Chapter 1
Towards the Next Generation of Industrial Cyber-Physical Systems

Armando W. Colombo, Stamatis Karnouskos, Thomas Bangemann

Abstract Intelligent Networked embedded systems and technologies, ranging from components and software to Cyber-Physical Systems (CPS) [1], are increasingly gaining importance for the ICT supply industry, the system integrators and all major mainstream sectors for the economy [9]. Development of new technologies for provisioning innovative services and products can lead to new business opportunities for the industry. Monitoring and Control are seen as key for achieving visions in several CPS dominated areas such as industrial automation systems, automotive electronics, telecommunication equipment, smart-grid, building controls, digitally driven smart cities, home automation, greener transport, water and waste water management, medical and health infrastructures, online public services, and many others [10]. This chapter introduces the cloud-based industrial CPS and describes the first results of making it a reality towards the Next Generation SOA-based SCADA/DCS systems. The reader is taught about the research, development and innovation work carried out by a set of experts collaborating under the umbrella of the IMC-AESOP project, for specifying, developing, implementing and demonstrating major features of Intelligent Monitoring and Control Systems and the advantages of implementing them in different industrial process control environments.

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1.1 Current Paradigms and Technologies associated to CPS

The advances in computation and communication resources have given rise to a new generation of high-performance, low-power electronic components that have advanced communication capabilities and processing power. This has led to new possibilities that enable improved integration of heterogeneous devices and systems, with particular emphasis on platform independence, real-time requirements, robustness, security, stability of solutions, among other major requirements.

Industrialists, researchers and practitioners are associating these advances with a 4th Industrial Revolution (referred to as Industrie 4.0 in Germany [15]) happening today, where physical "Things" get connected to Internet [12] allowing that the real touchable world integrates part of the cyber-space. With these foundations in CPS [1] and IoT, a number of different system concepts and architectures (e.g. www.iot-a.eu) have become apparent in the broader context of Cyber-Physical Systems [20, 1, 4] over the past couple of years such as Collaborative Systems [11], Service-Oriented Architectures (SOA) [3], networked cooperating embedded devices and systems [22], cloud computing [2] etc.

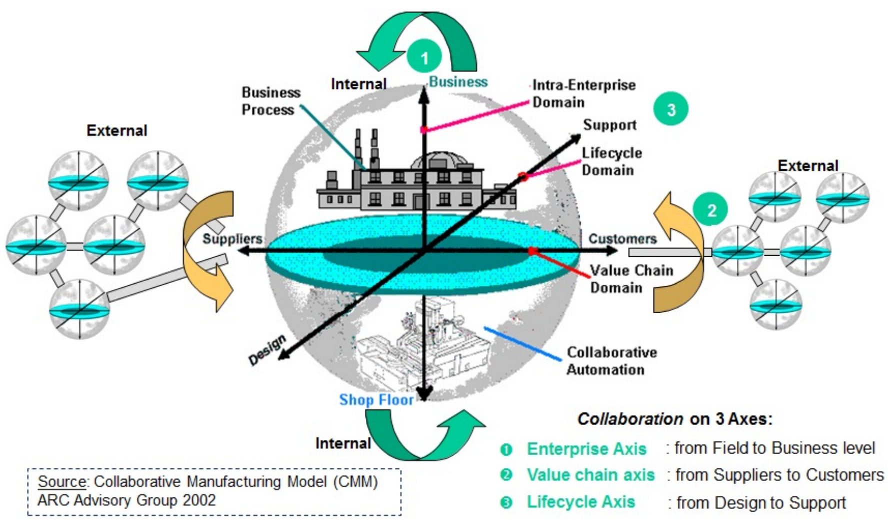

Fig. 1.1 Collaborative Manufacturing Model

The umbrella paradigm underpinning novel collaborative systems is to consider the set of intelligent system units as a conglomerate of distributed, autonomous, intelligent, pro-active, fault-tolerant and reusable units, which operate as a set of co-operating entities [6]. These entities are capable of working in a pro-active manner, initiating collaborative actions and dynamically interacting with each other in order to achieve both local and global objectives, and this along the three basic collabora-

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tion axes (as depicted in Fig. 1.1) associated to any application domain and related infrastructure, i.e. enterprise, supply-chain and life cycle axes [11].

From the physical device control level up to the higher levels of the business process management system, as defined in ISA-95 (www.isa-95.com): from suppliers through the enterprise to the customer [5], and from design through operation to recycling phases of an engineering system life cycle, collaboration will be enabled if, on one hand, the involved systems act and react on their environment, sharing some principal commonalities and, on the other hand, have some different aspects that complement each other to form a coherent group of objects that cooperate with each other to interact with their environment [22].

As we are moving towards Smart Cyber-Physical Systems and the "Internet of Things", millions of devices, not all time smart, are interconnected, providing and consuming information available on the network and are able to exchange capabilities collaborating in reaching common goals. As these devices needs to interoperate, both at cyber and also at physical level, the service-oriented approach seems to be a promising solution, i.e. each device should offer its functionality as standard services, while in parallel it is possible to discover and invoke new functionality from other services on-demand. These technologies can be leveraged to build advanced functionality into smart Cyber-Physical Systems, thus enabling building ad-hoc new distributed application paradigms based on interconnected "smart components" with a high level of autonomy.

This evolution towards global service-based infrastructures [6] indicates that new functionality will be introduced by combining services in a cross-layer form, i.e. services relying on the enterprise system, on the network itself and at device level will be combined. New integration scenarios can be applied by orchestrating the services in scenario-specific ways. In addition, sophisticated services can be created at any layer (even at device layer) taking into account and based only on the provided functionality of other entities that can be provided as a service [18, 7]. In parallel, dynamic discovery and peer-to-peer communication will allow to optimally exploit the functionality of a given device. It is clear that we move away from isolated standalone hardware and software solutions towards more cooperative models. However, in order to achieve that, several challenges need to be sufficiently tackled.

The convergence of solutions and products towards the SOA paradigm adopted for smart Cyber-Physical Systems contributes to the improvement of the reactivity and performance of industrial processes, such as manufacturing, logistics, and others. This is leading to a situation where information is being available in near real-time based on asynchronous events, and to business-level applications that are able to use high-level information for various purposes, such as diagnostics, performance indicators, traceability, etc. SOA-based vertical integration will also help to reduce the cost and effort required to realize a given business scenario as it will not require any traditional high-cost solutions such as custom-developed device drivers or third-party integration solutions.

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1.2 A Service-oriented cross-layer Automation and Management Infrastructure

A Service-oriented cross-layer Automation and Management Infrastructure adopts the "collaborative automation" paradigm, combining cloud computing and Web services technologies [16], among others. The aim is to effectively develop tools and methods, to achieve flexible, reconfigurable, scalable, interoperable network-enabled collaboration between decentralized and distributed Cyber-Physical Systems. A first step towards this infrastructure is to create a service-oriented ecosystem. That is, networked systems that are composed by smart embedded devices that are Web service compliant (as depicted in Fig. 1.2 and Fig. 1.3), interacting with both physical and organisational environment, able to expose, consume and sometimes process (compose, orchestrate) services, pursuing well-defined system goals.

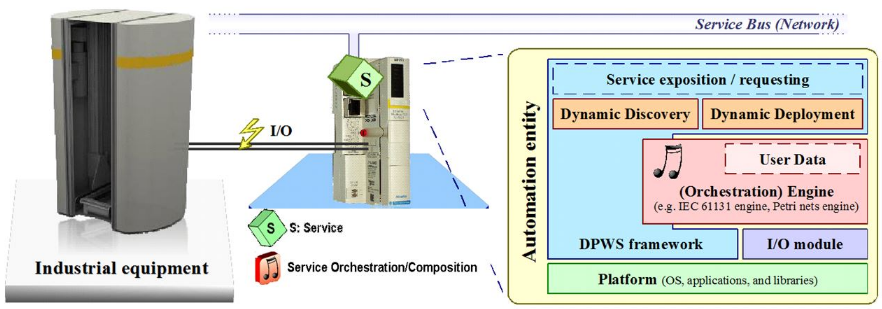

Fig. 1.2 An industrial component virtualised by a Web service interface embedded into smart automation device (adapted from [23])

Taking the granularity of intelligence to the automation device level allows intelligent system behaviour to be obtained by composing configuration of devices that introduce incremental fractions of the required intelligence. From a run-time infrastructure viewpoint, the result is a new breed of very flexible real-time embedded devices (wired/wireless) that are fault-tolerant, reconfigurable, safe and secure. Among other characteristics of such systems, automatic configuration management is a new challenge that is addressed through basic plug-and-play and plug-and-run mechanisms. The approach favours adaptability and rapid reconfigurability, as reprogramming of large monolithic systems is replaced by configuring loosely coupled embedded units.

The use of device-level Service-Oriented Architecture contributes to the creation of an open, flexible and agile environment, by extending the scope of the collaborative architecture approach through the application of a unique communication infrastructure [26], down from the lowest levels of the device hierarchy up into the manufacturing enterprise's higher-level business process management systems [18]. The result of having a single unifying application-level communication technology

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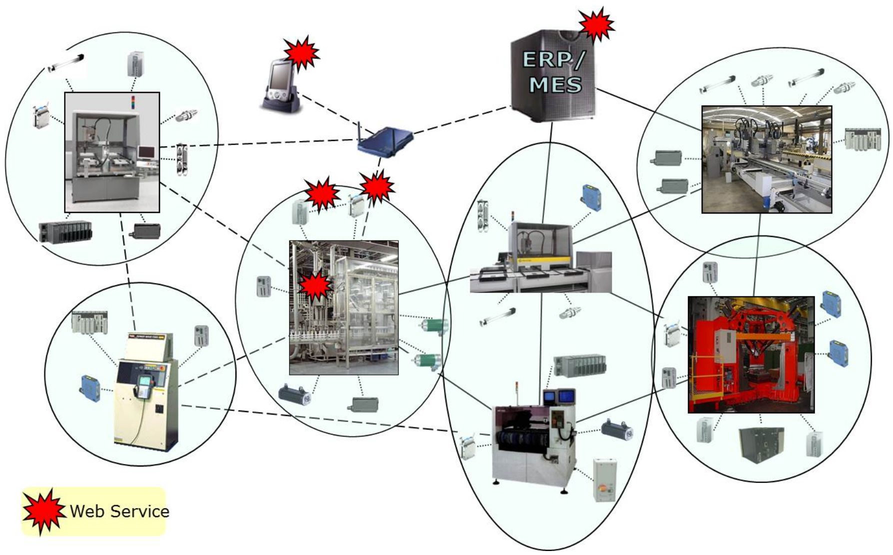

Fig. 1.3 An industrial system viewed as a distributed set of smart service-compliant devices and systems

across the enterprise, labelled as "service bus (network)" in Fig. 1.4, transforms the traditional hierarchical view of the industrial environments into a flat automation, control and management infrastructure. That is, devices and systems located in different levels are all having the same Web service interface and are able to interact. This functional interaction is completely independent from the physical location in the traditionally implemented enterprise hierarchy.

From a pure functional perspective, one of the major challenges is focussed, on one side on managing the vastly increased number of intelligent devices and systems populating the collaborative SOA-based system and mastering the associated complexity. On the other side, following emerging requirements of control, automation, management and business applications, other challenges are the engineering, development and implementation of the right infrastructure to make usable the explosion of available information exposed as services in the "service cloud" originated, e.g. on the SOA-based shop floor [24]. Industrial applications can now be rapidly composed / orchestrated, by selecting and combining the new services and capabilities offered as service in an automation cloud, which represents the partial or total virtualisation of the automation pyramid, as depicted in Fig. 1.5 and explained in this book's Chapter 3.

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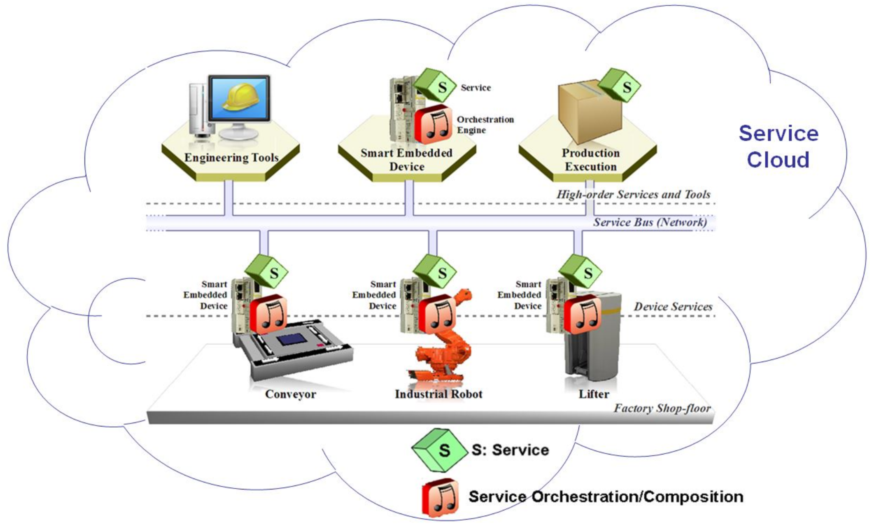

Fig. 1.4 A service-oriented view of an industrial system (adapted from [23])

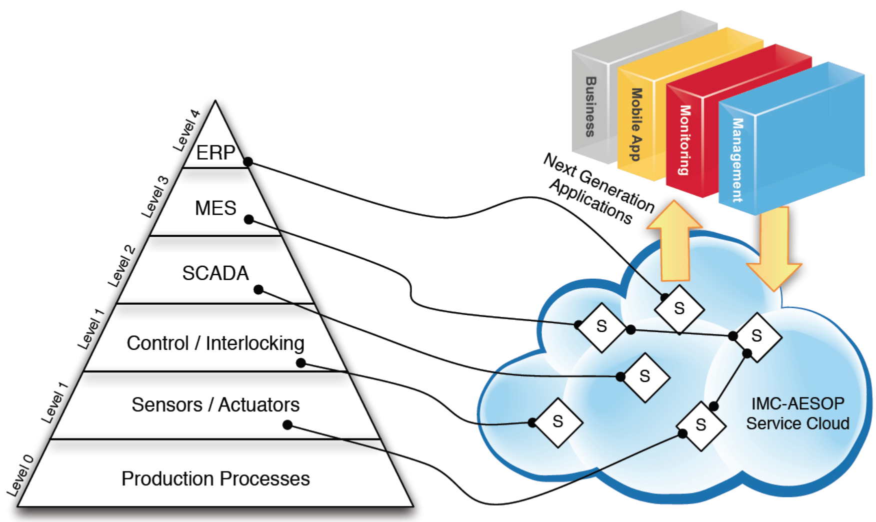

Fig. 1.5 Building supervisory control and management functions as applications using services exposed by devices and systems in the physical world and by the IMC-AESOP cloud in the cyber world

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1.3 Intelligent Service-oriented Monitoring and Control – The IMC-AESOP Approach

The world market for technologies, products, and applications alone that are related to what the Internet of Things enables, i.e. monitoring and control (M&C), will increase significantly in the next years. World M&C market is expected to grow reaching 500 € Billion in 2020. The M&C European market follows the same trends as the M&C world one in terms of product repartition and also market product evolution. The European monitoring and control market will be reaching 143 € Bn in 2020 [25]. When analysing the major application domains for real-time monitoring and control, from the large process industry viewpoint, these indexes and the related expectations outline the tremendous potential and value.

Large process industry systems are a complex (potentially very large) set of (frequently) multi-disciplinary, connected, heterogeneous systems that function as a complex distributed system whose overall properties are greater than the sum of its parts, i.e. very large scale integrated devices (not all time smart) and systems of which the components are themselves systems. Multidisciplinary in nature, they link many component systems of a wide variety of scales, from individual groups of sensors to e.g. whole control, monitoring, supervisory control systems, performing SCADA and DCS functions. The resulting combined systems are able to address problems which the individual components alone would be unable to do and to yield control and automation functionality that is only present as a result of the creation of new, “emergent”, information sources, and results of composition, aggregation of existing and emergent feature- and model-based monitoring indexes.

These very large scale distributed process automation systems that IMC-AESOP is addressing, constitute systems of systems [14], and are required to meet a basic set of criteria known as Maier’s criteria [21], i.e.:

1. Operational independence of the constituent systems
2. Managerial independence of the constituent systems
3. Geographical distribution of the constituent systems
4. Evolutionary development
5. Emergent behaviour

Such systems should be based on process control algorithms, architectures and platforms that are scalable and modular (plug & play) and applicable across several sectors, going far beyond what current Supervisory Data Acquisition and Control (SCADA), and Distributed Control Systems (DCS) and devices can deliver today.

A first fast analysis of current implemented SCADA and DCS systems detects a set of major hinders for not completely fulfilling some of all those criteria: the big number of incompatibilities among the systems, “hard coded” data, different view on how systems should be configured and used, co-existence of technologies from a very long periods of time (often more than 20 years), use of reactive process automation components and systems instead of having them working in a proactive manner. If we began hooking all these hinders, we would soon have an unmanageable mess of wiring, and custom software, and little or no optimal communication. Today this

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has been the usual result, where "point solutions" have been implemented without an overall plan to integrate these devices into a meaningful "Information Architecture".

Looking at latest reported R&D solutions for Control and Automation of very large distributed systems, it is possible to identify today that there are already many known possibilities for covering some and if possible many or all the criteria addressed above. The IMC-AESOP concept is pointing to optimisation at architectural and functional levels of the logical and physical network architectures behind the process automation systems, mainly towards a potential optimal configuration and operation, e.g. of energy consumption [17] in current complex and power hungry process industries, based on service-oriented process control algorithms, scalable and modular SOA-based Supervisory Data Acquisition and Control (SCADA) and Distributed Control Systems (DCS) platforms, going far beyond what current mainly centralized SCADA and DCS can deliver today [16].

To address integration of very large numbers of subsystems and devices, the IMC-AESOP approach takes its roots in previous work in several research and development projects [13, 7, 18], which demonstrated that embedding Web services at the device level and integrating these devices with MES and ERP systems at upper levels of an enterprise architecture was feasible not only at conceptual but also at industrial application level. The first results shown in pilot applications running in the car manufacturing, electromechanical assembly and continuous process scenarios have been very successful, confirming that the use of cross-layer Service-Oriented Architectures in the Industrial automation domain is a very promising approach, able to be extended to the domain of control and monitoring of batch and continuous processes.

This application domain of large process systems composed of very large numbers of systems is very challenging in terms of:

- Distributed monitoring and control of very large scale systems (tens of thousands of interconnected devices are encountered in a single plant) enabling plant efficiency control, product and production quality control.
- A multitude of plant functions requesting information and functionality due to continuously changing and increasing business requirements.
- Integration of existing devices which generates the data and information necessary for the multitude of plant functionalities like plant operation, maintenance, engineering, business and technology, i.e. system of systems integration, operation and evolution.
- The very large spread in device and system performance requirements regarding e.g. response time, power consumption, communication bandwidth, security.
- Legacy compatibility (20 years old systems have to interoperate with modern ones).

When using Service-Oriented Architectures in Process Control applications, several advantages are expected. For open batch and/or process automation monitoring and control systems these include:

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- the ability to be accessed by any other system of the enterprise architecture able to call other services
- improved ease-of-use and simplified operation and maintenance of SOA-based SCADA and DCS system embedded devices due to the universal integration capabilities that the services are offering
- a next generation of SOA-based process automation components offering plug-and-play capabilities, providing self-discovery of all devices and services of the complete plant-wide system.

For proactive batch and/or process automation monitoring and control systems these include:

- the ability to expose their functionalities as services
- the ability to compose, aggregate and/or orchestrate services exposed by themselves and from other devices in order to generate new distributed SCADA and DCS functions (also exposed as "services" at the shop floor)
- at the shop floor these systems are interoperable with SOA-based systems of the upper levels of the enterprise architecture (e.g. integrating ERP and MES with the SCADA and DCS).
- a next generation of SOA-based devices and system exposing SCADA and DCS self-adaptable (emergent) functionalities (as a result of automatic service composition or orchestration), taking care of real-time changes in the dynamic system
- the generation of new monitoring indexes and control functions at different levels of the plant-wide system, as a result of using event propagation, aggregation / orchestration / composition of services and management properties of the SOA-based distributed SCADA and DCS.

All of the systems can benefit from cost-effectiveness, thanks to optimized SCADA and DCS distribution at the device level on the shop floor and at upper IT system levels. An additional benefit stems from the easier network management of large-scale networked systems. Based on these advantages a clear possibility is to generate system energy usage optimisation. With the SOA-approach integration of subsystems having the appropriate information, it can be done both at the operator level and at the business level, where different approaches to energy optimisation can be applied.

1.4 Positioning the IMC-AESOP Approach within the Industrial Automation Landscape

The degree of reliability and efficiency of energy consumption / utilisation in the operation of industrial environments depends not only on the operation of the individual mechatronic/hardware components but also on the structure and behaviour of the embedded supervisory control system. Supervisory tasks have to be performed at two different and separate but networked levels, i.e. the shop floor and the upper levels of the enterprise architecture. At each of those levels is possible to identify a set of functional and logical components that are responsible for performing the

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following functions: sensing, information collection, signal and information processing, decision-making and diagnosis, and discrete-event control.

Each level (enumerated as 1–6 in Fig. 1.6), is having its own time-constraints (from micro-seconds to days and weeks) and its own domain of data and information processing. Monitoring of operations, of the behaviour of the mechatronic/hardware components, and of the system as a whole, is an essential function of such a supervisory control system. Consider the definition of "monitoring" as the act of identifying the characteristic changes in a process and in the behaviour of mechatronic/hardware resources by evaluating process and component signatures without interrupting normal operations [8].

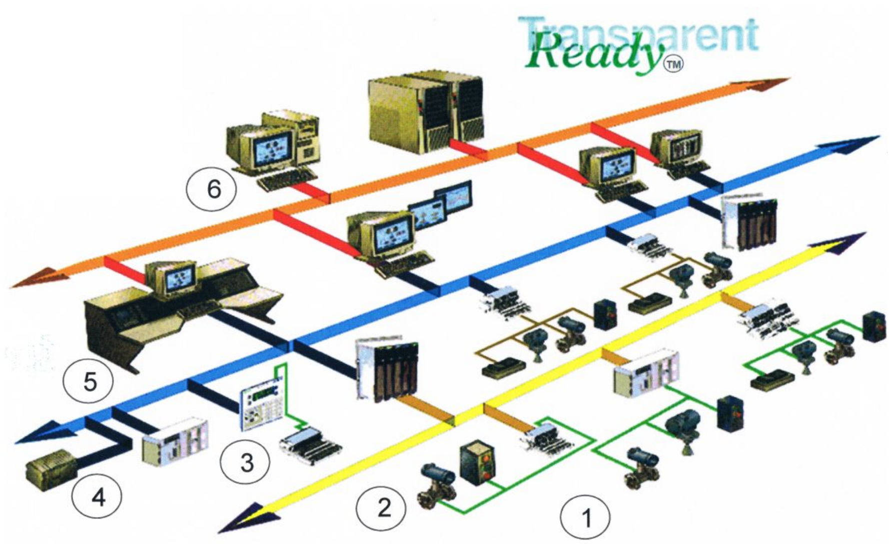

Fig. 1.6 Schneider Electric Enterprise System Architecture "Transparent Ready ™"

In the plant, there are a set of process control stations that control different process sections in the plant, numbered as 2 and 3 in Fig. 1.6). They are connected to various devices, distributed I/O stations, PLCs etc. that are themselves connected to the process equipment labelled with the number 1. For much larger and process-specific equipment, the supplier also includes dedicated and unique devices, systems or complete control. In the overall plant monitoring and control, other systems and sections are also integrated like lubrication systems, transformers, switchgears, valves, ventilation, heating etc. For operators, engineers, maintenance personnel and management, there are one or several control and engineering rooms available, as well as mobile devices for local monitoring and control, depicted under the number 4 in Fig. 1.6). At the enterprise level, there are information access, control and analysis through various management and enterprise information and control systems, identified by the numbers 5 and 6 in Fig. 1.6).

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1.5 Introducing SOA and Cloud-Computing paradigms into the Architecture of a Process Control System

IMC-AESOP proposed an infrastructure that goes well beyond existing approaches for monitoring and supervisory control, as depicted in Fig. 1.7. Following the development of computer network architectures, supervisory systems have undergone a continuous evolution from a first generation based on centralized monolithic structure throughout, a 2nd and 3rd generations exploiting distribution and networking capabilities. The next step was to evolve to a new service-oriented generation, called here "The Next Generation SCADA/DCS systems", exposing functionalities and offering information that spans both domains, i.e. physical world and cyber world as represented in Fig. 1.7 by the service cloud.

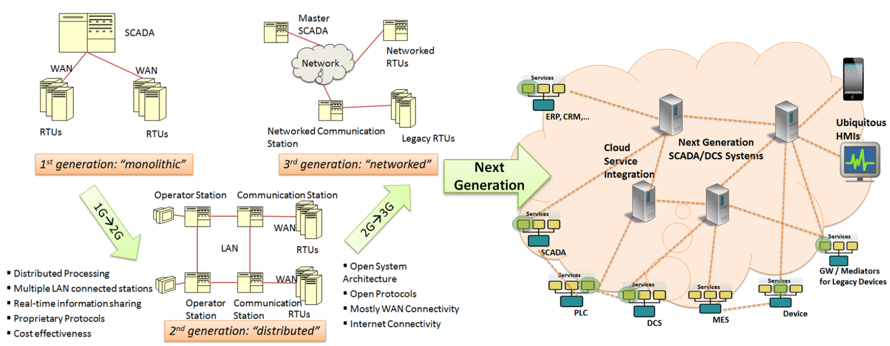

Fig. 1.7 IMC-AESOP impact on evolution of supervisory systems

This Next Generation SCADA/DCS systems enable cross-layer service-oriented collaboration not only at horizontal level, e.g. among cooperating devices and systems, but also at vertical level between systems located at different levels of a computer integrated manufacturing (CIM) or a plant-wide system (PWS). Focusing on collaboration and taking advantage of the capabilities of cooperating objects, poses a challenging but also very promising changes on the way future plants will operate, as well as to the way control and automation software will be designed. Also the form to specify, model and implement the interactions among objects inside the plant. The future "Perfect Plant" [19, 6] will be able to seamlessly collaborate and enable monitoring and control information flow in a cross-layer way. As such, the different systems are part of a SCADA/DCS ecosystem, where components (devices and systems) can be dynamically added or removed, where data and information is exposed as services, where dynamic discovery enables the on-demand information acquisition and where control, automation and management functions can be performed as composition, orchestration, choreography of those services.

All current systems migrated under the SOA-based paradigm start being capable to share information in a timely and open manner, enabling an enterprise-wide

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system of systems that dynamically evolves based on business needs. With this approach, industrialists, researchers and practitioners also target future compliance and follow concepts and approaches that start enabling to design today the perfect "legacy" system of tomorrow. That is, a system being able to be easily integrated in long-running infrastructures (e.g. in chemical industry with lifetime of 15-20 years).

The SOA-based approach, proposed by IMC-AESOP and explained in the following chapter, when applied to manufacturing and process control systems, allows, on one hand, to present a set of SCADA and DCS functionalities as services, simplifying in this manner the integration of monitoring and control systems on application layer. On the other hand, the networking technologies that are already known to control engineers, could also simplify the inclusion of, or migration from, existing solutions into the next generation SCADA and DCS systems at network layer.

To achieve this, the focus of the research, development and innovation works has been put onto collaborative large-scale dynamic systems combining physical devices and systems with cloud-based infrastructure. Architectures and platforms that are scalable and modular (plug & play) and are applicable across several sectors have been implemented supporting the cyber-physical infrastructure. Populating the cloud-based infrastructure with the adequate cyber (and physical systems) presents another set of challenges to the engineers and specialists responsible for "Engineering" the manufacturing and process control and automation systems as depicted in Fig. 1.8. Starting with the connectability of devices and systems, following with the interoperability that facilitates the collaboration, a new form of component-functional-oriented thinking affects the development and the use of the whole set of engineering methods and tools and this along the whole engineering life cycle.

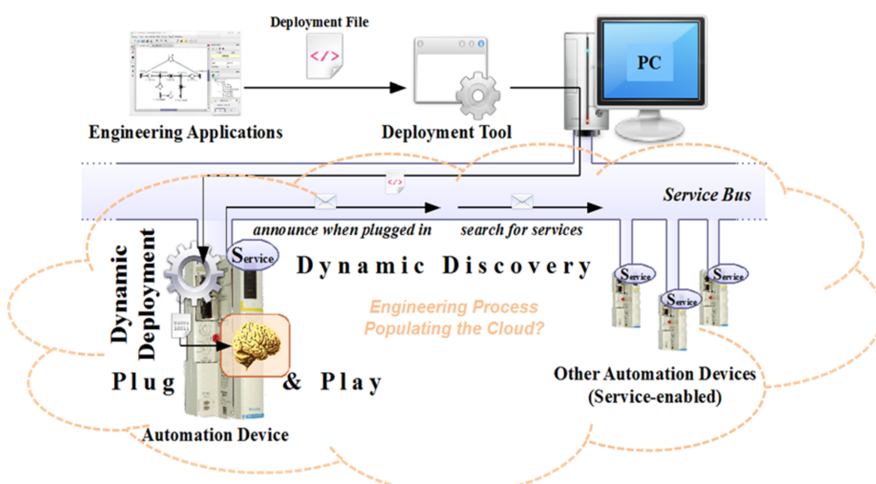

Fig. 1.8 Challenging the Engineering – Populating the Automation Cloud

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Having populated the cloud with the right and necessary services exposed in the cyber-space by smart SOA-compliant devices and systems located in the physical-space is the first obligatory step towards the realisation of the vision addressed above. But the vision goes clearly far beyond from what current SCADA and DCS can deliver today. Collaborations will be able to be created dynamically, serve specific purposes and will span multiple domains, as explained later in Chapter 11.

Summarizing, the advent of the SOA paradigm for being applied in management and automation presents a significant aid to manufacturers in face of today's industrial challenges. The availability of SOA-ready smart devices and systems with associated or even built-in monitoring and other supervisory control services delivers to the production engineers a new way of looking at the industrial environment. It is opening new avenues to visualize the evolution of the systems and associated processes by making available a more detailed visualisation of the system's status in real-time.

1.6 The IMC-AESOP Approach – Beyond the state-of-the-art

The IMC-AESOP approach builds on top of well-known scientific and technological trends such as virtualisation, software-as-a-service, cloud computing, collaborative automation, cooperative objects, etc. and responds to main industrial requirements which are summarized in Fig. 1.9.

In the following sub-sections, the progress beyond what is known today, reached applying the IMC-AESOP Approach, is briefly described in three major dimensions i.e. (i) end-user perspective, (ii) supplier perspective and (iii) tools and basic technology perspective. Table 1.1 depicts the relationship between these three perspectives and the innovation aspects addressed by the approach. An intensive and carefully prepared analysis of the state-of-the-art in industrial automation is depicted Chapter 2.

1.6.1 End-user dimension

The industrial state of the art of large process control systems can be exemplified by the latest LKAB investment in their KK-4 pellets plant [1], which was taken in production in early 2009. The system has more than 23.000 I/Os running in classical hierarchical control architecture. Parallel to the control system, they have other systems, e.g. for maintenance.

End-users like LKAB do run a number of such large process control systems, continuous or batch. They already have identified areas where cooperation between systems like those discussed above can generate large benefits regarding e.g. pro-

[1] http://www.lkab.com/en/Future/Investments/Refining/

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Table 1.1 Overview of the relation between industrial requirements and IMC-AESOP objectives

Industrial Requirements	**IMC-AESOP Objective**	**Thoughts**
…to enable the optimal operation of large-scale dynamic systems through proactive process automation systems	Propose a Service-Oriented Architecture (SOA) for very large scale distributed systems in Batch and Process Control applications (up to tens of thousands of service-compliant devices and systems distributed across the whole plant-wide system (as depicted in Fig. 1.3 and Fig. 1.4) exposing SCADA/DCS monitoring and control functions as services	Optimisation of the operation of the plant provided by new monitoring indexes and control functions exposed and/or applied as Web services (using discovery mechanism, event filtering, service composition and/or aggregation capabilities offered by the SOA and Web services concepts).
Pro-activeness requires novel predictive models for higher performance and fault adaptation and recovery. The architectures should enable QoS, and reduce the reconfiguration effort	Investigate how "deep" we can go within the plant-wide system (enterprise architecture) with SOA-based monitoring and control models and functions (are we able to get SOA at the device level inside process control loops?)	Process control and monitoring functions will be distributed. Plug & play will be provided by discovery mechanisms, which will be extended to work for large-scale distributed systems
Pro-activeness requires novel predictive models for higher performance and fault adaptation and recovery	Build a foundation for predictive performance of such service architecture based on a formal approach to event based systems	Investigations will determine if event-based mechanism can be used for process control loops and if sufficient performance for use in the lowest levels of control loops can be achieved
Such systems should be based on architectures and platforms that are scalable and modular (plug & play) and are applicable across several sectors, going far beyond what current SCADA and DCS can deliver today	Investigate the co-habitat of current used synchronous SCADA and DCS with the new asynchronous SOA-based monitoring and control system, going beyond what the current implemented control and monitoring systems are delivering today	It should be possible to build many different SCADA and DCS functions by combining the current centralized with the new SOA-based systems
The architectures should facilitate re-use	Propose a transition path from legacy systems (e.g. a 20 year old machine) to a SOA compliant system. To investigate, how the today's DCS structures (runtime as well as engineering) can be mapped to SOA, exploding the natural similarities that seem to exists	The transition path should consider the requirement that the new SOA-based process control system has to be an adequate legacy system in the next 5-10 years
…a new generation of open and proactive batch and process automation monitoring and control systems, and to address associated standardisation	Contributing to relevant standardisation bodies like IEC65E (IEC 61512-1 and -2), based on the former IS SP88, NAMUR NE33, OASIS (e.g. WS-DD WG) etc.	

duction efficiency, product quality control, energy usage optimisation, CO_2 minimisation.

Research projects like "Mine of the future" [2] have been providing results targeting the needs for increased integration of ICT-based systems. Here the capability of seamless and timely integration of data and information between systems and functionalities is identified as critical. These capabilities have to be flexible to handle continuously changing business and technologies.

Progress beyond the State-of-the-Art: Based on the SOA approach supported by standard-based and formal-based software design methods, the IMC-AESOP approach has been applied to define architectures (see Chapter 3), technologies (see Chapter 4), migration strategies (see Chapter 5) and methods and tools (see Chapter 6) suitable for addressing seamless and timely integration of data and informa-

[2] http://www.rocktechcentre.se/completed-projects/conceptual-study-smart-mine-of-the-future-smifu/

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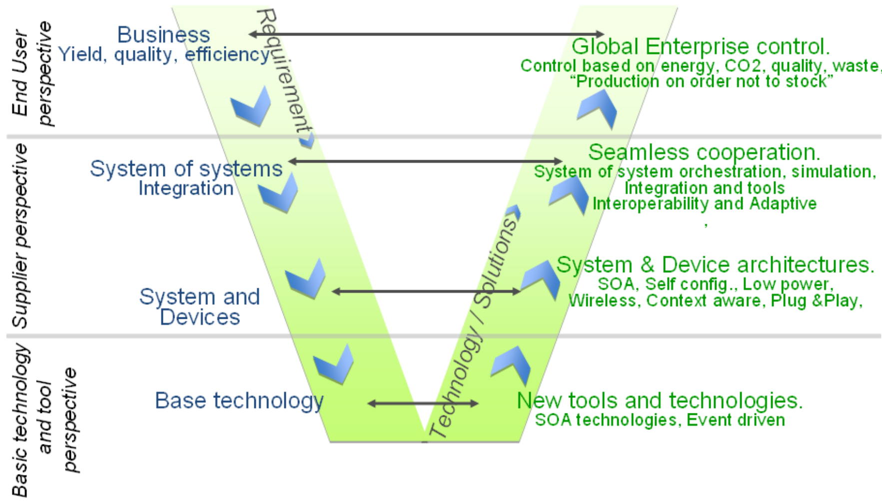

Fig. 1.9 State-of-the-art perspectives

tion from SOA-compliant subsystems and devices. Altogether, this opens the door for larger improvements in the flexibility of monitoring and control of very large systems. Thus, making it economically and man power-wisely possible to address knowledge improvement possibilities regarding product and production quality as well as e.g. energy usage optimisation.

1.6.2 Supplier dimension

The FP6 SOCRADES (www.socrades.net) project evaluated several SOA solutions, applicable at the device level, including DPWS and OPC-UA, in the context of manufacturing automation. The DPWS solution was provided as a complete open-source software component, which was embedded in several devices and tools, and was successfully demonstrated in the car-manufacturing domain, in electromechanical flexible assembly systems,in continuous process control and in mechatronics interoperability trials. A potential merger between DPWS and OPC-UA was also investigated. Potential solutions were identified to reduce the costs of embedding DPWS in very simple devices. A first set of generic and automation-application services were identified, specified, developed and implemented in pilot industrial applications. Complementary to those results, the ITEA2 SODA project looked at the ecosystem required to build, deploy and maintain a SOA application in several application domains (industrial, home, automotive, telecommunication, etc.).

However, none of these projects was addressing the specific challenging requirements coming with the engineering, development, implementation and operation of large-scale distributed systems for batch and continuous process applications. Ma-

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jor issues and associated challenges arise when SCADA/DCS functions have to be performed, e.g.:

- How deep into the system is possible to go with SOA-based monitoring and control solutions (including associated costs, real-time and security, among other issues)?
- How can monitoring and control (SCADA) services with real-time aspects be modelled, analyzed and implemented?
- How can be managed a system with thousands of dynamic SOA-compliant devices with SCADA-functionality (in the overall system, which may be composed of many different control loops, each one with several devices)?

Progress beyond the State-of-the-Art: The IMC-AESOP approach was proposing and prototypically implementing SOA-based components and systems for monitoring and control of very large industrial systems (see Chapters 7. 8, 9 and 10). The technology-posed limits for SOA on subsystems and devices were investigated regarding real-time, event aggregation and filtering, event-driven mechanisms etc.

1.6.3 Tools and basic technology dimension

Currently, the tools and basic technologies supporting SOA for seamless and timely integration of data and information from subsystems and devices, and related communication systems, are based on standard programming languages like C and Java and operating systems like Linux, Windows and a variety of RTOSs.

Progress beyond the State-of-the-Art: Applying the IMC-AESOP approach means to investigate and introduce formal-based technologies, thus open for the automated validation of SOA-based system structural and behavioral specifications, e.g. orchestration topologies, the automated verification of code functionality guaranteeing real-time performance, making code generation, debugging and verification more economical (see Chapter 10).

1.7 Validation of the IMC-AESOP Approach in selected Use-Cases

The Next Generation of SCADA/DCS systems, as envisioned in IMC-AESOP, address the major needs of the end-users of distributed control systems within large-scale environments. The four use cases depicted in Fig. 1.10, express the wishes of end-users leading to technological improvements in monitoring and process control. These use cases listed hereafter span from an evolutionary process (starting from a process controlled in a classical way) with migration to an event-driven approach, to a complete system controlled and monitored based on the new approaches envisioned by IMC-AESOP, and even extends to combining systems to systems-of-

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systems, specifically addressing monitoring, control and orchestration/composition of cross-domain services. The wide range of applications illustrates the needs to build new concepts applicable across several sectors.

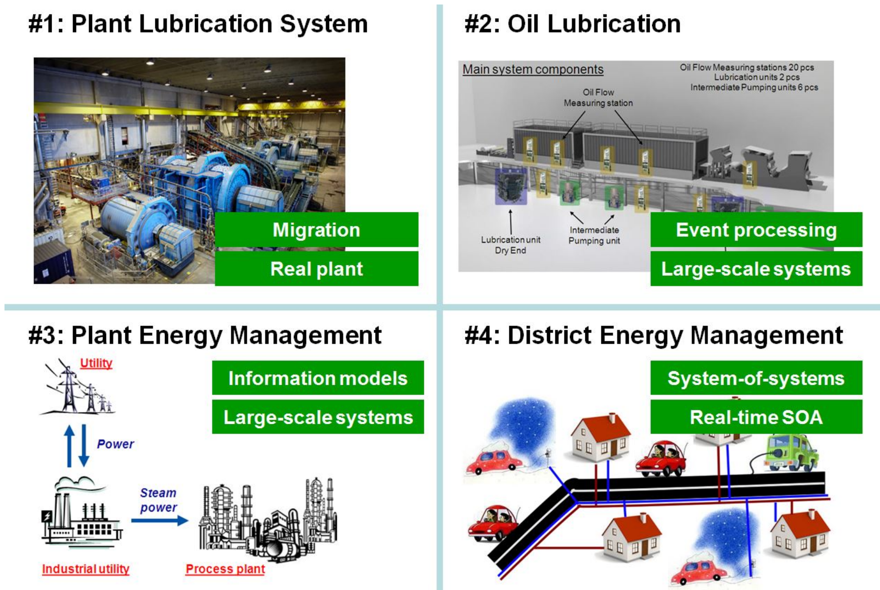

Fig. 1.10 Use cases validating the IMC-AESOP Approach

Beside the individual use cases raised by individual end users targeting specific applications, there are several aspects of common nature, applicable to the different use cases listed below.

Those aspects are:

- *Isolation aspect with long time view*: A part of the plant has to be perpetual in order to be architecturally and functionally integrateable (this feature is called "future compatible" with new coming "emerging technology / components"). This can be realized through: (i) description of a plant / plant-section as Web service compliant (Architecture), where functions are exposed as Web services, and (ii) SW implementation of a gateway or mediator.
- *Building a "New Generation" plant (prototype or simulation)*: A full plant or plant-section may be built with IMC-AESOP-compliant technology.
- *SCADA-DCS functions (aspects) as services*: Aspects will be specified and deployed into a pilot plant built as described above. This might be applicable to, e.g. Asset Management.

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1.7.1 Use case 1: Migration of a Legacy Plant Lubrication System to SOA

Industries continuously work on increasing the overall plant and equipment effectiveness leads to increasing requirements on open systems and much better system integration, availability, maintainability, performance, quality, functionality etc. The use-case scenario addressed here are targeting the plant control to increase the overall plant performance including predictive maintenance. With increased quality and information from sensors on process and critical equipment for plant control, a more effective plant operation and production planning shall be achieved.

The use case is an overall control scenario based on plant lubrication system installed in a mineral processing plant, or other similar equipment suppliers specific monitoring and control systems addressing the migration aspects between classical control systems and the new approaches addressed here. It targets systems that are there for the function of numerous process equipments and that are critical for the operation and effectiveness of these equipments. The lubrication systems are typical critical systems for almost all process industries. The system for the control of the lubrication system provides important information to other DCS. Information that can be used by operators to avoid critical and damaging incidents, by operators, planning staff and management to improve production and plant efficiency and by the maintenance staff and management to analyse and improve the predictive maintenance.

The information provided is on the equipment itself and consequences of malfunction but also on the sensor, system or infrastructure itself. The trail focusses on a system and equipment that must provide much better information in order to increase production availability and effectiveness and at the same time decreases work like daily maintenance. It shows integration of IMC-AESOP devices into a legacy system at an end-user, like a mineral processing plant at LKAB, Kiruna, Sweden. More detailed information is found in this book in Chapter 7.

1.7.2 Use case 2: Implementing Circulating Oil Lubrication Systems based on the IMC-AESOP Architecture

The hydraulic control in industry is often used in applications where the electrical drives cannot provide enough power. In fluid automation, the latest technologies could provide solutions that could allow better performance of the hydraulic systems. One important type of the processes found in fluid automation is the oil lubrication process, which is of demand in pulp & paper, steel, and gas & oil industries, to name just a few. Application of oil lubrication systems to the large distributed systems brings new challenges such as strict environmental regulations. The new technologies can address this challenge by e.g. reducing the costs (both environmen-

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tal and production) associated with the oil exchange thanks to advanced monitoring techniques of the oil quality.

The oil lubrication systems found in paper machines could include dozens of lubricated nodes (gear boxes). The application of smart meters can make it possible to identify different parameters of the lubrication oil and make a conclusion on the need of maintenance work. Applying the IMC-AESOP approach, FluidHouse (www.fluidhouse.fi) achieved an increase in performance of large-scale distributed systems by

- Application of advanced measurement techniques;
- Information collection and processing with the next generation SCADA systems based on standardized and widely accepted communication protocols.

It should be noted, that the later item refers not to the old existing standards but to emerging IT standards and their applicability in industrial applications, e.g. SOA-related standards. More detailed information is found in this book in Chapter 8.

1.7.3 Use case 3: Plant Energy Management

A steam generation unit (steam boilers) provides steam for other units in the plant (process steam) and also drives turbo-generators. Generated electricity is used in the plant itself and/or is supplied to the power grid. In case of energy peaks, the plant may consume electricity from the grid. Steam generation consists of several boilers connected to a common header or to the system of common headers if more different levels of pressure are produced by the boilers. Overall steam production may be split into independent sub-plants connected via steam transfer line.

Optimisation of such a system provides hierarchical overall plant optimisation across several levels, i.e.(i) base/device level, (ii) unit level, (iii) plant level, (iv) global level. Several basic requirements can be derived:

- *Model Consistency*: The basic and critical requirement for hierarchical optimisation is a consistency of model of all levels of optimisation. For instance if a boiler has to be operated on higher O_2 level due to problems with a mill, its efficiency drops. If the new efficiency curve is not propagated to higher levels, the benefits from optimal load allocation may be lost completely.
- *Integration issues*: Large scale plants usually have some kind of optimisation controllers implemented on device level, but it can be very difficult to get right information in a right form to higher level optimizers.
- *Event-driven processing*: Some changes in a plant (e.g. boiler shutdown, closing of a transportation pipe) may require reconfiguration of optimisation problem in a remote optimizer. Such events must be communicated from a device to an optimizer.
- *"What-if" analyses*: Optimizers and all levels should support, besides real-time optimisation, also on-demand optimisation for what-if analyses. On-demand optimisation should run the same algorithm as the real-time one, but on the data

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provided by a user. Usually, only a sub-set of data is provided by a user and the rest is taken from the process.

This use case evaluates how to address these requirements while using service-oriented approaches. More detailed information is found in this book in Chapter 9.

1.7.4 Use cases 4: Building System of Systems with SOA Technology – a Smart House Use Case

The purpose of this use-case is to investigate how a SCADA/DCS-like functionality can be generated by composing monitoring and control services. It primarily demonstrates how a domestic home and its supply and distribution systems for heat and electricity can be integrated to smart power grids and smart heat grids. This will be paired with the detection of incoming and outgoing vehicles exposing and consuming services inside a SOA-based transportation system. For this purpose, necessary services are specified, implemented and deployed on resource-constrained devices. It addresses aspects and characteristics associated to the system-of-systems paradigm, as the district monitoring scenario (system) covers heating, electricity and transportation systems. More detailed information is found in this book in Chapter 10.

1.8 Conclusion

A number of new different system concepts and paradigms have become apparent in the broader context of Cyber-Physical Systems [20] over the past couple of years such as Collaborative Systems [11], Service-Oriented Architectures (SOA) [3], networked cooperating embedded devices and systems [22], cloud computing [2] etc. This chapter presented the major aspects related to the vision of cloud-based industrial CPS. It is an introductory chapter briefing the research, development and innovation work carried out by a set of experts collaborating under the umbrella of the IMC-AESOP project, for specifying, developing, implementing and demonstrating major features of a Next Generation SOA-based SCADA/DCS systems and the advantages of implementing them in different industrial process control environments. The depicted IMC-AESOP efforts constitute a prelude to the CPS and Industry 4.0 vision [1, 15].

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