexible **configuration** and **reconfiguration** (even dynamic, “on the fly” reconfiguration) are enabled by the **management services** defined in IEC 61499-1, supported by Compliance Profiles:
  - a. **FB management services** for the management of individual FBs within resources, including

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<sup>30</sup> *ibid.*.

<sup>31</sup> *ibid.*

- querying, starting, stopping, creation and deletion.
- b. **Connection management services** for the querying, creation and deletion of data and event connections within resources.
5. IEC 61499's **open, distributed, event-driven** and **object-oriented architecture** will enable early adopters to address these large, complex applications more **effectively** and **economically** than with existing technologies such as PLCs, DCSs or Personal Computers (PCs).
- a. The **open** architecture, in conjunction with **Compliance Profiles**, can ensure that early adopters will have a choice of compatible software tools, hardware devices and component libraries without the cost and risk of “lock-in” to a single vendor.
  - b. The **inherently distributed** architecture minimizes the costs of system integration.
  - c. The **event-driven** architecture provides a uniform and simplified means of synchronizing communication and I/O with the execution of algorithms without the need for additional software tools and configuration tasks.
  - d. The **object-oriented** architecture simplifies the programming and reuse of high-level code for autonomous, cooperative (“holonic”) devices, as well as for integration with enterprise systems.

#### IV. CRITICAL SUCCESS FACTORS

With the availability of cheap and powerful embedded computing hardware, distributed automation and control systems based on IEC 61499 can be implemented on a large scale in industrial and commercial applications<sup>32</sup>. Almost all the elements necessary to ensure a successful Takeoff phase for IEC 61499 adoption would seem to be in place. However, two critical factors, **compliance profiles** and **trained personnel**, need to be addressed in order to maximize the potential returns to early adopters of IEC 61499.

##### COMPLIANCE PROFILES

An increasing number of tool vendors are now providing software tools and runtime platforms as the necessary building blocks for early adopters farther up the value-added chain. In addition, a number of vendors are beginning to offer domain-specific libraries for reuse<sup>33</sup>. However, the lack of a universally accepted multi-vendor consensus *compliance profile* and corresponding *test suites* and *certification procedures* imposes serious barriers to entry and limits flexibility of choice for potential early adopters. The means for addressing these problems are described in a separate paper<sup>34</sup>.

##### TRAINED PERSONNEL

The lack of trained personnel can be a significant barrier to adopters of a new technology, and IEC 61499 is no exception. This lack may be especially acute in regions where little academic training in the new technology

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<sup>32</sup> T. Sauter, S. Soucek, W. Kastner, D. Dietrich, “The Evolution of Factory and Building Automation”, Industrial Electronics Magazine, IEEE , vol.5, no.3, pp.35-48, Sept. 2011.

<sup>33</sup> See, for instance, <http://www.nxtcontrol.com/en/products/nxtlib.html>

<sup>34</sup> J.H.Christensen *et.al.*, “The IEC 61499 Function Block Standard: Software Tools and Runtime Platforms”, *op.cit.*

has become available, i.e., most regions of the world except continental Europe and New Zealand.

Experience has shown that students with some background in IEC 61131-3 programming of control systems, or in object-oriented design and programming, or both, can achieve a modest level of proficiency in the use of IEC 61499 software tools in three days of hands-on training<sup>35</sup>. Following this, a student with familiarity in an application domain can typically learn to use design patterns and their associated software libraries for that domain at a rate of approximately one pattern per day. Additional expert consulting may be required to enable design teams to accomplish specialized tasks such as porting runtimes to target hardware platforms.

This situation presents a promising opportunity for professional organizations such as ISA to present a series of training courses for early adopters of IEC 61499, to be followed by training for much larger groups of practitioners as the technology approaches the maturity phase.

## V. CONCLUSIONS

There is abundant evidence that the adoption curve of IEC 61499 technology is poised for takeoff, presenting significant potential payoffs for early adopters of this technology. The most promising application domains for this technology are those that require the encapsulation, reuse and distribution of intellectual property (IP = “know-how”) in distributed, intelligent automation and control systems. An increasing number of software tools, hardware and firmware platforms, and design methodologies and expertise are becoming available to support these early adopters.

The major risks to early adopters are that they may not have access to all the required functionality in portable, configurable and interoperable form, and may not be able to deploy a sufficient number of adequately trained personnel. These risks can be mitigated through adequate training programs and ongoing development of multi-vendor compliance profiles, test suites and certification procedures.

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<sup>35</sup> S.A.Sierla, J.H.Christensen, K.O.Koskinen, J.P.Peltola, "Educational Approaches for the Industrial Acceptance of IEC 61499," *12th IEEE Conference on Emerging Technologies and Factory Automation (ETFA 2007)*.