IIoT Message Modeling for Enterprise Integration and Interoperability

A Whitepaper from OAGi and MIMOSA

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Table of Contents

1 Introduction

Rapid advances in Information and Communications Technologies (ICT) are being applied to manufacturing systems, driving a shift from traditional labor-intensive processes to advanced-technology-based Smart Manufacturing (SM) [1]. Among all the smart manufacturing technologies, the Industrial Internet of Things (IIoT) is a critical element fueling the modern manufacturing ecosystems. Coupled with data analytics and manufacturing and enterprise applications, they allow manufacturing systems to be proactive or respond in real time to changing demands and conditions in the factory, in the supply network, and in customer needs. While traditional hierarchical and domain-specific industrial system architectures are being adapted to enable such capabilities, i.e., the direct use of field measurement data in enterprise services across the entire manufacturing value chain; there is no documented standard and guideline for how such data should be conveyed to the manufacturing operation management level or the business logistics level.

Among the various options for enterprise services/applications integration, standards-based messaging provides both flexibility and reliability to allow loosely coupled communications. Standards from the Open Applications Group Incorporated (OAGi) provide a common content model and common message definitions, called OAGi Integration Specification (OAGIS) [2], for communication for various business application scenarios. OAGIS leverages the Core Component Specification, which is an ISO and UN/CEFACT standard [3]. The semantic refinement tools provided by OAGi make the implementation easier by pruning a message schema for a specific business communication scenario [4][5]. However, OAGIS has limited specified provisions to communicate IIoT or other plant floor operations data not covered by OAGIS. This becomes particularly challenging as there is a growing need to introduce IIoT data into business-to-business (B2B) and enterprise application integration (EAI).

At the same time, in the pluralistic standards system, there are many existing standards development organizations (SDO) providing measurement data models and common language, vocabulary and events for business information exchange [14]. Standards from GS1/EPCIS address supply chain, while those from Open Group, MIMOSA, MTConnect include data models for measurements. The MIMOSA CCOM [6] enables representations of complex physical assets as systems of systems, systems, and systems elements, providing context for asset management activities and asset-related measurements. MIMOSA CCOM also leverages the Core Component Specification, leading to a possible integration path for communicating CCOM data within various business application scenarios.

The need to ensure that plant-floor and B2B/EAI-level standards can inter-operate between themselves, to bring plant-floor measurement data to the enterprise level to inform business decisions is ever increasing. Leveraging existing data and message models for the enterprise/IoT integration will be vital in addressing this need. Members of the OpenO&M Initiative, including OAGi and MIMOSA, publish standards to effectively manage data supporting manufacturing processes and they have agreed to collaborate to help solve business problems where combinations of their existing standards may be useful. OAGi members needed better IIoT measurement capabilities as existing OAGIS measurement components could not be used as a first class message, profiled as stand-alone APIs (using Score, described in section 4), handling cross-industry needs and communicating the required contextual information. MIMOSA CCOM appeared to be the best option to solve these challenges. Likewise, MIMOSA members saw the value of embedded MIMOSA components within ERP and Supply Chain level messages, and the number of use cases has been increasing in demand. On 20 February 2019, OAGi and MIMOSA agreed on a collaborative project to explore mechanisms to accomplish this, by identifying gaps in applicable standards that need to be addressed to support the specified use cases, and addressing the gaps. Furthermore, the two organizations will explore RESTful API patterns (JSON syntax) that would facilitate the exchange of such data between systems. MIMOSA and OAGi also have an interest in continued cooperation under the auspices of the prior OpenO&M Initiative MOU [7]. That MOU has already resulted in various standards, including messaging service models. This paper explores IIoT message modeling options to how OAGIS and MIMOSA CCOM standards may work together and is the first deliverable of this collaborative work effort.

> Note: While cybersecurity is critical to information-system design, implementation, and operation, for the sake of brevity the concepts described in this paper are focused on the data content aspect of interoperability, under the assumption of secure data exchange. MIMOSA, OAGi and other members of the OpenO&M Initiative anticipate additional collaboration in conjunction with NIST to help improve overall enterprise risk management, specifically including, but not limited to IT oriented risks.

2 IIoT/Enterprise Integration Use Cases

IIoT and enterprise integration opens up new avenues to smart manufacturing. This section documents use cases that motivate this paper. They illustrate both a general/abstract and domain specific uses cases faced by the industrial contributors.

2.1 Smart Manufacturing

Historically, manufacturing systems have been designed to follow the Purdue Reference Model for Computer Integrated Manufacturing, which was standardized in ISA-95 [8]. The ISA-95 model includes five levels of manufacturing functions that are often separated into the operation technology (Field Devices and Control) and information technology (ERP and MOM) domains. In this paradigm, legacy measurement data move up and are contextualized hierarchically, shown as shown by the blue arrows in Figure 1. In the emerging smart manufacturing paradigm, every part of a manufacturing enterprise is designed to be connected through a network that enables communication, integration, automation, and decision making. Data integration challenges rise as IIoT devices are connected ubiquitously (shown as the orange links in Figure 1).

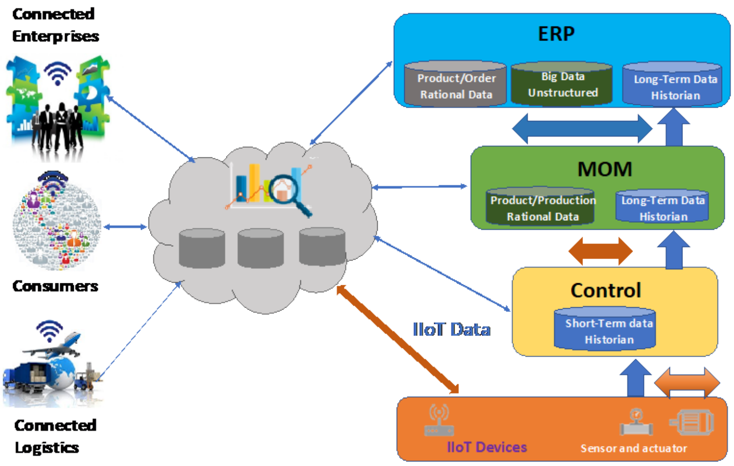


Figure 1. Paradigm shift of information integration for smart manufacturing

The emerging connected and distributed manufacturing systems demand a new and information-centric architecture where IIoT data can be communicated with sufficient context for real-time analytics. Operational and business analytics, such as those used for predictive maintenance condition-based maintenance, condition-based operations, supply chain logistics, on demand manufacturing and design for manufacturing, can then efficiently include real-time data with historical data to support decisions in real-time.

> Note: To "contextualize" something, is to take something specified generally and, given a specified business context, specify restrictions that result in something more concrete (and almost always smaller).

2.2 Smart Supply Chain

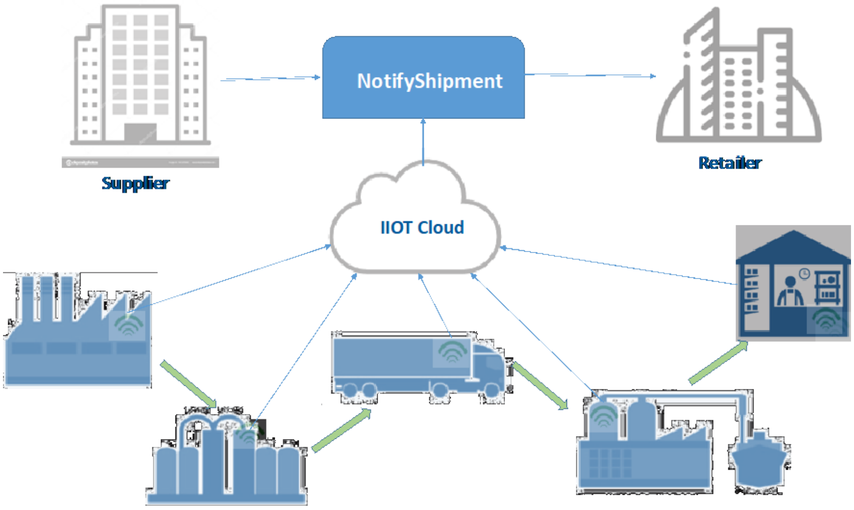


Figure 2. IIoT integration in supply chain management

IIoT devices in many forms are also leading supply chain into a smart era. As goods flow through the supply chain, business events related to the flow of goods are captured that convey the status of the order/shipment. Those business events trigger messages that communicate status among supply chain participants such as shippers, customers, transporters and regulatory agencies; and they convey changes in state for the shipment such as "ready for shipment", "leaving the shipper", "in transit", "arrived at intermediate checkpoint", "arrived at destination", etc. Various standards are used to communicate those business events, such as EDI, GS1/EPCIS and OAGIS.

What is new is the advent of sensor technology, and supporting communications infrastructure, that can be used to communicate finer grained IIoT data about the shipment, such as temperature, GPS coordinates for location, humidity, velocity, vibration, etc. One common characteristic of business-level standards, unfortunately, is that they lack a defined way to accommodate the IIoT data. Consequently, users and standards organizations are considering several options for addressing this issue:

- Define extensions to the standards so that IIoT data can be accommodated in the already defined business events (by the sender of the IoT data)
- Define a procedure for capturing IIoT data that can be combined with operating context/events to provide additional meta-data "after the fact".

This is a problem worth solving as the IIoT data, combined with the business status, provides great business value for the enforcement of contractual issues such as a requirement that goods be maintained within a temperature range during the entirety of a shipment.

2.3 An IIoT integration Use Case for Discrete Manufacturing

The diagram in Figure 3 illustrates the basic landscape of IIoT in a discrete manufacturing use case. The objective is to weave in OAGIS as to standardize an information architecture to enable operation-to-business interoperability. The interoperability addresses business problems like providing consistency and standardized data for business systems integration.

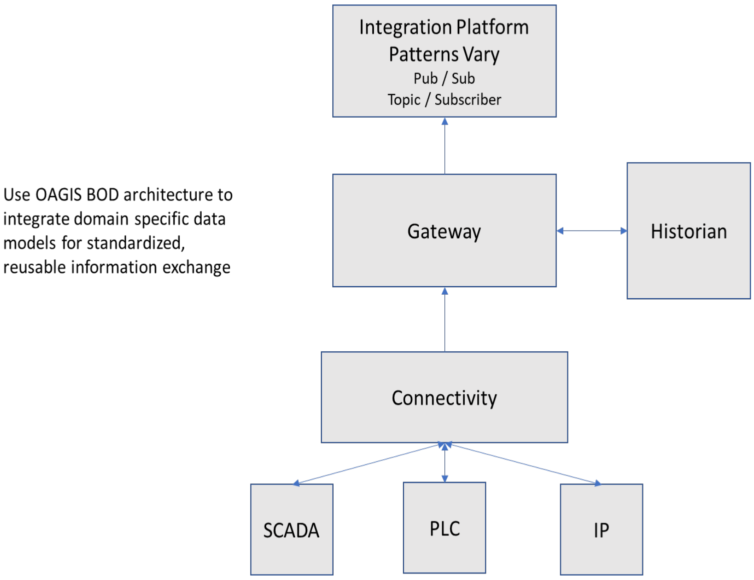


Figure 3. Manufacturing IIoT integration for information exchange

The lowest level of the diagram demonstrates the diversity that is experienced within most typical manufacturing floors. Equipment connectivity spans a broad range from connectivity via SCADA (Supervisory Control and Data Acquisition) to connecting to manufacturing floor IP based computers.

Typically, once connected, there is a transition for an Operations network to an IT network through a Gateway. The Gateway service accomplishes many functions, from serving as a connection point to acting as a security device, and managing the exchange of data messages. The messages are where broadly applicable standards and specifications like OAGIS apply. The challenge is to apply these standards and specification in the correct time and manner to add value.

The power and structure of OAGIS is the ability to encapsulate the many data formats and standards (e.g. MIMOSA), from the various devices and business systems going into and out of a manufacturing floor, into a standardized messaging infrastructure. An integration platform can apply various patterns to be able to deliver this data as information in a reliable fashion.

2.4 IIoT Big Data Integration for Additive Manufacturing

Large amounts and large varieties of IIoT data are being generated throughout the Additive Manufacturing part development lifecycle. That IIoT data includes data produced throughout the value chain, e.g., in research labs for process understanding, from material providers associated with the precursor and as-built material property characterization, and by machine vendors generated during process and equipment qualification. Thus, the ability to exchange IIoT data is critical to streamlining and accelerating AM-component certification and deployment. That ability is currently hampered because AM IIoT data is usually big, embodying all the 4 V characteristics of Big Data - volume, velocity, variety, and veracity. Achieving the interoperability to exchange IIoT data is challenging because accurate and complete descriptions of the big data sets from in-situ monitoring or ex-situ inspection do not exist. These descriptions are needed when the data sets are procured by, or shared with, business partners.

Standardized message models will not only provide descriptions of AM big data, but also define what should be exchanged in the AM digital data chain, including IIoT device registration, IIoT data set registration, and AM big data procurement. When an AM big data transaction is initiated, the AM big data registry can generate a message to AM data consumers that carries a payload including the description of the requested data set as well as a link to the big data.

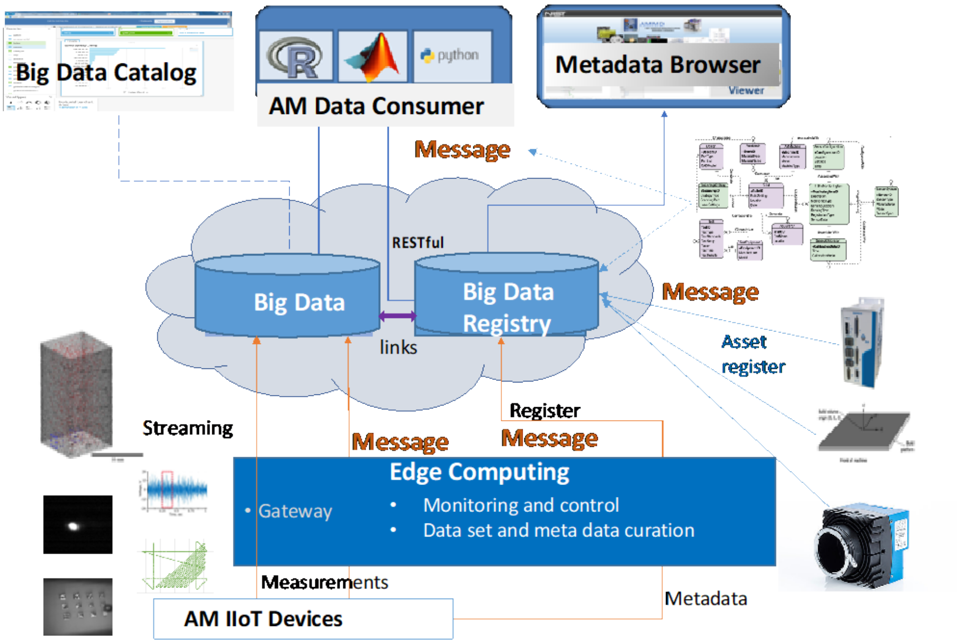


Figure 4. Message based IIoT big data exchange

2.5 Smart Production and Maintenance

In the areas of smart production and smart maintenance, Condition-Based Maintenance (CBM) and Condition-Based Operations (CBO) are two key techniques to leverage data from both legacy sensors and IIoT sensors for decision making. Both CBM and CBO systems need the collected measurements for continuous condition monitoring of assets. By sending the information in parallel to both systems, their specific cases, such as the smart production scheduling and maintenance scheduling, can be enabled in an integrated environment.

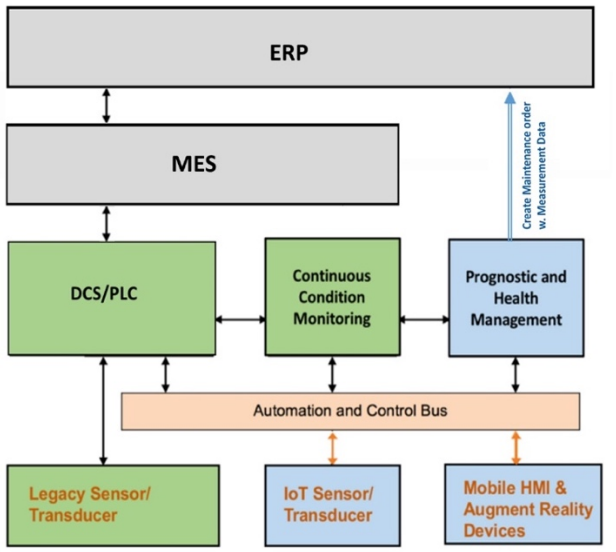


Figure 5. IIoT and legacy data combined in Condition-Based Maintenance

Such a use case not only improves production efficiency and asset performance but also reduces asset lifecycle costs. In Figure 5, measurement data from legacy sensors are aquired in a PLC and trigger an alarm of an equipment anomaly. The Condition Monitoring system and Prognostic and Health Management system combine the information from the operation system with the IIoT data to assess the condition and health of the equipment and decide to request maintenance for the equipment. A maintenance work order is created with a snapshot of the measurement data, which could be vibration, power, heat transfer, or any sensor data. The measurement data, perhaps in conjunction with other statistical population data such as historical averages, variance, etc., help the Asset Maintenance system and task scheduler to make a more informed decision.

3 Challenges and Opportunities for IIoT – Enterprise Integration

In the traditional manufacturing data integration architecture (shown as blue arrows in Figure 1), measurement data is contextualized incrementally as it rises up the hierarchy. This data is usually maintained within the applications that originally acquires it, e.g., production, quality, inventory, maintenance and material flow management. On the other hand, in the IIoT enabled distributed manufacturing paradigm, IIoT data (orange lines and arrows in Figure 1) need to be shared and accessible near real time across the functional hierarchy. Therefore, appropriate context data such as that shown in Figure 6 needs to be immediately attached to IIoT data and broadly accessible, particularly to smart applications and services at MOM and ERP levels. For that to be possible, two types of enabling methods and standards are necessary – a comprehensive data model for information exchange and a mechanism for fast and accessible contextualization across application domains.

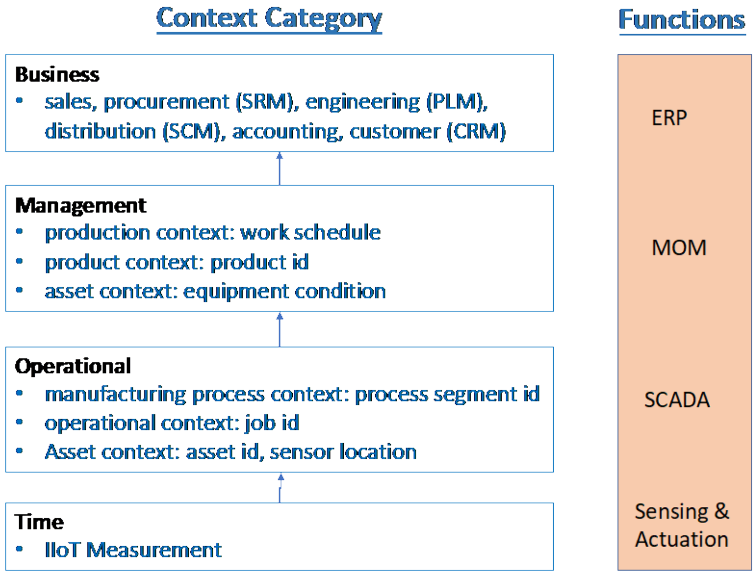


Figure 6. Context categorization for IIoT data application

OAGi and MIMOSA members met with NIST researchers to develop a vision for a combination of their standards and tools to address the challenges of IIoT and enterprise integration, especially for the condition-based maintenance and production application scenarios. Founded in 1994, The Open Applications Group Inc. (the OAGi) is organized to promote business process interoperability for both inter & intra enterprise business processes based on open standards and tools. Open Applications Group Integration Specification (OAGIS) defines a common content model and common messages for communication between business applications. In addition, tools like the OAGi-NIST Semantic Refinement Tools (a.k.a. Score) [5][9] are used to create, maintain, and use message standards in a revolutionary way. Message standards will be versioned at the component level allowing for more efficient migration between releases. They will be delivered in a syntax independent representation and can be contextualized on-demand and be generated in a syntax-specific representation for timely deployment within an integration environment.

First meeting in 1993, MIMOSA has been dedicated to developing and encouraging the adoption of open, supplier-neutral IT and Information Management (IM) standards enabling physical asset lifecycle management spanning plants, platforms, and facilities environments. MIMOSA CCOM (Common Conceptual Object Model) serves as an information model for the exchange of asset lifecycle information encompassing As-Engineered, As-Designed, As-Built, and As-Maintained information of a digital twin. As part of the model, CCOM defines data models for exchanging contextualized real-time measurement and event information. In addition, MIMOSA supports the data exchanges between applications based on the OAGIS BOD message model. Both OAGi and MIMOSA are key members of the OpenO&M Initiative, which was set up to provide a harmonized set of information standards for the exchange of Operations & Maintenance data (e.g. Production Orders and Maintenance Orders). The OpenO&M Initiative provides a platform for a new collaboration between the two SDOs on IIoT-Enterprise integration.

The next several sections provide the technical basis for IIoT and enterprise integration based on the OAGi message model and MIMOSA CCOM information model. A preliminary investigation is presented on how the two sets of standards can be utilized to overcome IIoT-enterprise integration challenges. Although this paper considers only the OAGIS and

MIMOSA standards, the investigation lays the groundwork for standardizing combinations of other standards.

3.1 OAGIS Message Model

OAGIS data models are created using the ISO 15000-5 Core Components Specification (CCS) as the modeling methodology [3]. OAGi released OAGIS Version 10 in 2013, the major release current as of this paper's publication is 10.6 [2].

The high-level architecture of BODs is illustrated graphically in Figure 6. A BOD contains two areas: one devoted to application and the other to business and engineering data. The Application Area contains information needed by the communication infrastructure to deliver and track the message. It also contains the business process context information that the receiver application may need in order to process the data correctly. Examples include the engineering or business process it is a part of, and whether it is a production or a test message. The Data Area contains the message content, which comprises Verbs and Nouns. The Verb indicates the action to be performed on the Nouns; the Noun is an object conveying business or engineering data or instruction to be acted upon or performed by the receiver application.

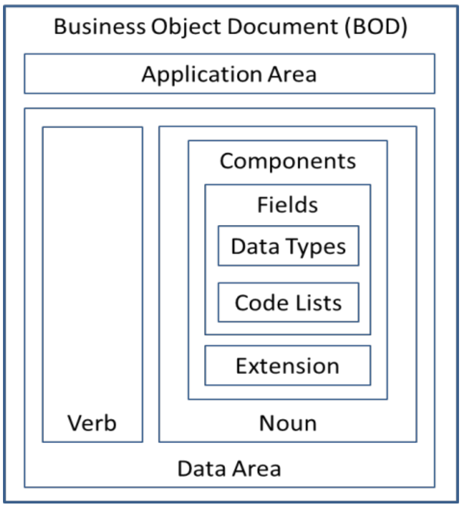


Figure 7. OAGIS message model/architecture.

Nouns are made up of reusable elements including Components and Fields. Components convey business data that have a complex structure. A component is made up of fields, and it may in turn contain other components. Fields convey business data that have a simple structure, i.e., a single value. Each Field is bound to a Data Type or a Code List that restricts its format and value domain. An important feature of OAGIS is its extension capability. OAGIS has a built-in extension capability for every component including the Application Area.

Although BODs begin with the word 'business', they also support transactions in various engineering functional areas throughout a single enterprise or across multiple enterprises. Example transactions include design, manufacturing, supply chain, finance, sales, and accounting. OAGIS support for manufacturing integration is also extended by the Business-to-Manufacturing Markup Language (B2MML) message standard published by MESA International [10]. It adopted OAGIS message model. In addition, OAGi has recently completed a suite of Quality Content nouns that address third party lab inspection orders, test results, test methods, test specifications, corrective action requests, plans and actions. The direct binding and read of measure off test instruments were not explicitly covered, but test measurement reporting from a Lab Information Management System to ERP-level was detailed.

OAGIS has adopted a model-driven approach (MDA), which separates the models from language-specific implementations. Starting in the first release of OAGIS 10, it defined the OAGIS Model in the Garden of Eden style XML schema, which is then derived into three OAGIS Expressions that are optimized for various deployment environments. For example, OAGIS JSON (JavaScript Object Notation) expression allows light-weight messages optimized for cloud and mobile deployments. This was an important development because, until recently, OAGIS focused exclusively on XML. Since OAGIS 10.4, the standard was also available in the NIST/OAGi Score tool. Score tool allows data exchange standards such as OAGIS to be managed and used in a syntax independent form according to ISO 15000-5 specification. In supporting the use of a data exchange standard, the tool allows standard messages or objects to be profiled based on contextual requirements. And instead of working with full schemas of those messages and objects that can include hundreds of thousands of data element the tool generates only the necessary data elements (and documentation) in a syntax of user choice include Russian Doll style XML schema, JSON schema, and Open API 3.0 schema object.

3.2 CCOM Data Model

MIMOSA CCOM (Common Conceptual Object Model) serves as an information model for the exchange of asset lifecycle information required for operation and maintenance of plants and complex facilities. The information model covers engineering, asset, configuration, lab testing, and operation and condition information, among others. Its core mission is to facilitate standards-based interoperability between systems: providing an exchange model for systems to electronically exchange data via adaptors to their internal data models, as illustrated in Figure 78 Towards fulfillment of that mission, CCOM is one of the standards incorporated in the OIIE (Open Industrial Interoperability Ecosystem) specification [11] and referenced by ISO TS 18101-1. ISO 18101 brings together several standards and specifications with the aim of supporting broad interoperability between industrial systems in a vendor-neutral fashion. ISO 18101 uses the OIIE Use Case Architecture and is based on the requirements validated in the OIIE Oil and Gas Interoperability (OGI) Pilot [13]. Moreover, the OIIE specification generalizes the concept of the CCOM adaptor to other data models and combinations thereof, resulting in a more general purpose OIIE adaptor.

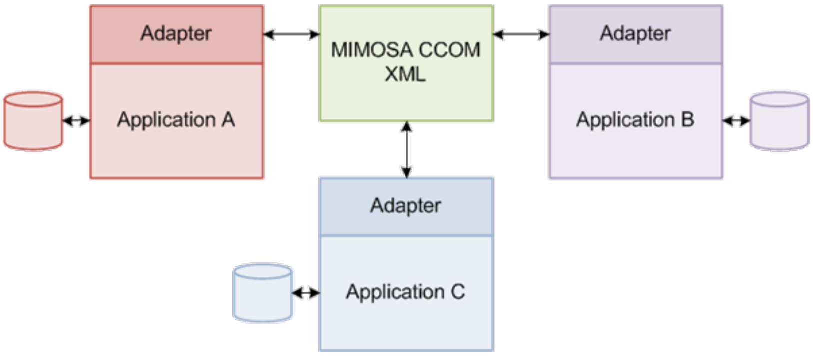


Figure 8. Supplier neutral standards-based application integration based on the CCOM model

CCOM follows prior MIMOSA standards of the layered architecture specified by ISO 13374-2, which separates implementation models, such as XML Schema and JSON schema, from the logical model (defined in UML). The layered architecture is displayed in Figure 9, while each layer is briefly described below.

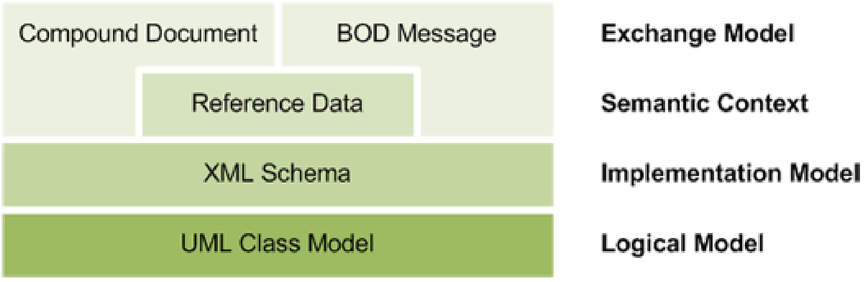


Figure 9. CCOM Architecture based on ISO 13374

Logical Model—The UML Class Model provides a diagrammatic representation of CCOM and documents classes, attributes and associations to explain concepts. In addition, CCOM adopts the UN/CEFACT Core Component Types as a set of underlying data types to achieve a common understanding of data structures and message types on a syntax independent level.
Implementation Model—The CCOM XML Schema encodes the CCOM UML Class Model as an implementation model. MIMOSA has more recently developed a JSON Schema implementation to support member requirements for lighter-weight message exchanges.

Semantic Context—CCOM provides an industry-agnostic information model; however, it allows for industry specificity through the use of Reference Data, which provides the semantic context of the information exchanges. Other international, industry, or company-specific reference data libraries can also be used as long as all parties using CCOM for data exchange are made aware that reference data.

Exchange Model—CCOM supports two methods of data exchange between applications: (1) as a compound document and (2) as BOD messages following the OAGIS BOD Architecture. Compound documents simply provide a container in which to place CCOM data of any type defined in the model, while BODs facilitate message-oriented exchanges between applications.

Of particular interest in the area of IIoT is the representation of Measurement data in MIMOSA CCOM, including various types of measurement data such as single measurements, time series, images, etc. Most important is the ability to associate each measurement to the operating context in which that measurement was taken, including the virtual or physical measurement location, the system or ‘measurement source that collected and aggregated the measurement; the transducer that made the measurement, the asset associated with the measurement at the time the measurement was taken, and/or the *segment* associated with the measurement at the time it was taken.

The term *segment* is a generic term representing some logical element of a model such as a functional location in a plant design, an element of a business process model or its instance, or a logistics/supply-chain segment, etc. The exact segment type is defined through an appropriate industry specific reference data set. Furthermore, the measurement location, asset, and segment are connected to a much broader context, for example, the entire process plant and its design considering a temperature transmitter in a plant.

This association to the context in which a measurement was taken supports the traceability of measurement data throughout an interconnected set of systems and supports advanced analytics, such as those required by CBM and CBP.

4 Integrated OAGIS-CCOM IIOT Message Models

This section investigates the message modeling options to integrate the CCOM data model within OAGIS business messages based on a concrete CBM use case. While we use real-world requirements from a specific scenario, one of our goals is to identify an approach that allows the CCOM and OAGIS standards to be used together in a general way, and which can potentially be applied to the integration of other standards as well.

4.1 Proof-of-Concept CBM/CBO Uses Case

To illustrate the possible modeling approaches of integrating the OAGIS and CCOM message payloads, we extend a general Condition-based Maintenance (CBM) use case to Condition-based Operations (CBO), where condition and operations data, e.g., measurements, are taken into account to make decisions about maintenance based on operational needs or impacts such as reduced quality of the product. The use case is illustrated in Figure 10.

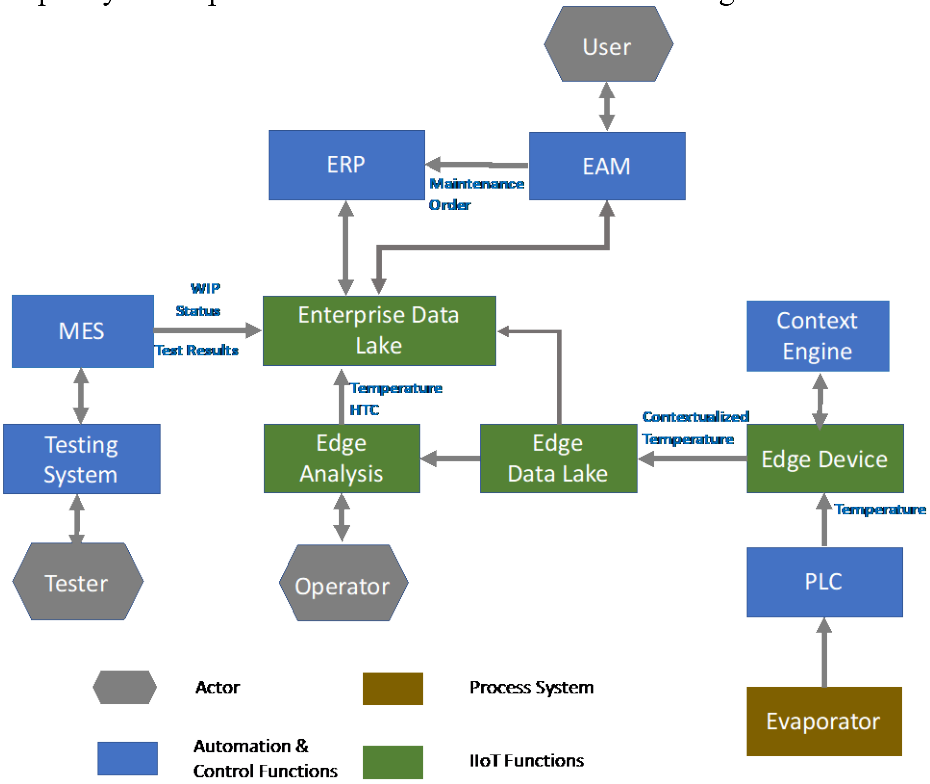


Figure 10. A CBM use case

In the CBM use case, while a work order is active in the shop floor, temperature measurements are collected from the evaporator by a PLC and streamed to Edge Data Lake via a gateway. The Heat Transfer Coefficient (HTC) is calculated by an Edge Analysis engine and ingested into an Enterprise Data lake together with the temperature measurement. Based on the trended HTC value as well as the work order and product quality information stored in a context engine, operators and plant personnel are able to detect and identify equipment faults resulting in a maintenance order created in the ERP and a resource allocated to maintenance crew to adjust equipment.

To fulfil the use case, it requires the representation and management of the operating context (e.g., business, management, operational, and temporal context) in which the data is obtained. The context of a measurement may include:

- the time it was taken (temporal context)
- the physical asset for which the measurement was taken (operational asset context)
- the sensor that took the measurement (operational asset context)
- the configuration of the sensor, when it was last calibrated, etc. (operational asset context)

- the time and place (functional location, unit, plant, …) at which the physical equipment was installed (management asset context)
- the production order that is being executed at the time (operational context); this may need to be correlated up to the production order (management context), purchase order (business context), or sales order (business context) level for the smart business decision
- the serial number or batch/lot number of the product/WIP the measurement was taken (asset context, operational to management level)
- the business process (general and process instance) in which the asset is performing its function (operational and management context)

The use case is centered around the inclusion of CCOM Measurement data within an OAGIS message featuring the MaintenanceOrder Component. A summary of the structure and most relevant fields is illustrated in Figure 11.

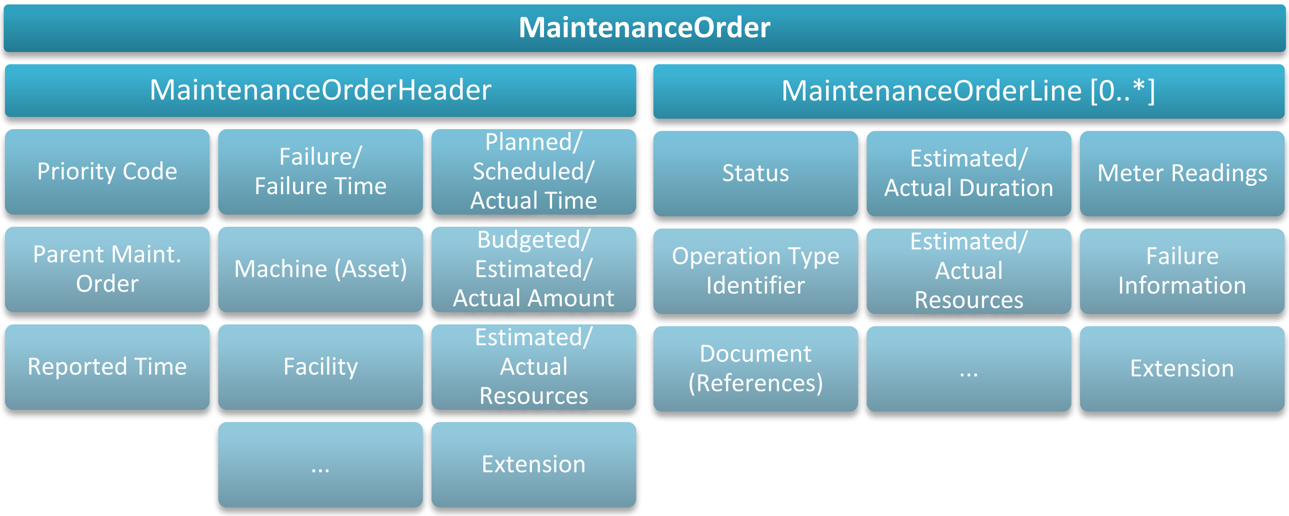


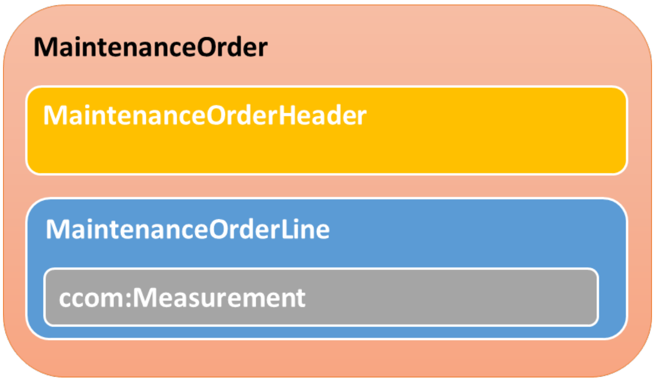
Figure 11. MaintenanceOrder structure in OAGIS

4.2 OAGIS and CCOM Integration Options

Eight options have been identified for CCOM and OAGIS integration. The integration can be performed in both directions, i.e., CCOM-based information included in exchanges to OAGIS-based systems and OAGIS-based information in exchanges to CCOM-based systems. In the following options for the integration of CCOM and OAGIS, options A-F relate to incorporating CCOM information in OAGIS-based exchanges, while G and H relate to representing OAGIS-based context information within CCOM. The identified options are as follows:

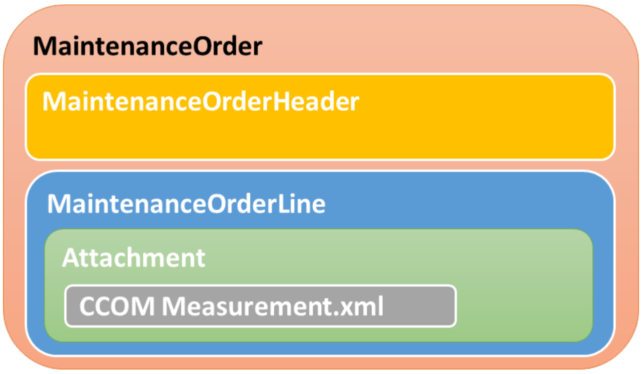
A. Enhance OAGIS with CCOM components

In this approach, CCOM entities are imported into the OAGIS library as common components, where necessary additional associations to CCOM components are added to OAGIS components. By plugging the content of one standard into another, the information can be represented in the most appropriate location in the message in a single payload. If two standards are in the same schema representation that is sensitive to federation such as XML Schema, a combined schema will be easier to understand and be available for further manipulation in other tools such as Score, mapping tool, or middleware tool. Since OAGi members have previously imported other XML Schemas into the OAGIS platform schemas, the combination method seems very straight-forward without breaking the standards.



B. Inline attachment of CCOM data in the OAGIS message

Another approach is to attach, unchanged, the MIMOSA CCOM Measurement data to a OAGIS Component, such as MaintenanceOrderHeader using its Attachment component. Content in the Attachment is base64Binary encoded. Hence, the CCOM data is treated as opaque binary content in this approach, which has the benefit that it does not need to be manipulated. The drawback is that the message processor needs an additional capability to decode base64Binary objects into structured content first. Moreover, not all OAGIS Components support document attachments. Without enhancing OAGIS so that all Components have an Attachment component, this approach could make the relationship between the Component and the additional data unclear.



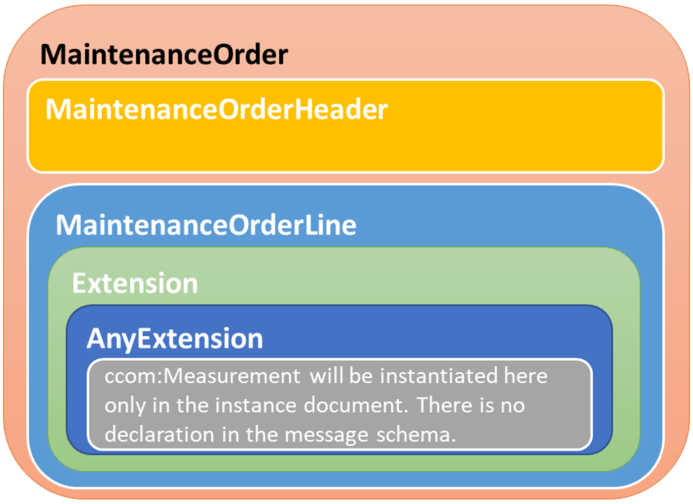
C. MIME Multi-part attachment of CCOM data in the OAGIS message

Similar to Case (b), the OAGIS Attachment component is used. However, actual CCOM content is not embedded in the OAGIS message but rather separated into another MIME body part. The Attachment simply captures the meta-data (e.g., using the ID or URI in the Attachment to point to MIME Content-ID) about which MIME body part contains the attachment. In this case, the MIME content-type can be specified as text, and no binary encoding/decoding is necessary. On the other hand, an additional capability to support MIME is needed in the middleware, and message processing needs to understand the meta-data associated with the MIME attachment.

D. Attach CCOM data through OAGIS run-time extension

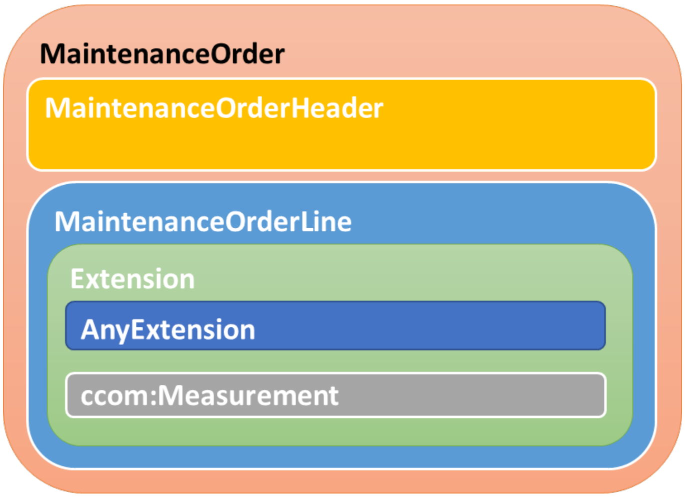
In this approach, CCOM data is instantiated within the Extension element of an OAGIS component without a declaration of CCOM element in the OAGIS schema. OAGIS provides such run-time extension through the AnyExtension subcomponent of the

Extension component. The message instance, however, is still validated with CCOM schema because the AnyExtension element is declared with strict content processing. With that facility, the whole CCOM Measurement data structure can be instantiated directly under the AnyExtension in any OAGIS Component in a message. In this way, CCOM data is encoded in the same way as an OAGIS message and is interpretable within the message component to which it is related.



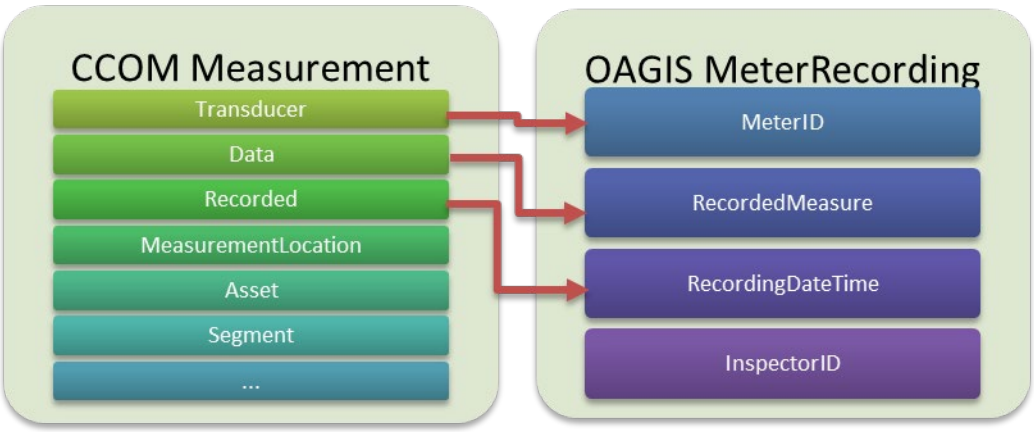
E. Attach CCOM data through the OAGIS design-time extension

In this approach, CCOM component is first declared within the component-specific extension type of the corresponding OAGIS component. For example, the component-specific extension types MaintenanceOrderHeaderExtensionType or MaintenanceOrderLineExtensionType may be associated with an element from the CCOM schema, such as CCOM Measurement, at design time. Instance data can then be validated against the combined schema. In this way, the CCOM element is part of the data exchange specification, and the Score tool can be used to profile (trimmed down) OAGIS messages, as well as the included CCOM elements, such as Measurement. The Score tool can then express the profiled message specification in several syntaxes such as XML schema, JSON Schema, Open API schema object. The message schema would look like the figure below.



F. Map from CCOM data model to OAGIS components

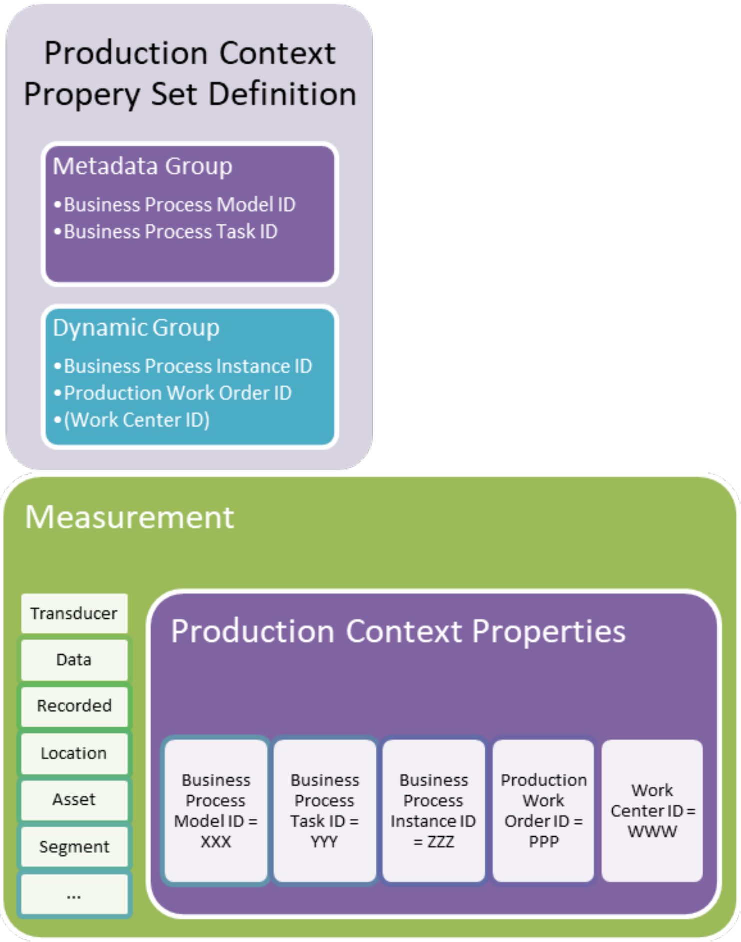
An alternative to integrating the content of the two standards into a single message is to perform a transformation between them. In this case, it would require the development of mappings between the CCOM Measurement data and the equivalent Components of OAGIS. A starting point for mapping can be between the CCOM Measurement and the OAGIS MeterRecording. In general, transformation is a useful approach, but the mappings can be complex and incomplete, so it is important to ensure transformations are used where appropriate.



G. Additional operating context within CCOM via Mappings

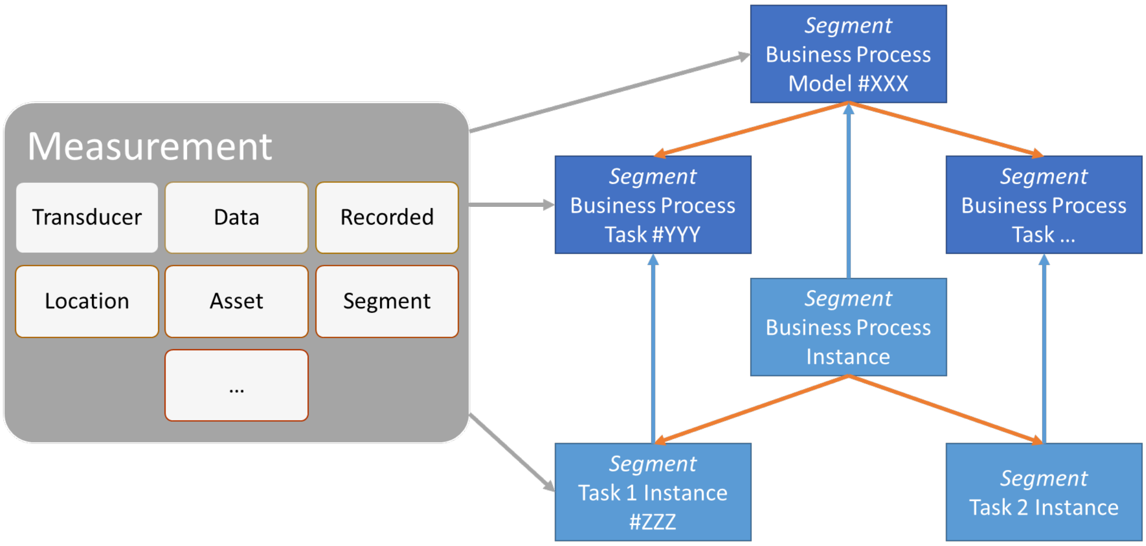
MIMOSA CCOM supports the association of user data to entities through its extensible Property model. For the example use case, custom properties will have to be defined to associate the Measurement data to the additional operating context, including the production order, the business process model, the business process task, and the business process instance identifiers. Other contextual information may also need to be captured by properties if it is not already included in the CCOM representation or if it is desired to capture it all in one place. For example, the work center may be incorporated in the breakdown structure represented in CCOM but may also be captured as an additional property if the breakdown structure does not include the work center or it is desirable to flatten out the information. In the latter case, care needs to be taken to ensure values are kept consistent.

Alternatively, property definitions can be defined in such a way as to allow other content to be attached, similar to the runtime extensions of OAGIS (option D). Depending on the granularity of the attachment, the semantics may be preserved to a greater or lesser degree.



H. Mapping external Context to CCOM

CCOM is designed to capture the context of the various elements as discussed in Section 3.2. For the example use case, a reference data set would need to be created to help represent the business process model as Segment entities. The idea of CCOM is to support the exchange of information to achieve a purpose and link back to the original systems, so the level of granularity does not need to capture all the control-flow of the business process. Rather, the mapping to CCOM need only capture the tasks of the business process and the logical connections between.



4.3 Comparison of the Integration Options

The table below shows the comparison of the integration options based on the use case study. From the table, the integration options can be compared in four dimensions including the type of approach (plug-in or conversion), their syntactical flexibility, the requirement to support multiple namespaces, and the pre-processing sensitivity. These dimensions are described briefly below.

The plug-in **type of approach** means each standard remains in its original form. This approach, generally, requires less effort to integrate or use the standards together. When the approach is not plug-in, i.e. it requires conversion, a higher effort is needed, but more consistency/accuracy of the integrated specification may result. The variety of options should be explored further, necessary to meet the different demands of different application scenarios.

The **content validation** criterion indicates how an instance can be validated against the combined message schema. **Single** (or single step) means the instance can be validated altogether while **Multi** (or multi-step) means parts of the instance need to be validated separately.

The **requirement to support multiple namespaces** means whether the resulting specification and correspondingly the main message instance has multiple namespaces; and hence, the integration environment needs to be able to support that. In some cases, with tools like Score, the namespaces can be flattened, provided that there are no local name clashes.

The **pre-processing sensitivity** indicates whether an approach requires additional capability beyond the syntax used in the main message body to process the message with the integrated content. For example, MIME multi-part processing capability is needed in Option C to relate the content in MIME part with the message context.

Table 1: Comparison of the integration options

Options	***Plug-in Approach?***	***Content Validation***	***Single Namespace?***	***Sensitive to Pre-processing?***
A. Enhance OAGIS with CCOM components	Yes	Single	Yes with tool	No
B. Inline attachment of CCOM data in the OAGIS message	Yes	Multi	Yes	Yes
C. CCOM as MIME Multi-part attachment	Yes	Multi	Yes	Yes
D. *Attach CCOM data through the OAGIS run-time extension*	Yes	Single	No	No
E. *Attach CCOM data through the OAGIS design-time extension*	Yes	Single	Yes with tool	No
F. Map CCOM data model to OAGIS components	No	Single	Yes	No
G. Additional operating context within CCOM via Mappings	Yes	Single	Yes (No with embedded content)	No
H. Mapping external Context to CCOM	No	Single	Yes	No

5 Conclusion

In the age of the emerging Industrial Internet of Things (IIoT), there is an ever-growing need for efficient, reliable, and robust integrations to allow direct use of field measurement data across the entire manufacturing value chain. Message standards are key to enabling flexible, reliable, and loosely coupled integration of enterprise systems. Yet, no single standards organization has or can realistically cover all aspects of message standards development for systems integrations.

The purpose of this whitepaper is to show how two standards development organizations – OAGi and MIMOSA – have joined forces to use each other's message standards capabilities rather than replicate these capabilities within their message specifications. To achieve that, they collaborated with industry organizations to identify several IIoT use cases that are of shared interest to the two organizations. With these representative IIoT use cases as a backdrop, the whitepaper provides insight into an essential problem: how context data can be immediately attached to IIoT data and broadly accessible to all smart applications and services at MOM and ERP levels.

For this data contextualization problem to be solved, OAGi and MIMOSA brought to bear a data model for information exchange and contextualization and a mechanism for fast access of contextualized information across application domains. The whitepaper builds on OAGIS and MIMOSA resources to analyze eight different message models as alternative standards integration approaches for the OAGIS message model and MIMOSA data model. By comparing these standards integration options with respect to the type of approach (plug-in or conversion), their syntactic flexibility, the requirement to support multiple namespaces, and the pre-processing sensitivity, this whitepaper provides a foundation to assess these integration options for industry IIoT-Enterprise integration use cases. Thus, the whitepaper advances technology-based smart manufacturing by providing objective recommendations for selecting a standards-based approach to optimal conveyance of IIoT data across supply chain.

While more use cases may be explored such as those for critical infrastructure management, a logical next step is to select a small subset of the use cases identified in section 2 of this white paper and perform deep dive analysis of the eight MIMOSA-OAGI message integration options and turn the results into joint specifications. These joint specifications should be incorporated into the OpenO&M set of specifications already developed with partnerships between SDOs that include OAGi, MIMOSA, ISA, and OPC Foundations and with technical support from NIST. Industrial digital ecosystem pilots using those OpenO&M OIIE specifications that include the IIoT-compatible ISBM messaging framework will be planned. This joint work also aims to contribute to the further development of ISO 18101 that has been proven to assist in enabling a true standards-based interoperability in the OIIE Oil & Gas Interoperability Pilot. NIST and OAGi are additionally interested in developing new messages needed for big data sharing and analyses. To those ends, an additional series of white papers are planned to explore the most pragmatic methods for accelerating this process of developing more joint specifications and industry pilots.

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