OPC UA and ISA 95
Interoperability for MES by implementing ISA 95 with OPC UA

ISA 95 provides an information model representing materials, personnel, equipment, physical assets and other information on the level of Manufacturing Operations Management. OPC UA offers a robust and reliable communication infrastructure. OPC UA’s rich information modeling capabilities can be used to represent ISA 95 information in a generic and configurable way that allows for high-speed synchronous data exchanges required for manufacturing workflows. This paper introduces an approach mapping ISA 95 information into OPC UA allowing an interoperable manner of information exchange.

KEYWORDS ISA 95 / OPC UA / Interoperability / Information Modeling / MES
Automation does not end with equipment control; it also includes higher levels of control that manage personnel, equipment, and materials across production areas. Effectiveness in manufacturing companies is not based solely on equipment control capability. Manufacturing companies must also be efficient at coordinating and controlling personnel, materials, and equipment across different control systems in order to reach their maximum potential. This coordination and control must occur in at least four different parts of an organization: production, quality tests and test labs, warehousing and inventory management, and maintenance.

This coordination and control is often supported by Manufacturing Execution Systems (MES) for management of production operations, Laboratory Information Management Systems (LIMS) for quality tests and test lab management, Warehouse Management Systems (WMS) or Tank Farm Management Systems (CMMS) for management of inventory operations, and Asset Management or Computerized Maintenance Management Systems (MOM) for maintenance operations. These systems together are collectively called Manufacturing Operations Management (MOM) systems. MOM defines a diverse set of functions that operate above automation control systems, reside below the level of enterprise business systems and are local to a site or area.

1. OVERVIEW ON TECHNOLOGIES

1.1 ISA 95

The ANSI/ISA 95 Enterprise/Control System Integration standard [1], also released as IEC 62264 [2], defines five levels of activities in a manufacturing organization. Generally, automation and control support Levels 1 and 2, MOM systems support Level 3, and business Enterprise Resource Planning (ERP) systems support Level 4 activities. The ISA 95 levels are shown in Figure 1.

- Level 0 defines the actual physical processes.
- Level 1 elements are the sensors and actuators attached to the control functions in automation systems.
- Level 2 automation and control systems have real-time responses measured in sub-seconds and are typically implemented on Programmable Logic Controllers (PLC), Distributed Control Systems (DCS), and Open Control Systems (OCS).
- Level 3 typically operates on time frames of days, shifts, hours, minutes, and seconds. Level 3 functions also include maintenance functions, quality assurance and laboratory functions, and inventory movement functions, and are collectively called Manufacturing Operations Management. A wide variety of systems support the Level 3 activities, including SCADA (Supervisory Control and Data Acquisition) systems for monitoring the process and providing operator control, batch control systems for execution of recipes, data historians for the collection and preservation of time based data from Level 2 systems, recipe and document management systems for managing recipes and workflow instructions, detailed scheduling, campaign management or work dispatching, and work or product tracking.
- Level 4 is called Business Planning and Logistics. Level 4 typically operates on time frames of months, weeks, and days. Enterprise Resource Planning (ERP) logistics systems are used to automate Level 4 functions.

It is important to remember that each level has some form of control and each level has its own definition for real-time. Level 3 systems consider real-time to mean information available a few seconds after shop floor events occur. Level 4 systems consider real-time to mean that logistics and material information is available daily or within a few hours after the end of a shift.

This paper deals with information exchange across Level 3 systems or between Level 2 and Level 3 systems. Specifically this would involve information exchange
between MES, WMS, LIMS, AM, PLC and DCS systems. This information exchange in real-time, often requiring transaction times measured in seconds or subseconds, in order to allow workflows and recipes to execute in a timely manner. ISA 95 defines four primary types of information that often must be exchanged among MOM systems and between ERP systems and MOM systems, these types are; information about material and the properties of materials, information about equipment as it pertains to the operations being performed, information about the physical assets that make up the equipment, and information about personnel and their roles and qualifications.

Material Class, Material Definition, Material Lot, Material Sublot, and Material Test Information – This is the definition of the lots, sublots, material definitions, and material classes involved in production. This information allows Level 3 and Level 4 systems to unambiguously identify material specified in production schedules and consumed or produced in actual production.

Equipment Class, Equipment, and Capability Test Information – This is the definition of the roles that equipment and equipment classes perform in production, inventory management, and quality test labs. This information may be used to associate production with specific equipment as part of a production record, or with equipment classes to schedule production and allocate costs.

Physical Assets, Physical Asset Classes, and Physical Asset Capability test information – This is an identification of the specific physical asset (by serial number or asset ID) used in manufacturing operations. It also includes the make and model information that identifies the type of physical asset and its properties.

Personnel Class, Person, and Qualification Test Information – This is the definition of the persons and personnel classes (roles) involved in production. This information may be used to associate production with specific persons as part of a production record, or with personnel classes to allocate production costs.

1.2 OPC UA

Classic OPC – the predecessor of OPC UA – is used to provide interoperable data exchange in automation between components of potentially different vendors. It is focusing on the second level defined by ISA 95 (see Figure 1). With over 15,000 OPC products on the market from more than 2,500 companies [3] it is very well accepted and applied and almost every system targeting industrial automation implements classic OPC. With its flavors OPC DA (data access), A&E (alarms and events) and HDA (historical data access) it allows exchanging current, real-time related data and their history, as well as alarms and events between automation components like controllers and HMI (human machine interface) running on a Windows based PC.

OPC UA (unified architecture, [4]) unifies these specifications and brings them to state-of-the-art technology with a service-oriented architecture (SOA). By switching the technology foundation from Microsoft’s COM/DCOM to web service technology OPC UA becomes platform-independent and can be applied in scenarios where classic OPC cannot be used. OPC UA can directly be deployed to controllers and intelligent devices without the need for a Windows-based PC to expose the data, as in classic OPC. It can also be seamlessly integrated into MOM and ERP systems running on UNIX/Linux. It still fits very well in the Windows-based environment where classic OPC lives today.

FIGURE 1: ISA 95 Activity Levels in a Manufacturing Organization
OPC UA provides a robust and reliable communication infrastructure having mechanisms for handling lost messages, failover, heartbeat, etc. With its binary encoded data it offers a high-performing data exchange solution. Security is built into OPC UA as security requirements become more and more important especially since environments are connected to the office network or the internet and attackers are starting to focus on automation systems [5].

In addition, OPC UA provides powerful information modeling capabilities. Unlike classic OPC with a very basic model, OPC UA provides the ability to define types and add semantic information to the data exchanged. With these capabilities OPC UA offers a high potential for becoming the standardized communication infrastructure for various information models. Several information models are already defined based on OPC UA making use of the generic and powerful meta model of OPC UA. This includes models for:

- the IEC 61131-3 programming model [6] used to program control applications;
- a model for analyzer devices [7];
- a base model used by FDI (field device integration). OPC UA has built-in support allowing several different standardized information models to be hosted in one OPC UA server [8].

OPC UA is easily scalable. It can be applied on embedded devices with limited hardware resources as well as on very powerful machines like mainframes. Of course, an application running on limited hardware can only provide a limited set of data to a limited set of partners whereas an application running on high-end hardware can provide a large amount of data with several decades of history for thousands of clients. The information modeling capabilities also scale. An OPC UA server might provide a very simple model or a very complex model depending on the application needs. An OPC UA client can make use of the model or only access the data it needs and ignore the meta data accessible on the server.

2. MOTIVATION

MOM systems must often share definitions about resources: personnel, equipment, materials, and physical assets. This is needed to uniquely identify the resource and to verify that it is qualified or appropriate for the task to be performed, such as a material status that indicates that a material has been released for use in production. ISA 95 provides a standard framework to describe this information model for exchange, but ISA 95 does not define a mechanism to exchange this information. MESA International defined B2MML [9] as a transport for exchanging ISA 95 based information, but this information exchange is for periodic Level 3/Level 4 exchanges, not for sub-second based data exchange. OPC UA provides an infrastructure for defining information models in a standard manner and for exchanging the data associated with the information model in a secure reliable real-time manner. OPC’s typical applications are for integrating Level 2 and Level 3. By adopting the ISA 95 Information model to OPC UA, the ISA 95 information model can be extended to Level 2. In addition it allows the information represented by ISA 95 models to be exchanged using OPC UA on Level 3. It provides services to query, browse, and update this information in a controlled manner in a highly efficient communication protocol.

The following subsections summarize the information that needs to be exchanged.

Sharing Material Information

Manufacturing requires materials. It is not surprising that manufacturing systems have a requirement to identify and track materials because the main purpose of manufacturing is to convert materials in one form into materials of another form. An important part of MOM integration is maintaining and exchanging material identification and information.

- MES identify materials and their suitability for use, batch management systems confirm that the correct materials are used as specified in the recipes,
- tracking and tracking systems (bar-code scanners and RFID readers),
- LIMS confirm that the correct materials are tested and the correct materials are used in testing,
- WMS identify materials in their storage locations,
- Shared material information can be divided into three main categories:
  - material class information identifies the materials without regard to the source of the material,
  - material definition information identifies material from specific vendors or sources,
  - material lot information identifies actual material, its location and quantity.

Sharing Equipment Information

One important element of managed information is the correct identification of the equipment used for manufacturing. Equipment identification is used for:

- scheduling,
- tracking and tracing,
- maintenance,
- troubleshooting,
- visualization (HMI),
- capacity tracking,
- OEE (Overall Equipment Effectiveness) calculations.

Unfortunately, it is not uncommon for a manufacturing company to have multiple identifications for a single piece of equipment. Therefore, a critical aspect of equipment information management is managing different equipment ID’s across multiple vendor systems and applications.

Sharing Physical Asset Information

Identification of a unique physical asset, irrespective of the role the equipment is performing is vital for:
maintenance,
equipment qualification and regulatory compliance,
financial asset tracking

Each physical asset has a vendor serial number that is needed for financial tracking and maintenance contracts. Vendor serial numbers are not unique, so each physical asset is usually given a unique company-specified financial asset tag number. The financial asset tag number is maintained in a financial system and may not be compatible with maintenance system identifications. Usually differences are in the number of characters or numbers used and the naming rules required by the applications. Therefore, maintenance systems often have a separate maintenance tag that is added to the physical asset. In the case of small equipment, the three separate identification tags and vendor make and model information can cover most of the equipment’s surface area. All of these different identifications often require that a system can quickly determine if a physical asset is qualified for production, and to obtain the physical asset identification for any regulatory records.

Sharing Personnel Information

Multiple regulatory rules, laws, and internal procedures require that personnel who perform shop floor actions are unequivocally identified, are authorized to perform the actions, and have valid training or qualifications to perform the actions. Because personnel information is usually maintained in multiple IT and control systems, it is a key area of exchanged information. Specific uses in different systems that require coordination and sharing include:

- MES Personnel qualification to be checked before someone is allowed to take an action
- LIMS Identification of approved personnel to perform tests and handle materials, often based on their training qualifications,
- AM Certification information about personnel performing maintenance activities to ensure that they have the proper training required by the activity,
- WMS Certification that personnel are trained and qualified to handle material movement systems, such as fork trucks or crane systems.

3. MAPPING ISA 95 TO OPC UA

After relating the benefits of implementing the ISA 95 model with OPC UA and describing the information to be exchanged this section focuses on how the mapping can be done. To generate a mapping of the ISA 95 information model to an OPC UA information model, first the information model available in ISA 95 has to be understood. This is described in section 3.1. The information modeling capabilities of OPC UA as base of the mapping are described in section 3.2. The mapping approach is defined in section 3.3, and details as well as examples given in sections 3.4 and 3.5. Section 4 describes an implementation of the mapping in order to verify the efficiency of the proposed mapping.

3.1 Modeling Approach of ISA 95

The ISA 95 modeling approach to information is based on a “Property” model. The ISA 95 models define a minimum set of industry-independent information as attributes. Industry specific, application specific, and company specific information are represented as property objects. For example, the personnel class property would be used to define application or industry specific attributes for personnel classes, and person property would be used to contain instance values for the properties.

In the ISA 95 resource models there are “Classes” and “Instances”. The word “Class” used as part of an object definition name should be considered as a category, not as a “Class” in the official UML Modeling definition. For example: “Personnel Class” should be considered a “Personnel Category”, because it is used to distinguish between the kinds of personnel in the real world and to define properties that would be common to personnel within the same category. The Figure 2, from ANSI/ISA 95.00.02, is the Personnel object model. Each instance of the Personnel Class defines a role that a person can perform, such as a Draftsman. Each role may have specific properties, such as a Drafting License Number and a License Expiration Date. Each Person can be associated to one or more Personnel Class Roles. If the person is Draftsman, then the Person Properties define the values for the Drafting License Number and License Expiration Date for that person. The Qualification Test Specification identifies a test that may be associated with determining the value for a property (such as a test for Draftsman used to obtain a Drafting License Number.) The information obtained from taking the test can be modeled in the Qualification Test Result.

This modeling approach for ISA 95 means that properties must be able to be dynamically queried and browsed. The properties available for individual objects will be different, for example in Figure 3, Joe Smith has a Drafting License Number, but Sally Jones does not. The OPC UA modeling approach provides the flexibility to have the dynamic data discovery required for Level 3 communications.

3.2 Modeling Approach of OPC UA

The basic information modeling principles of OPC UA are (taken from [3]):

- Using object-oriented techniques including type hierarchies and inheritance. Typed instances allow clients to handle all instances of the same type in the same way. Type hierarchies allow clients to work with base types and to ignore more specialized information.
- Type information is exposed and can be accessed the same way as instances. The type information is provided by the OPC UA server and can be accessed with the same mechanisms used to access instances.
FIGURE 2: Class Diagram of ISA 95 [from ANSI/ISA 95.00.02]

FIGURE 3: Example of a personnel class instances and person instances

FIGURE 4: Modeling concepts of OPC UA – the OPC UA meta model
Full meshed network of nodes allowing information to be connected in various ways. OPC UA allows supporting various hierarchies exposing different semantics and references between nodes of those hierarchies. The same information can be exposed in multiple ways depending on the use case.

- Extensibility regarding the type hierarchies as well as the types of references between nodes. OPC UA is extensible in several ways regarding the modeling of information. In addition to the definition of subtypes of nodes it allows the definition of additional types of references between nodes and the definition of methods extending the functionality of OPC UA.
- No limitation on how to model information in order to allow an appropriate model for the provided data. OPC UA servers targeting a system that already contains a rich information model can expose that model “natively” in OPC UA instead of mapping the model to a different model.
- OPC UA information modeling is always done on the server-side. OPC UA information models always exist on OPC UA servers, not on the client. They can be accessed and modified from OPC UA clients. An OPC UA client is not required to have an integrated OPC UA information model and it does not have to provide such information to an OPC UA server.

Those principles support very basic as well as very complex and powerful information models such as ISA 95. In Figure 4, the base concepts of OPC UA – the meta model – are summarized. There are different node classes for different purposes. Nodes are connected by references. Node classes represent objects for structuring the address space, methods, and variables containing data. Node class attributes are described in the figure.

OPC UA defines a UML-like notation for modeling OPC UA address spaces. Figure 5, illustrates the modeling notation and concepts. The notation illustrates the object, variable and data type symbols as well as object type, variable type and reference type. The example shows one object type called MyType inheriting from the OPC UA defined BaseObjectType. It uses the Has-
Subtype reference. MyType contains a variable called MyCounter, referenced by a HasComponent reference. Variables, objects and methods on types are called instance declarations and define the structure of the types. That means that instances of MyType also have a variable called MyCounter. As variables are typed as well, they reference to the OPC UA defined BaseDataVariableType. Variables have data types assigned to them defining the data type of the value of the variable. This can be built-in data types like Int16 or Boolean but also user-defined data types.

Those concepts allow the definition of object types with a specific structure and semantic, as well as reference types with specific semantic.

3.3 Mapping Approach

When mapping the ISA 95 model to OPC UA typically the same mapping rules should be applied when mapping similar ISA 95 structures. However, sometimes there are several useful mapping alternatives and it is more effective to have different mappings depending on the expected use of the models.

In the following, the rules and potentially alternatives are described.

ISA 95 Properties
ISA 95 properties are mapped to OPC UA variables. That means that for each UML class representing Properties (e.g. Person Property in Figure 2) an OPC UA variable type is created (inheriting from a variable type ISA95PropertyType). Instances of the ISA 95 properties are instances of the specific type, referenced by a HasISA95Property reference.

ISA 95 Classes
As described in section 1.1, ISA 95 classes are used for categorization rather than in the object-oriented sense of class and instance. That means each class has some ISA 95 properties assigned to it and each instance assigned to the class contains at least the properties in

FIGURE 8: OPC UA ISA95 Architecture Sample

FIGURE 9: OPC UA ISA 95 Server Address Space
the class. An instance can have several classes and thus all their properties.

Each ISA 95 concept representing a class (e.g. Personnel Class in Figure 2) is mapped to an OPC UA object type. There are two alternatives how to map the concrete class (i.e. instances of Personal Class).

- Map them to OPC UA objects (see Figure 6)
- Map them to OPC UA object types and objects (see Figure 7)

The first approach is the direct mapping from the ISA 95 model. Each instance fulfilling the class would reference the object and clients aware of the ISA 95 model would be able to interpret it. However, it does not make use of the OPC UA type model and it would be hard for generic clients to interpret and program against (e.g. it would require a specific user interface that understood all of the Operator properties for a person). A more generic approach is shown in Figure 7, which defines subtypes of the object type containing all properties and the instances contain instances of the subtypes. Both alternatives can make sense, depending on the expected use.

### ISA 95 Objects

The ISA 95 Objects are mapped to OPC UA object types and object instances. Therefore each UML class modeling instances (e.g. Person in Figure 2) is mapped to an OPC UA object type and the instances are instances of that type. Depending on the mapping of the ISA 95 class it either references the object or contains an instance of the object type. In both cases it contains all properties of the classification (see Figure 6 and Figure 7).

### ISA 95 Relations

ISA 95 relations (e.g. from Person to Qualification Test Specification) are mapped to OPC UA references. In order to expose the specific semantic new OPC UA reference types need to be defined. However, this is a fixed set of new reference types.

### Implementation of the Mapping

The overall architecture of the model has been completed and is illustrated in Figure 8. It includes the physical asset and equipment models, their interactions with test specification and personal models. The equivalent material handling models are not shown.

### AUTOREN

**DENNIS BRANDL** (born in 1951) is the founder and chief consultant for BR&L Consulting, specializing in Manufacturing IT applications, including Business-to-Manufacturing Integration, MES solutions, General and Site Recipe implementations, and automation system security. He has been involved in automation system design and implementation in a wide range of applications over the past 25 years. Dennis has been an active member of the ISA 95 Enterprise/Control System Integration committee for the past 15 years and is editor of the set of standards. He is a USA expert on batch control to IEC, is the former chairman of the ISA SP88 Batch System control standard, and is the chairman of the IEC and ISO Joint Working Group on Enterprise/Control Integration. Mr. Brandl has written numerous papers and articles on business to manufacturing integration and flexible manufacturing solutions and has a regular column in Control Engineering. Dennis has a BS in Physics and an MS in Measurement and Control from Carnegie-Mellon University, and a MS in Computer Science from California State University.

BR&L Consulting,
208 Townsend Ct, Suite 200 Cary, NC 27518 – USA,
Tel. +1 (0) 919 852 53 22,
E-Mail: dnbrandl@brlconsulting.com

### REFERENZEN

A prototype of the information model is maintained as part of the OPC UA ISA 95 working group, which is developing the information model. The prototype includes a fully functional version of the information model. The information model includes samples of typical extensions that a company may generate to adapt the generic ISA95 information model to a company or deployment specific information model.

The address space shown in Figure 9 illustrate sample properties and objects such as an ISA 95 based temperature sensor or larger ISA 95 based model of a boiler, which include the aggregation of other equipment items.

**SUMMARY**

This paper describes the union of two widely accepted technologies – ISA 95 and OPC UA – that expands on the strengths of both. The ISA 95 model is widely used to define the information required for system integration. It provides a set of abstract UML models that can be used to represent exchanged information about materials, personnel, equipment, physical assets and other information. The OPC UA standard is an integration technology that is based on web service technology, is platform independent, and can be deployed from small embedded systems up to large scale plant-wide systems. OPC UA provides a robust and reliable communication infrastructure having mechanisms for handling lost messages, failover, heartbeat, and a binary encoding for high performance data exchanges. OPC UA’s open data model can be used to represent ISA 95 information in a generic and configurable method that allows for high-speed synchronous data exchanges required for manufacturing workflows.

The resulting union provides a robust high speed communication system for widely accepted common MOM information model. It also allows the ISA 95 model to be extended down to the level 1-2 systems without custom interfaces. It also allows ERP system to obtain select information directly from level 1-2 systems. It is expected that the OPC UA ISA 95 working group will finalize a mapping specification by the end of 2012 and it will be made available via the OPC Foundation.