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Open Process Automation: A standards-based, open, secure, interoperable process control architecture

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Abstract: Approximately 100 organizations (operating companies, hardware and software suppliers, system integrators) are working to define standards for Open Process Automation (OPA) – an open, secure, interoperable process automation architecture. Two versions of the standard have been published. Starting in 2017, ExxonMobil and Lockheed Martin built two OPA systems (a laboratory proof-of-concept and a hydrocarbon process-controlling prototype). The paper shares results from these two projects. Finally, the paper relates Open Process Automation, NAMUR Open Architecture (NOA) and Module Type Package (MTP).

Keywords: Logical design, physical design, and implementation of embedded computer systems; Secure networked control systems; Systems interoperability; Internet-of-things and sensing enterprise

1. INTRODUCTION

Open Process Automation is an industry initiative to improve the total lifecycle benefits from industrial control systems through the use of a standards-based, open, secure, interoperable architecture and an open business model. It is driven by the Open Process Automation Forum of The Open Group. As of Apr 2020, the OPA Forum consists of 97 member organizations including 22 operating companies; 6 of the 7 major distributed control system suppliers; and a host of hardware and software suppliers, and system integrators. The Forum has published a Business Guide (Blue et al. 2017), the Open Process Automation Standard (O-PAS^{TM}) (Brandl et al. 2019, 2020), and a Conformance Certification Policy (Duran et al. 2020). Several operating companies, including ExxonMobil and BASF, have developed and tested prototype instances of OPA systems.

Significant enablers of Open Process Automation are the incorporation of technologies from adjacent industries, such as modular open systems avionics systems (Akers et al. 2017), and telecommunications network function virtualization (Mijumbi et al. 2016).

This paper overviews the O-PAS standard. The paper shares results of ExxonMobil's O-PAS Proof-of-Concept and Prototype projects. It concludes with a discussion of the relationships among OPA, NOA, and MTP, including a recommendation to harmonize these initiatives.

2. OPEN PROCESS AUTOMATION STANDARD

Ten quality attributes, listed in Table 1, have been defined as goals for the Open Process Automation standard. The attributes of interoperability and portability are distinguishing relative to currently available commercial distributed control systems (DCS) and programmable logic controllers (PLC).

Table 1. Open Process Automation quality attributes

Interoperability	Scalability	Affordability	Availability
Modularity	Securability	Portability	Discoverability
Standards conformance	Reliability		

A "standard of standards" approach is being used to define the OPA Standard. The OPA Forum has liaison agreements that enable exchange of pre-publication information with multiple organizations, including NAMUR, ZVEI, PLCopen, etc. Table 2 lists the industry standards that are incorporated in O-PAS Versions 1.0 and 2.0.

Table 2. Industry standards incorporated in the Open Process Automation Standard

O-PAS Part	Subject matter	Referenced standards
Part 1	Technical architecture	IEC 62264 (ISA 95)
Part 2	Security	IEC 62443 (ISA 99)
Part 3	Profiles	n.a.
Part 4	Connectivity framework	IEC 62541 (OPC UA)
Part 5	System management	DMTF (Redfish)
Part 6	Information and exchange models	IEC 62714 (AutomationML) IEC 62682 (ISA 18) IEC 61131

		IEC 61499
Part 7	Physical platform	"whitespace"

The OPA Reference Architecture is depicted in Figure 1. The following three components are novel compared to current distributed control systems: (1) Distributed Control Node (DCN), (2) industry-standard based control network (O-PAS Connectivity Framework (OCF)), and (3) the Advanced Computing Platform (ACP).

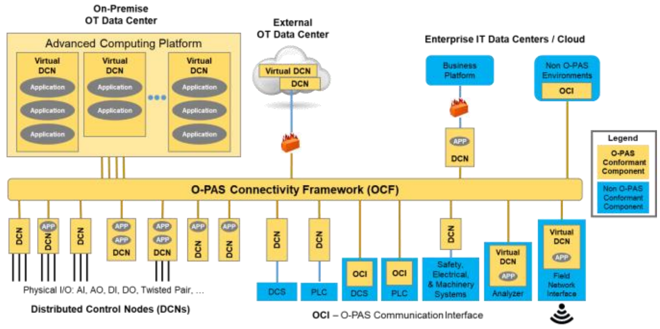


Figure 1. Open Process Automation reference architecture

2. PROOF OF CONCEPT

In 2017, ExxonMobil and Lockheed Martin designed and built an OPA Proof of Concept system. The hypothesis was that an industrial control system exhibiting the quality attributes listed in Table 1 could be made by the third-party integration of hardware and software components sourced from different suppliers. Interoperability, configuration portability, and application portability were the priorities. The Proof of Concept demonstration was completed successfully in 1Q18.

The plant was a high-fidelity dynamic simulation of a fired heater. 37 emulators of 4-20 mA sensors and final elements were used and connected to the IO devices listed in Table 3.

2.1 Equipment

The hardware and software used are listed in Table 3. With one exception, currently available industrial hardware and software products were used for the DCN, OCF, and ACP components.

Table 3. Hardware and software used in OPA Proof of Concept

Term	Description	Products used
Basic IO	Remote IO device slave to host controller connected by Ethernet. Receives commands from host controller.	R. Stahl is1+ Yokogawa N-IO Moxa ioLogik E1262
Intelligent IO or 61499 COTS DCN	Distributed or edge controller with integrated or remote IO. Intelligent IO can run control programs with direct access to integrated IO or be host for remote IO.	Schneider Electric M580 Phoenix Contact AXC F2152
DCN IO Concept or 61499 Concept DCN	Distributed or edge controller with limited quantity of IO to support single loop integrity. DCN IO can run control programs with direct access to integrated IO. Field wire termination is on a separate cradle so the compute module is replaceable.	Intel DCN (product prototype) Raspberry Pi NxtControl nxt4EVAL
Soft controller	Controller application running on compute resource and using remote IO. Compute resource can be dedicated or virtual computer.	Debian WindRiver Linux Ubuntu
ACP	Server class device combining Purdue model L1 – L3. Supports component modularity, application portability/interoperability/extensibility, and compute power scalability.	WindRiver Titanium Cloud, Dell, HP, Cisco VxRail, VmWare
High availability ACP	ACP with additional hardware and software components providing dynamic failover.	WindRiver Titanium Cloud, Dell, HP, Cisco
Network software	Data exchange	RTI DDS Profinet Open62541 OPC UA Matrikon OPC UA
Basic control software	PID, ratio control	nxtControl nxtStudio Eclipse 4diac ABB 800xA
Advanced control software	PLC code generation; Model predictive control	Mathworks Matlab AspenTech DMC3
Human-machine interface	Operator display	Inductive Automation Ignition ANSYS

2.2 Methods

Systems integration was done by (1) applying methodologies and adapting code from the Future Airborne Capability Environment (FACE^{TM}) standard (Akers et al. 2017), and (2) by anticipatory implementation of the emerging O-PAS standard. Figure 2 depicts the layered software architecture.

Definitions of the acronyms in Fig. 2 are as follows:

- PCS: Portable Components Segment
- TSS: Transport Services Segment
- PSSS: Platform Specific Services Segment
- IOSS: Input/Output Services Segment

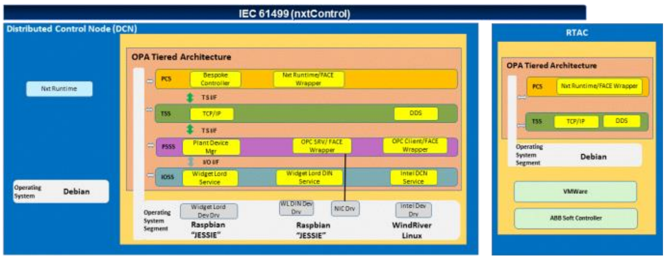


Figure 2. Software architecture and operating systems used for the OPA Proof of Concept

2.3 Results

The following key quality attributes were achieved:

- *Interoperability*: Implemented closed loop control using controller from Supplier A, I/O from Supplier B, and HMI from Supplier C.
- *Interchangeability*: Replaced DCN from Supplier A running user applications with DCN from Supplier B with no changes to application source code.
- *Portability - configuration*: Exported control configuration from Supplier A's engineering tool, imported configuration into Supplier B's engineering tool, and redeployed to DCN with no changes to source code.
- *Portability – application*: Moved control logic running on DCN from Supplier A to "soft controller" virtual machine from Supplier B with no changes to source code.

Table 4. Communications performance results

	TCP	DDS	OPC UA
Bytes per message	196	176	478
Transmission time mean (ms)	2.0	1.6	8.6
Transmission time std. dev. (ms)	1.6	1.7	7.0
Max. messages @ 10 Hz	44,642	49,942	18,305

2.4 Conclusions

Open Process Automation has been demonstrated at Technical Readiness Level 4 on the 9-level NASA/EU scale.

3. PROTOTYPE

During 2018 and 2019, ExxonMobil, Lockheed Martin, and Wood plc designed and built an OPA Prototype system that was used to control a pilot plant. The hypothesis was that the technology demonstrated with the Proof of Concept could be used to control an actual petrochemical process. The on-process testing of the Prototype was completed successfully in 1Q2020.

The plant was a catalyst development unit composed of pumps, reactors, separators, and an online analyser. It processed hydrocarbons at 315 degC and 8300 kPa. There were 130 analog and discrete input/output devices.

3.1 Equipment

The Prototype used a subset of the hardware and software used on the Proof of Concept. Two components were added: Phoenix Contact plcNext and OSISoft PI. The Prototype also required interfaces to a gas chromatograph and a Safety Instrumented System.

3.2 Methods, Results, and Learnings

Software architecture: The FACE methods and code were revised further from the Proof of Concept to adapt to industrial control requirements and the O-PAS standard.

nxtStudio function blocks were developed for configuration and device interface management (CIFB). A CIFB was developed for each IO device type.

A System Manager was developed to start, monitor, stop, and restart all processes. The System Manager monitored CPU utilization, memory, mass storage, and CPU temperature.

An Aggregation Server was developed for communications among the DCN and ACP components. It used OPC UA. A short term historian was built to provide a data cache.

A Plant Device Manager was built to manage all IO. A single interface on the system-facing side was presented on the IOSS. Interfaces on the field-facing side were unique to each IO device type.

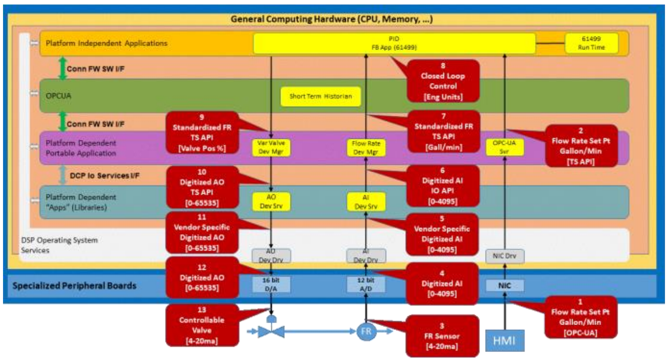


Figure 3. As-built software architecture of the OPA Prototype

Accessing device IO from the control programming execution engine: nxtStudio Composite Automation Types (CAT) were used for one-to-one mapping between physical IO and its use in a function block. Two types of hardware CATs were used – bus master and individual IO channel. In the function block applications, symbolic link blocks were used to access the data. For OPC UA, the hardware CATs provided the location in the UPC UA Address Space.

OPC UA abstraction layer: Given variations in OPC UA implementation by suppliers, the challenge was to ensure that changes to OPC UA clients and servers did not disrupt the rest of the system. An OPC UA abstraction layer was built that made swapping implementations as simple as a configuration file edit.

Security: The following three mechanisms were used for cybersecurity: (1) SSL certificates, (2) zones using VLANs and firewalls, and (3) device authentication. Zones separated types of data traffic. VLANs segmented traffic logically. Firewalls regulated traffic to the zones and VLANs. Device authentication was as follows: (1) creation of SSL certificates for 802.1x, (2) setting up a Radius server to provide authentication, and (3) configuring edge switches to use 802.1x.

High availability: Several mechanisms for providing high availability without pair-wise physical redundancy were explored. Among DCN's, high availability was demonstrated using orchestration-based dynamic failover. At the ACP level, two solutions were used – Titanium Cloud and VxRail.

3.3 Conclusions

Open Process Automation has been demonstrated at Technical Readiness Level 6 on the 9-level NASA/EU scale.

4. HARMONIZATION OF OPA, NOA, AND NOA

NAMUR Open Architecture defines a modelling and optimization (M&O) capability – separate from the process control system – that acquires data directly from sensors or indirectly from the control system (Klettner et al. 2017).

OPA comprehends the NOA functional requirements. In Figure 1, the Field Network Interface acquires data from sensors. These data are transmitted via the OCF network to any of several higher-level, on- or off-premise compute nodes (ACP, OT Data Center, IT Data Center, or Cloud Computer) where M&O applications can be run. Data do not have to pass through any control nodes.

In current industrial control systems, the modelling and optimization capability is implemented in Level 3 of the Purdue model. This is where operating companies have implemented model predictive control and realtime optimization applications since the 1990's. Arguably, the computational part of M&O in NOA is a solved problem.

The unsolved problem is an integrated architecture for sensing and network transmission of data with consideration of the use of the data – control, optimization, or monitoring. NOA requires an either/or choice – into the control system or into the M&O system. Similarly, operating companies currently implementing wireless instrumentation face an equivalent either/or choice – acquire data into the control or the IT system. Industry experience shows that data originally justified for monitoring-only tend to be useful for closed-loop control and optimization. Therefore, an integrated sensing and data network architecture is desired by which data availability and timeliness are configured based on quality-of-service -- not implemented by separate hardware infrastructures.

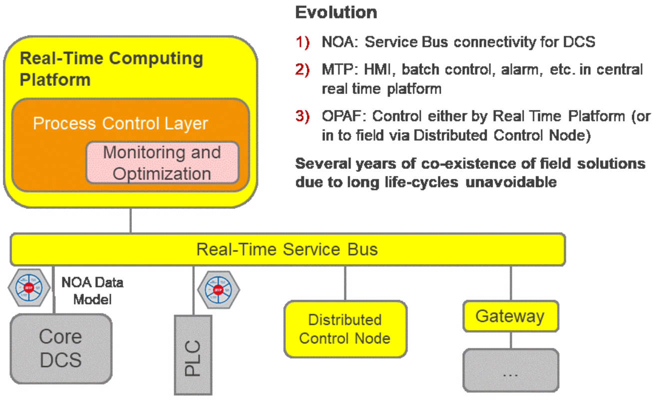
Module Type Package defines middleware that abstracts proprietary control systems (Bernshausen et al. 2016). This middleware enables a unified "orchestration" layer for the HMIs and supervisory controls above the control devices on the process modules that could be sourced from different suppliers.

OPA comprehends the MTP functional requirements. Figure 1 shows two types of interfaces between the O-PAS conformant system (yellow) and currently available DCS or PLC control system components (blue). The depicted DCN or O-PAS Connectivity Interface (OCI) components serve as "gateways" to non-O-PAS conformant products.

By providing an interface to a multiplicity of currently available proprietary control systems, MTP solves part of the problem OPA is addressing. The problem that MTP does not solve is interchangeability and software portability of the proprietary systems beneath MTP. For an end user to repurpose the controls on a process module, the software on the proprietary controls would probably need to be rewritten. If an end user wanted to use software not currently available on the proprietary controls, they would have to get the controls vendor to integrate it. These are the root cause business problems that OPA is trying to solve.

While MTP does not solve the root cause business problem, it is certainly valuable as a technology that enables the transition from the current state to the desired future state. MTP is a gateway. Since MTP is currently being implemented as software added to PLC and DCS products, the OCI element of the OPA reference architecture most closely matches MTP. Both MTP and OPA use AutomationML to configure the software in the interacting modules. Both MTP and OPA use OPC UA for the information model and data transmission. It is not difficult to imagine a new profile of MTP with OPA on the orchestration side of the interface.

From the above discussion, one concludes that OPA, NOA, and MTP are complementary – not contradictory. Krauss, et al. (2017) proposed a harmonized vision for OPA, NOA, and MTP that is illustrated in Figure 4. NOA concepts are used for partitioning data on the control network into separate control and monitoring channels, and MTP concepts are used for the gateway interfaces to existing DCS and PLC products.



Evolution

1) NOA: Service Bus connectivity for DCS
2) MTP: HMI, batch control, alarm, etc. in central real time platform
3) OPAF: Control either by Real Time Platform (or in to field via Distributed Control Node)

Several years of co-existence of field solutions due to long life-cycles unavoidable

Figure 4. Harmonization of OPA, NOA, and MTP

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