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ORIGINAL PAPER

PROPOSAL FOR NEW AUTOMATION ARCHITECTURE SOLUTIONS FOR INDUSTRY 4.0

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ABSTRACT. **Background:** New automation technologies that incorporate an Industry 4.0 perspective for the integration of production environments are increasingly being considered by industrial organizations. The concept behind these solutions is to break the current paradigm of automation layers, which is based on their hierarchical level rather than their functions. In this sense, a new architecture is needed to address the needs that arise from the perspective of Industry 4.0.

The purpose of this article is to propose a new architecture based on integrated functions to meet the current requirements of production systems.

Methods: An analysis of case studies of automation solutions deployed in real-world production systems is performed and the results can be used for further discussion of this area of research.

Results and conclusions: The case studies applied to 5 large multinational companies showed that the current architectures in the plants in operation already provide strong signs of technological evolution. These architectures have technologies that can support the construction of a new Industry 4.0-oriented architecture. However, more than cutting-edge technologies, the actual architectures need to be better defined in terms of functions within a solution.

Key words: automation technology, ISA-95, interoperability, Industry 4.0.

INTRODUCTION

The integration of different equipment into an automated system is essential to optimize and make improvements to production processes. In recent times, new developments in equipment and automation systems generated renewed interest in this subject, particularly making communication more efficient between components of a system. Current automation architectures in operation show the necessity of flexibility and modularity, with interoperability between manufacturers to allow for optimized and efficient systems. A key feature of today's manufacturing systems is the impact of exponential technologies (additive manufacturing, autonomous robotics, Internet of Things and other technologies referred to as Industry 4.0 technologies) as an accelerator or catalyst that enables individualized solutions, flexibility and cost savings in industrial processes [Schlaepfer, Koch 2015].

Traditional models of automation architectures, which focused on integration between hierarchical layers, such as ANSI/ISA-95 [ISO/IEC 62264, 2007], are losing ground in new technological systems. The division into layers splits the systems into isolated "islands" in an automation platform; this creates obstacles that compromise access to some information. Sometimes, this model also supports the development of alternative solutions so that different and limited machines

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of different manufacturers may communicate with each other. Establishing communication through the hierarchical layers of an automation platform in order to access data may freeze the system and make the integration of intelligent systems difficult.

The necessity of ubiquitous information sharing for automation systems is not a requirement of the traditional hierarchical models and, thus, there is a need for new systems focused on integrated functions. These functions allow all equipment, regardless of their hierarchical layer, to be connected in real-time and share information. The shared connection among all machines using the same platform prevents loss of data by deviation in secondary communication and allows more rapid decisions to be made by intelligent systems. For this reason, unified architectures are being utilized as support to meet the Industry 4.0 requirements in many systems, regardless of the platform and the manufacturers. Using these architectures allows a direct connection to be made between controller and equipment, without passing through a computer to manage and display data. A new automation architecture is proposed, which is better suited to Industry 4.0 and addresses the needs of intelligent systems for more efficient processes. The traditional industrial automation pyramid does not meet the requirements of the coming technological systems and a new architecture must provide a single integrated base for all machines in a shared automation platform. Autonomous production systems inside the concept of I4.0 depend on an automation architecture that enables access to all the components of a platform in real-time. The integration of all systems into a common base will become a requirement for technological solutions in a connected industry. Furthermore, this integration must allow decision-making to be instantaneous, to prevent losses in production processes and to increase the performance in data flow to guarantee better results in the final product.

Section 2 presents the method utilized to raise the essential requirements for a new architecture. In Section 3, an architecture model is proposed with the requirements for the new technological solutions. Discussions about the results can be found in Section 4. The conclusions are presented in Section 5.

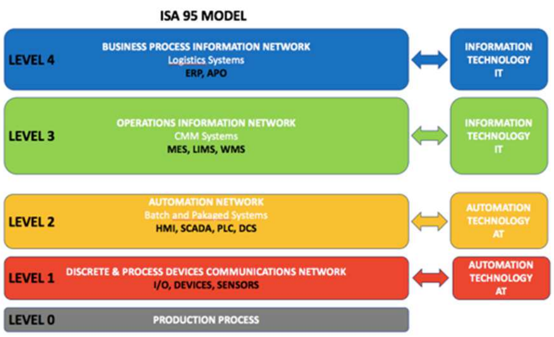
LITERATURE REVIEW: DEFINITION OF THE ELEMENTS

ANSI / ISA 95: Traditional view

The ANSI/ISA 95 standard [ISO/IEC 62264, 2007] is a consolidated architecture that defines 5 levels in a manufacturing organization. These levels are layers hierarchically organized in a system in which each layer represents a set of organizational elements. Level 0 defines the real physical processes. The automation devices and systems responsible for the automation of manufacturing processes are represented by levels 1 and 2, where actuators and sensors monitor the field devices in level 1 linked to automation and control systems represented by level 2 (DSC, SCADA, PLC). Level 3 is composed of monitoring systems used to manage manufacturing operations through the control of productivity, quality and maintenance indicators (MES, LIMS, WMS). Level 4 consists of Enterprise Resource Planning (ERP) systems that are responsible for business planning and logistics through the entire supply chain. The hierarchical structure formed by the proposed architecture in the ISA 95 standard is presented as the following organizational sequence [Brandl et al. 2013]:

- Level 0: The actual production process (time range: minutes, seconds, milliseconds).
- Level 1: Monitoring and manipulating the production process (time range: minutes, seconds, milliseconds).
- Level 2: Monitoring, supervisory control and automated control of the production process (time range: minutes, seconds).
- Level 3: Workflow, batch and discrete control to produce the desired products, maintaining records and optimizing the production process (time range: days, shifts, hours, minutes, seconds).
- Level 4: Establishing the basic plant schedule, production, material use, delivery and shipping, determining inventory levels (time range: months, weeks, days).

The new scenario boosted by new technologies from Industry 4.0 brings with it the necessity of devices and systems with new functions suited to this architecture. Optimizing the production process requires systems to be able to identify demands with predictability and to make decisions automatically, without human interaction [Hanebrink et Al.2015]. Therefore, the architecture must have systems with the ability to access all available information from a process in real-time. New machines and systems are being developed with superior capacities in this area. Around the world, the traditional manufacturing industry is in the process of a digital transformation, accelerated by the application of exponentially growing technologies (e.g. autonomous robots and drones, intelligent sensors and additive manufacturing) [Schlaepfer, Koch 2015]. The need for an architecture driven by system and device functions, instead of by hierarchy, is becoming more and more evident. This new proposal must approximate the layers and allow all information from the production process to be collected in the same shared base, with the possibility of access in real-time, even by mobile devices and technologies outside of the process.



Source: Saturno et al. [7]

Fig. 1. ANSI/ISA-95 hierarchical levels

Functions, systems and protocols

Functions and systems from the ANSI/ISA-95 [ISO/IEC 62264, 2007] model are fully operational in industrial environments today. Table 1 presents these functions and systems highlighted by the ANSI/ISA-95 model that, when combined with new technologies, support the proposal of a new architecture to meet the demand for connectivity and interoperability between systems.

Table 1. ANSI/ISA-95 functions and systems

Functions:

- Batch Control
- Continuous Control
- Discrete Control
- Order Processing
- Production Scheduling
- Production Control
- Materials and Energy Control
- Procurement
- Quality Assurance
- Product Inventory Control
- Product Cost Accounting
- Product Schipping Admin
- Maintenance Management
- Research & Development
- Marketing & Sales

Systems:

- **PLC** - Programmable Logic Controller
- **DCS** - Distributed Control System
- **BAS** - Batch Automation System
- **SCADA** - Supervisory Control and Data Acquisition
- **PMIS** - Project Management Information System
- **WMS** - Warehouse Management System
- **CMMS** - Computerized Maintenance Management System
- **PLM** - Product Lifecycle Management
- **ERP** - Enterprise Resource Planning
- **CRM** - Customer Relationship Management
- **HRM** - Human Resource Management

Protocols form the communication channel which establishes the connection between systems and allows functions to achieve the expected results in an integrated architecture. An interconnected industry requires flexible and open protocols of communication between systems, integrating all the components of an architecture and allowing easy access to data in real-time. The connected systems can interact with each other using standard protocols, forecasting failures, reconfiguring themselves and adapting to changes in the process [Bechtold et Al.].

Technologies and requirements

Technologies evolve constantly to promote better performance of systems, products and efficiency in production. This evolution, nowadays, is determined by the pillars of Industry 4.0, so that upgrades in technology meet the new demand for solutions that, in fully integrated and decentralized contexts, support the concept of smart factories. Implementation of decentralization mechanisms will be the only way to deal with the complexity of individualized industrial production [Rüßmann et al. 2015]. Current scientific literature shows that certain technologies are needed to support the pillars of Industry 4.0 and jumpstart the required technological evolution. Papers related to the subject presented in this study show little variation in their analysis of the most important technologies required to meet the fundamental needs of the connected industry. Papers referenced in this study show that, in the technological context, there is a highly consistent approach in efforts to meet technological demands.

The Boston Consulting Group (BCG) [Rüßmann et al. 2015] brings a selection of new technologies identified as necessary for the future of productivity. In this article, the authors present the technologies as a group of 9 technological advances fundamental to support the industrial production of the future. Capgemini Consulting [Bechtold et Al.] divides Industry 4.0 into four key pillars: (i) Smart Solutions, (ii) Smart Innovation, (iii) Smart Supply Chains and (iv) Smart Factories. These pillars are supported by a similar group of technologies to those which support the new proposed model for evolution. McKinsey & Company [Hanebrink et al. 2015] has broken down the same group of technologies into 4 areas: data, computational power and connectivity; analytics and intelligence; human-machine interaction; and digital-to-physical conversion. These 4 divisions are considered necessary for digitization and end up grouping the same technologies current in the literatures of the area. Figure 2 presents a compilation of the main technologies needed to fully implement Industry 4.0.

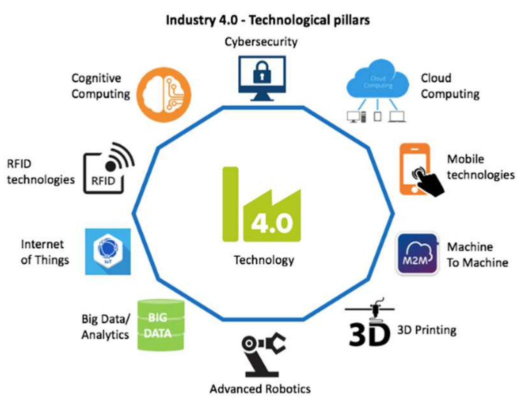


Fig. 2. Technologies for Industry 4.0

Technologies need to meet requirements extracted from functions inside existing architectures. These requirements are necessary to guarantee flexibility, reliability and connectivity among systems. Industry 4.0 will deliver greater robustness together with the compliance to higher quality standards in engineering, planning, manufacturing, operations and logistics processes. [Kagermann et al., 2013].

RESEARCH PROTOCOL

Identifying the current architecture structures and automation topologies in operation in the industrial environment is the first step towards the technological evolution to a fully interconnected industry. The starting point for technological evolution is to define the technologies available in the current architecture, its main gaps and how they can be filled to support a new solution. Defining the main barriers of an application in operation is the fundamental point to help in the proposal of a new model. Figure 3 depicts the research method used in this work, which is presented in the next subsections.

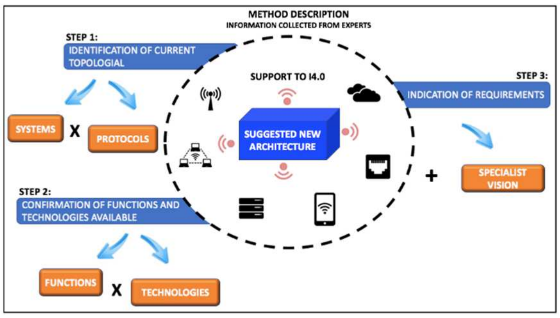


Fig. 3. Research method definition

Purpose of the study

This study aims to identify the main requirements necessary to ensure the integration of existing functions in current architectures into a common platform. These requirements must meet the current technological demands and concepts of Industry 4.0. To achieve the expected results, an analysis was performed, observing the main characteristics of the systems in operation. An evaluation was performed to identify available systems, the communication between them, the connections between them and the protocols used.

Research protocol definition

The research protocol was developed to allow information to be extracted in a simple and clear way, and to define architectures in operation. A series of questions was developed to guide the results through an orderly and organized logic based on the architectures proposed by ISA 95, with the inclusion of new technologies. The evaluation elements are based on the architecture proposed by ISA 95 and the technologies were extracted from current literature, according to Section 2 of this study.

In the first stage of the evaluation, the objective is to discover the topology of the current architecture. The systems in the current architecture are identified and communication between these systems is explored, indicating the protocols used. In the second stage of evaluation, the existing systems are assigned functions and the technologies. This evaluation triangulates the relationship between functions, available systems and technologies. In this stage, it is possible to have a sense of the adherence of the current system to the concepts of Industry 4.0 and its open gaps. Finally, in the third stage, experts are instructed to provide a view of the requirements necessary for the current architecture so that it can support a new solution for an intelligent and connected factory. A connection is made between the current architecture and the requirements discovered by a comparison of the different studied architectures.

Research protocol application

The application of this protocol is accomplished through the collection of information from specialists in various plant technology areas, in case studies. The insights collected from these experts can provide valuable insights into the current frameworks and architectures available, helping to identify the main barriers to be overcome to develop the new technologies for Industry 4.0 and to meet the current demands of connectivity and integration. The study was applied to 5 large multinational companies operating in different market segments. The protocol was applied in two organizations from the automotive parts industry, one organization from the industrial tools industry and two organizations from the household appliances industry, with the objective of seeking a broader view of existing architectures and avoiding making the results overly specific to one sector. The specialists were selected based on their roles within each evaluated company. The recorded results were compared and the comparison between the case studies brings practical and real information regarding the situation of the companies.

RESULTS AND DISCUSSIONS

This section presents and discusses the data that were collected from the experts of the AT/IT areas of the studied organizations. In the first stage, the study protocol sought to point out the current architecture in operation in these companies through the indication of the existing systems, primarily indicating which protocols are currently in use for communication between systems in order to identify the current degree of support for Industry 4.0.

Topologies

Observing Table 2, it can be verified that the Ethernet protocol is, in large part, the most commonly used communication standard among the systems. This information is important when one thinks of connected and intelligent factories, since this protocol already allows for the integration of all components of a solution. Direct communication between these systems allows for direct and real-time access, in order to process information.

Table 2. Systems and protocols

SYSTEMS	SYSTEMS AND PROTOCOLS USED										
	PLC	DCS	BAS	SCADA	PIMS	WMS	CMMS	PLM	ERP	CRM	HRM
PLC		3 1		3 1 1			5				
DCS	3 1			3 1			3	1	1		
BAS											
SCADA	3 1 1	3 1					4	5	4		
PIMS								5	4		
WMS								2	3	1	
CMMS	4 1	2 1		3 1				5			
PLM		1		4 1	5	2	5		5	1	
ERP		1		4	4	3		5		1	
CRM						1		1	1		
HRM											

PROTOCOLS	ETHERNET IPV4	PROFIBUS-DP	DEVICE NET

However, a major problem encountered in these platforms is the separation of the layered architecture within the topology. The architecture is usually divided, without direct communication between the layers. Information Technology (IT) systems are linked to an enterprise Ethernet network and Automation Technology (AT) systems are connected to an Industrial Ethernet network, a second independent network within the company. Another negative aspect observed is that although the architectures already have communication through the Ethernet protocol, the band usually used and in operation is still IPv4. Thinking of future solutions for the integration of equipment with autonomous decisions and the Internet of Things for communication between machines, the migration to IPv6 will be necessary to follow the evolution of these technologies. New, highly technological equipment is already IPv6 enabled, due to the scarcity of addresses available in the IPv4 protocol. It should also be remembered that Figure 3 shows the protocols most commonly used for communication between the control layer (PLC and DCS) systems and other layers. If one deepens the search for the communication information in the lower layers of sensing and drives, it will be seen that the use of several other protocols such as Profibus, Modbus, ASi and others are still widely used for communication with the logical controllers of the system. This does not directly affect the solutions in terms of technology, but makes access these sensors in real time by higher layers difficult without a gateway or other specific device. Figure 4 presents a traditional architecture from the compilation of the information of the topologies studied.

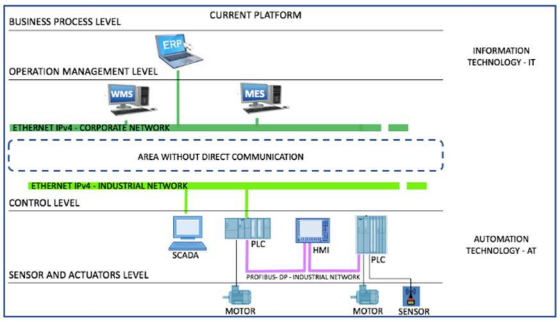


Fig. 4. Sample topology from the case studies

Systems x Functions

Systems in an automation architecture are always dependent on the evolution of technologies, so that it is possible to optimize a process by increasing its efficiency. However, this increased efficiency has been achieved over time through performance enhancements of automation equipment within each layer of the pyramid proposed by the ANSI/ISA-95 standard. These optimizations were restricted to the operating areas of the optimized systems. The new proposal for intelligent plants requires integrated solutions of independent layers, with all components communicating through the same platform. In this new model, the technologies optimized for a system allow a real increase in efficiency across all the functions of the architecture. Providing new technologies to improve the flexibility and connectivity between the functions of an architecture directly contributes to a real increase in the efficiency of the entire process.

In this second phase, the objective of the study among the participating organizations was to detect which functions are used within the existing architectures, and also which new technologies are already available that are proposed by Industry 4.0. Identifying how new technologies are being used for existing functions within an architecture is highly relevant to guiding the evolution of a plant. Table 3 shows this. Although they are companies from different industries, their architectures are similar when we observe the functions used. Most functions are common to all companies observed in this study. It can be observed in the table that new technologies are linked to existing functions, including the indication of which technologies are more adherent to the current scenario in the running architectures. Analyzing this cross-referencing, one can note that mobile technologies, cloud computing, advanced robotics, and Big Data/Analytics are already being tested or in use. The use of mobile applications and access to Web services has grown widely in facilitating remote access to many of the existing functions. In this respect, integrated networks and the Internet of Things are making both internal and external access flexible. Cloud computing technology and Big Data solutions also have great prominence, since data protection is increasingly important for the reliability of a more autonomous solution. Advanced robotics is another fast-growing technology in the industry. More efficient and expeditious processes are needed to meet the growing market demand. The integration of robots into functions within the architectures allows the adoption of autonomous and connected solutions. Other technologies suggested by Industry 4.0, though of equal importance to the evolution of the architecture, are still moving at a slower pace in today's architectures.

Table 3. Existing functions and technologies used in the automation topology

FUNCTIONS	SYSTEMS										
	PLC	DCS	BAS	SCADA	PIMS	WMS	CMMS	PLM	ERP	CRM	HRM
Batch Control				1 1							
Continuos Control	5 2 4 1	2 2 1		3 1 3 1			3 1 3	4 1 3 2			
Discrete Control	1 1 1 4	2 2 1		2 1 3 1			3 1 3	3 1 3 2			
Order Processing		2						1	3 4 4	1 1	
Production Scheduling	3 2 3	2 3				1 2 3					
Materials and Energy Control	2 1 2 1	3 1 1		2 2 1 2	2 3 3 2						
Procurement		1 1			3 4 3 2	1 4 4					
Quality Assurance	4 3 1 1	1 1		1 1 4			4 3 2	1 2 5 2		1 1	
Product Inventory Control		3 1				1 5 5					
Product Cost Accounting					3 4 3 2			2 4	1 3 4		
Product Shipping Admin		2 3 2				5 2 1 2			3 4 3		
Maintenance Management	4 1 3 1	4 3 1 1		4 4 2	5 5		5 2 5 1				
Research & Development					2 3 3 3			3 2 4			
Marketing & Sales								1 3 1		1 1	

TECHNOLOGIES
- MOBILE TECHNOLOGIES
- CIBERSECURITY
- CLOUD
- 3D PRINTING
- M2M
- IIoT
- BIG DATA/ANALYTICS
- RFID
- ADVANCED ROBOTICS
- COGNITIVE COMPUTING

Functions x Requirements

Defining the key requirements needed for functions within automation solutions is key to guiding the evolution of an automation plant, with the goal of making it more efficiently integrated. Based on the requirements raised, systems and technologies can be combined to form architecture solutions with integrated functions in a common platform with flexible and fully-connected technologies. These functions, in turn, can be more efficient through more autonomous and accessible systems in real time. The requirements must ensure that the choice of systems and technologies supports a solution for Industry 4.0, i.e., the requirements for the functions needed to meet the emerging demands of intelligent factories. Figure 6 presents the requirements raised by the specialists needed for the functions of the current architecture for the plant to evolve technologically. These requirements appear in the Industry 4.0 literature as the main items needed to implement new technologies and also as important items for the evolution of the factories in order to meet connectivity requirements. The experts evaluated the current facilities within the company and made their contribution to the key requirements for each function according to their opinion of what a smart plant should be like.

Table 4 indicates that the requirements for integrated data management, reliability and digital infrastructure seem to be of the greatest importance for the majority of functions. The other requirements are particularly relevant for specific functions.

Table 4. Requirements according to experts

Functions	Systems							
	STANDARDIZATION	ORGANIZATION OF THE PROCESS	PROTECTION KNOW-HOW	SCALABILITY	INTEGRATED DATA MANAGEMENT	RELIABILITY	DIGITAL INFRASTRUCTURE	HYPERCONNECTIVITY
Batch Control								
Continuos Control	5	5	4	5	5		5	5
Discrete Control	4	5	4	5	5		4	5
Order Processing	2	1			5	5	5	3
Production Scheduling	5	2		1	5	4	4	2
Materials and Energy Control	3		2	1	4	2	4	2
Procurement		3			4	5	1	
Quality Assurance	4		5		4	2	4	2
Product Inventory Control	4	2		2	3	3	1	
Product Cost Accounting		4	1		4	4	1	1
Product Shipping Admin	3	1		4	4	3	3	3
Maintenance Management	5	3	5	3	4	3	5	4
Research & Development		1	4		4	1	1	
Marketing & Sales			2		3	3	1	

New architecture proposal

The models provided by the current literature coupled with the information suggested by experts from the AT/IT areas within the studied companies suggest the need for new architecture models to accommodate intelligent factory concepts. Demand for autonomous solutions requires that the development of functions and systems within the architecture be designed to meet this requirement. Data from the entire production chain must be cross-referenced so that the supply, production, dispatch and sales areas provide each other with the information necessary to enable these autonomous decisions to be made. The use of a common bus for communication of all components in real time is one of the first points to be explored in order to allow the inclusion of open protocols and flexible communications among the most different solution providers. Figure 5 presents a suggested topology to meet the new technological demands. In this proposal, the centralization of communication networks indicates the possibility of real communication between all the components of the independent architecture of layers. In this proposed architecture, higher-level systems of monitoring and business planning can access information directly in the lower layers of process control. Autonomous decisions can be made without the need for human intervention since the equipment and machines can have a direct connection with the systems of production planning, supplies and sales. The inclusion of wireless technologies and the Internet provide greater flexibility to the process by allowing external users to have direct access to production information, because the company's architecture is integrated with mobile technologies and Web Service systems. In Industry 4.0, field devices, machines, production modules and products are comprised as CPS that autonomously exchange information, trigger actions and control each other independently [Weyer, Schmitt, Ohmer, Gorecky 2015].

Systems with integrated functions such as CPS are designed to focus information and make the integration of different layers within the architecture more flexible. The use of cyber-physical systems with intelligently networked objects in manufacturing will enable a new quality of flexible working in the future which will constitute tasks distributed in multiple dimensions of time, space and content [Bauer et. al. 2015].

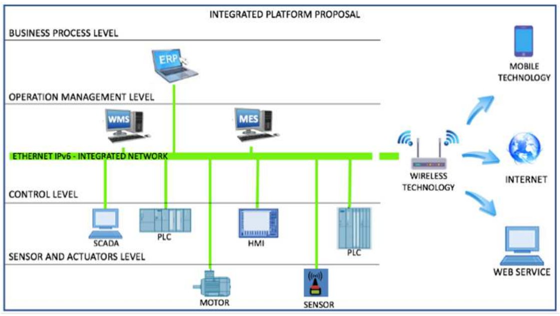


Fig. 1. Proposed architecture model

The challenge of new skills

A significant barrier that cannot be overlooked in the evolutionary path towards Industry 4.0 is the knowledge gap in the skills of users in contact with new technologies. The protocol of the research that was carried out in the companies presented in this study shows, from the point of view of specialists, that while technologies progress at a rapid pace, knowledge about these technologies does not develop so quickly. The emergence of new skills and new professions is inevitable and indeed is already happening, as is the case with Big Data/Analytics scientists, for example. Adaptations in the pattern of human resources training will be required, as well as the training of highly skilled manpower, bringing together management, engineering and innovation knowledge to withstand all the changes of this new industrial revolution.

CONCLUSIONS

Choosing systems and their technologies for an automation architecture is a challenge, especially when an architecture is already in place. The definition of technologies to meet the concepts of an intelligent plant must meet the requirements of the functions that are integrated within these architectures. When considering Industry 4.0, it can be observed through the conducted case studies that there is still a long way to go to a fully integrated, decentralized architecture. But the first step is diagnosing the current state of the plant in terms of automation and then defining what the necessary requirements are for the elements in the architecture for which a technological evolution plan needs to be defined. In order to apply the intelligent factory concept, architectures must meet the demands of Industry 4.0, and in this case the functions within an architecture must be thought out and developed to be compatible with this concept. Improving the performance of individual pieces of equipment and systems no longer supports the current demand for a fully integrated industry. In this scenario, the functions now become the core of automation architectures and the integration between all functions within a solution must be secure, flexible and integrated with a single communication standard, allowing internal and external connectivity to the production line tied to concepts of intelligent production systems.

The case studies applied to 5 large multinational companies showed that the current architectures in the plants in operation already provide strong signs of technological evolution. These architectures include technologies that can support the construction of a new Industry 4.0-oriented architecture. However, more than cutting-edge technologies, the current architectures need to be better defined in terms of functions within a solution. After all, the functions will be responsible for servicing the intelligent solutions. These functions still need to be better designed so that new architectures can be built with more autonomous and decentralized solutions.

This study has some limitations, as it is based on the ideas of specialists in 5 companies that are in direct contact with the architectures discussed in the present study. A compilation of information gathered in both scenarios generated the conclusions presented by this research. However, a survey also considering a larger sample of industries for data collection, and also considering the involvement of existing solution providers, could give better results in the development of a new architecture proposal to support Industry 4.0 concepts.

REFERENCES

Schlaepfer R.C., Koch M., 2015. Industry 4.0 Challenges and solutions for the digital transformation and use of exponential technologies. Deloitte, Zurique.

ISO/IEC 62264, 2003-7. Enterprise-control system integration" Part 1: Models and terminology, Part 2: Object model attributes, Part 3: Activity models of manufacturing operations management.

Brandl D., Hunkar P., Mahnke W., Toshio O., 2013. OPC UA and ISA 95 – Interoperability for MES by implementing ISA 95 with OPC UA. BR&L Consulting 64–73.

Bechtold J., Kern A., Lauenstein C., Bernhofer L., Industry 4.0 The Capgemini Consulting View.

Rüßmann M., Lorenz M., Gerbert P., Waldner M., Justus J., Engel P., Harnisch M., 2015. The Future of Productivity and Growth in Manufacturing industries. The Boston Consulting Group.

Hanebrink J., Kunze H.M., Mix T., Löffler J., Felten D., Leppien K., 2015. How to Navigate digitization of manufacturing sector. Mickinsey Industry 4.0 Global Expert Survey.

Saturno M., Pierin Ramos L.F., Polato F., Deschamps F., Rocha Loures E.F., 2017. Evaluation of interoperability between automation systems using multi-criteria methods. Procedia Manufacturing 00 001–008.

Liao Y., Rocha Loures E.F., Canciglieri Junior O., Panetto H., 2014. A novel approach for ontological representation of analytic hierarchy process. Advanced Materials Research 945: 675-682.

Kagermann H., Wahlster W., Helbig J., 2013. Recommendations for implementing the strategic initiative INDUSTRIE 4.0. Acatech – National Academy of Science and Engineering 001–082.

Weyer S., Schmitt M., Ohmer M., Gorecky D., 2015. Towards Industry 4.0-Standardization as the crucial challenge for highly modular, multi-vendor production systems. IFAC-PapersOnLine 48, 3: 579-584. http://dx.doi.org/10.1016/j.ifacol.2015.06.143

Bauer W., Hammerle M., Schlund S., Vocke C., 2015. Transforming to a hyper-connected society and economy - towards an Industry 4.0 Procedia Manufacturing 3, 417–424. http://dx.doi.org/10.1016/j.promfg.2015.07.200

PROPOZYCJA ARCHITEKTURY ROZWIĄZAŃ AUTOMATYCZNYCH DLA INDUSTRY 4.0

STRESZCZENIE. **Wstęp:** Nowe rozwiązania technologiczne automatyzacji obejmujące zakres Industry 4.0 dla zintegrowanych środowisk produkcyjnych cieszą się dużych zainteresowaniem organizacji zajmujących się produkcją. Istota koncepcyjna tych rozwiązań polega na zmiana paradygmatu warstw automatyzacji opartych o ich funkcje do poziomu hierarchicznego. W tym ujęciu, nowa architektura jest potrzebna to zaadresowania potrzeb wynikających z perspektywy Industry 4.0.
Celem tej pracy jest przygotowanie propozycji nowej architektury opartej na zintegrowanych funkcjach spełniających obecne wymagania systemów produkcyjnych.
Metody: Przeprowadzono analizę przypadków rozwiązań automatyzacji w istniejących systemach produkcyjnych. Jej wyniki posłużyły do dyskusji w dalszej części pracy.
Wyniki i wnioski: Analizę przeprowadzono w 5 międzynarodowych przedsiębiorstwach, których obecna architektura operacyjna spełnia obecnie wysokie wymagania ewolucji technologicznej. Architektury te są technologiami podtrzymującymi konstrukcję nowej architektury zorientowanej na Industry 4.0. Niemniej jednak, bardziej niż najnowsze technologie, obecnie stosowane architektury wymagają lepszego zdefiniowania w zakresie funkcji pełnionej w danym rozwiązaniu.

Słowa kluczowe: automatyzacja, ISA-95, współdziałanie, Industry 4.0.

EIN VORSCHLAG FÜR DIE ARCHITEKTUR AUTOMATISCHER TECHNOLOGIE-LÖSUNGEN FÜR INDUSTRY 4.0

ZUSAMMENFASSUNG. Einleitung: Neue technologische, Industry 4.0 umfassende Automatisierungslösungen für das integrierte Produktionsumfeld erfreuen sich wachsenden Interesses seitens der Produktionseinrichtungen und-organisationen. Das konzeptuelle Wesen solcher Lösungen beruht auf Veränderungen des Paradigmas von Automatisierungsebenen, die ihre Funktionen auf das hierarchische Niveau beziehen. Bei dieser Annahme braucht man die neue Technologie-Architektur für die Platzierung innovativer Bedürfnisse, die auf die Perspektive von Industry 4.0 zurückzuführen sind.

Das Ziel der vorliegenden Arbeit ist es, einen Vorschlag für eine neue Technologie-Architektur, die auf die integrierten Funktionen gestützt ist und gegenwärtig die an die Produktionssysteme gestellten Anforderungen erfüllt, auszuarbeiten.

Methoden: Es wurde eine Analyse der die Automatisierungslösungen in bestehenden Produktionssystemen anbetreffenden Studienfälle durchgeführt. Deren Ergebnisse dienten einer breiteren Diskussion im weiteren Teil der Arbeit.

Ergebnisse und Fazit: Die Analyse wurde in 5 internationalen Unternehmen, in denen die bestehende operative Architektur gegenwärtig hohe Anforderungen bezüglich der technologischen Evolution erfüllt, durchgeführt. Die betreffenden Architekturen gelten als Technologien, die die Konstruktion einer neuen, am System Industry-4.0 orientierten Architektur unterstützen. Allerdings erfordern die gegenwärtig angewendeten Technologien eine bessere Definition bezüglich der in einer gegebenen Aufgabe erfüllenden Funktion als die neuesten Technologie-Lösungen.

Codewörter: Automatisierung, ISA-95, Zusammenarbeit, Mitwirkung, Industry 4.0.

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