Information Model Integration for Service-oriented Manufacturing Operation Management Systems

Hartmut Schweizer
Institute for Applied Computer Science
TU Dresden
01062 Dresden
email: hartmut.schweizer@tu-dresden.de

Martin Wollschlaeger
Institute for Applied Computer Science
TU Dresden
01062 Dresden
email: martin.wollschlaeger@tu-dresden.de

***Abstract*—This paper presents a concept for the combined application of information models in automation as a basis for a service-oriented, component-based architecture of Manufacturing Operation Management Systems (MOM). It will be shown how the information models of the Automation Markup Language (AutomationML) and the OPC Unified Architecture (OPC UA) can be integrated into the Business To Manufacturing Markup Language (B2MML). This allows achieving an improved transparency and availability of process data and knowledge data within automated manufacturing processes. Here, the extension functionalities and the transaction specifications of B2MML are used. Finally, an application example is shown and is discussed.**

Keywords – Automation; Model integration; B2MML; AutomationML; OPC UA.

I. Introduction

In automated production, the organizational architecture, driven by increasingly powerful hardware, higher networking, and developments, such as the Industrial Internet of Things (IIoT) or Cyber-Physical Production Systems (CPPS), is changing from the classical pyramid structure to component-based architectures (Fig. 1). This applies both to the hardware, i.e., Personal Computers (PCs), Programmable Logic Controllers (PLCs), and field devices, and to the software used for tasks in the different company levels, e.g., Manufacturing execution System (MES) or Enterprise Resource Planning (ERP) [1].

This also results in new requirements for the form and availability of data and information within these distributed structures, e.g., addressing decentralization, interoperability and virtualization. The same applies to an information model, which needs to meet these requirements [2]. In the following, a concept for such a heterogeneous information system, consisting of OPC UA, B2MML, and AutomationML, is presented for a component-based organizational structure with a service-oriented architecture. The main advantage of this approach is given by the integration of existing information models into a harmonized information system.

II. Information Models in Automation

In the automated manufacturing, numerous different information models are used. Due to their different focus and degree of detail as well as other characteristics, such as service suitability and legibility, however, they are not all equally suitable for all aspects at every (company) level [11]. Among other things OPC UA [3], AutomationML [3], and the IEC 62264 implementation B2MML are three models that cover the required information spectrum for a MOM [11]. These are briefly presented below. Especially the elements of B2MML, which are used in the application example in section V, will be explained detailed.

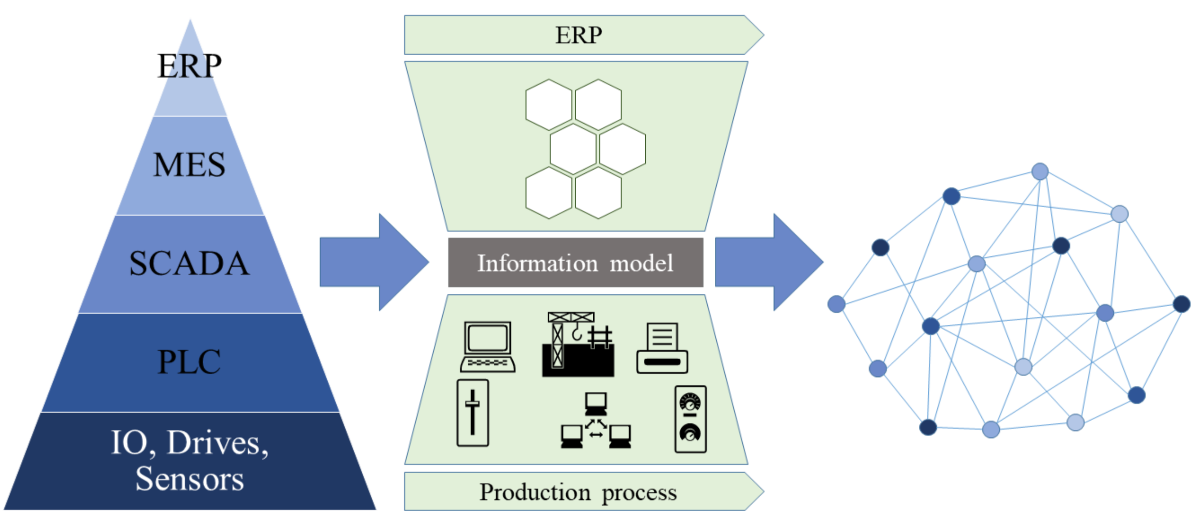

Figure 1. Development of the automation pyramid

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A. OPC UA

The standard OPC UA (IEC 62541) defines an object-oriented, flexible industrial information model with a defined communication protocol. The OPC UA architecture follows a Service-Oriented Approach (SOA). Its structure consists of several layers. All basic services (base services) defined by OPC UA are abstract method descriptions. Thus, they are protocol-independent and provide the basis for the entire OPC UA functionality. The communication layer provides access to these methods using a protocol that serializes and deserializes the data and sends it over the network (in binary or XML format) [4].

The OPC information model is a so-called full mesh network of nodes. A node resembles an object from object-oriented programming and can have attributes. It is also possible to define and call methods [4]. Furthermore, events are supported that can be sent to exchange certain information between devices. Further information models, e.g., for specific application domains, can be based on this base layer [4].

B. CAEX and AutomationML

AutomationML is a neutral, XML-based data format for the storage and exchange of plant design and engineering data. It is based on the Computer Aided Engineering Exchange (CAEX) data format defined in IEC 624242. The primary goal of AutomationML is the exchange of engineering data in a heterogeneous tool landscape of modern engineering tools, covering various disciplines such as mechanical design, electrical design, HMI development, PLC programming or robot control. AutomationML is standardized in IEC 62714. It supports the integration of other file formats. In particular, the integration of PLCopen XML [5] is provided for embedding PLC programs and logic, while COLLADA format [6] is intended for geometry information [7].

C. IEC 62264 and B2MML

The international standard IEC 62264 defines models, activities, and data exchange for Manufacturing Operations Management systems. B2MML [8] is an XML implementation of the IEC 62264 specifications in the form of XML schemata, which is designed as a link between ERP and materials management (supply chain) and to the production level [9]. Part 2 of IEC 62264 defines objects and attributes for the integration of enterprise management and control systems. This includes the resource types *Personnel*, *Equipment*, *Material*, and *Physical Asset* as well as the production process type *ProcessSegment*. In the following, the equipment model (Fig. 2) and the process segment model for the resources are explained in more detail.

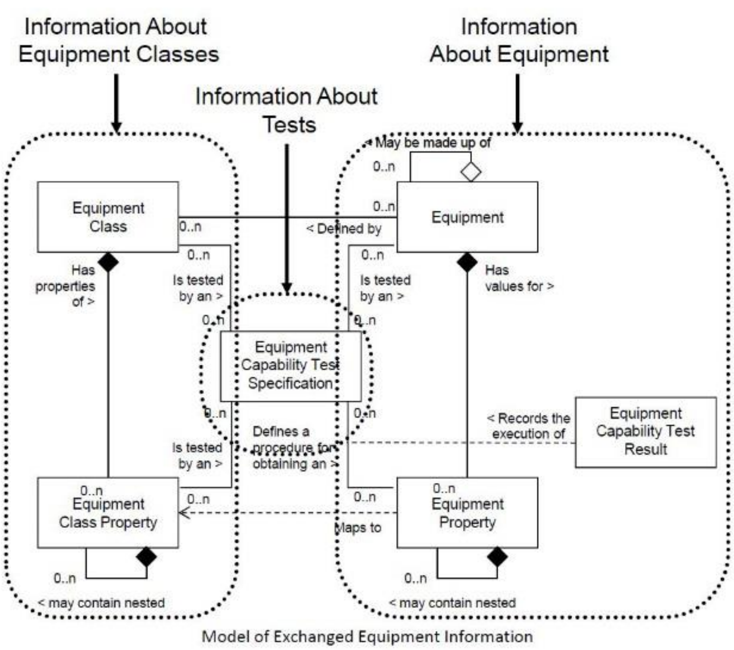
1) The role-based equipment model of IEC 62264

Each *Equipment* resource can be composed of other *Equipment* resources and aggregates *Equipment Properties*. It can also be defined using one or more *Equipment Classes*, which can have any number of their own class properties. Test specifications can also be defined for *Equipment* and *Equipment Classes* and their properties (Fig. 2).

Equivalent models are defined for the other resource classes *Personnel*, *PhysicalAsset*, and *Material* [10].

2) The process model of IEC 62264

Process segments in IEC 62224 are defined as the smallest elements of manufacturing activities that are visible to business processes. The process model is hierarchically




```xml
<xsd:complexType name = "EquipmentType">
  <xsd:sequence>
    <xsd:element name = "ID"
                 type = "IdentifierType"/>
    <xsd:element name = "Description"
                 type = "DescriptionType"
                 minOccurs = "0" maxOccurs = "unbounded"/>
    <xsd:element name = "Location"
                 type="LocationType"
                 minOccurs="0"/>
    <xsd:element name = "HierarchyScope"
                 type = "HierarchyScopeType"
                 minOccurs = "0" />
    <xsd:element name = "EquipmentLevel"
                 type = "HierarchyScopeType"
                 minOccurs = "0" />
    <xsd:element name = "EquipmentAssetMapping"
                 type = "EquipmentAssetMappingType"
                 minOccurs = "0" maxOccurs = "unbounded"/>
    <xsd:element name = "EquipmentProperty"
                 type = "EquipmentPropertyType"
                 minOccurs = "0" maxOccurs = "unbounded"/>
    <xsd:element name = "Equipment"
                 type = "EquipmentType"
                 minOccurs = "0" maxOccurs = "unbounded"/>
    <xsd:element name = "EquipmentClassID"
                 type = "EquipmentClassIDType"
                 minOccurs = "0" maxOccurs = "unbounded"/>
    <xsd:element name = "EquipmentCapabilityTestSpecificationID"
                 type = "EquipmentCapabilityTestSpecificationIDType"
                 minOccurs = "0" maxOccurs = "unbounded"/>
    <xsd:group   ref  = "Extended:Equipment"
                 minOccurs = "0" maxOccurs = "1"/>
  </xsd:sequence>
</xsd:complexType>
```

Figure 2. Equipment model IEC 62264 [10] and B2MML – Implementation of EquipmentType [8]

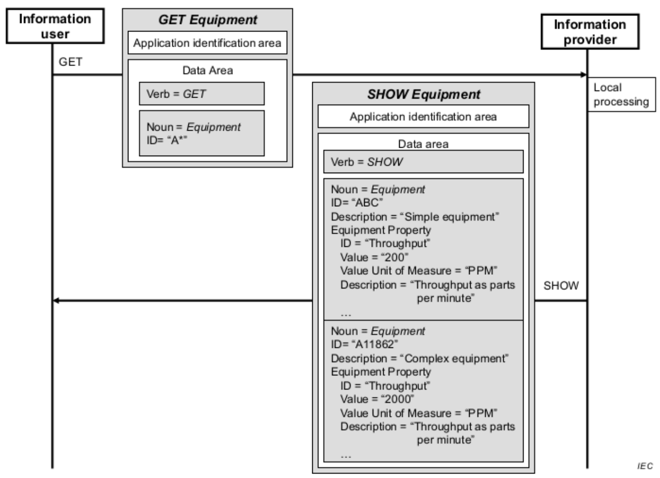


Figure 3. Transaction in IEC 62264 [15]

structured, i.e., each process segment can contain further subordinate process segments. The interdependencies between the process segments are realized by references in the form of *ProcessSegmentDependencies.* All resources can be aggregated from process segments as resource specifications via references. The processes in turn can correspond with *operation* or *product definition segments* [10].

3) The transaction model of IEC 62264

Part 5 of IEC 62264 defines transactions for the exchange of information between applications of business processes and applications of manufacturing processes. The extensive transaction specifications are one of the main reasons for using B2MML as a data model in this concept. The *GET/SHOW* transaction mechanism is briefly explained above (Fig. 3). The transaction model for GET and SHOW is the *PULL transaction model*. It is used when a user submits a data request to an information provider. A GET request can be issued for a specific object via its ID, or by means of a so-called "wildcard" (*) for several objects (Fig. 3) [15].

III. Heterogeneous Information Model for MOM as a Distributed Service-Oriented System

As already explained above, there are mechanisms in both OPC UA and AutomationML to integrate and use other information models. In OPC UA and AutomationML, Companion specifications exist, for example for ISA-95 (B2MML) [12] [13]. In addition to COLLADA and PLCopen XML, other information models – such as B2MML – can also be integrated and referenced in AutomationML [14]. From the point of view of the enterprise level, these two variants are bottom-up approaches. Thus, information from or for the enterprise management level (ERP) is represented in information models of the plant and process control level (OPC UA, AutomationML). If this information was not already created in the modelling using companion specifications, it must be integrated into the respective model by transformation. This is

- costly
- error-prone
- complex and difficult to read

To solve this problem, this paper presents an approach in which the information models of OPC UA and AutomationML are integrated into B2MML (Fig. 4 and Fig. 5). This allows using information from all three models in combination without having to modify the information

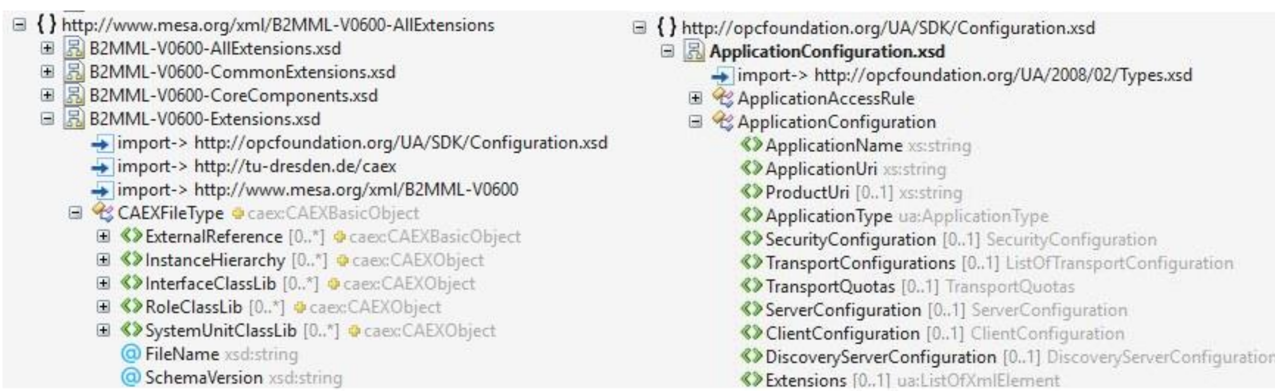


Figure 4. Integration of OPC UA and CAEX schema elements in the B2MML model schemata

```
<xsd:group name = "Equipment">
        <xsd:sequence>
                <!-- add extended elements here -->
                <xsd:element name="CAEXFile" type="CAEXFileType" minOccurs="0" maxOccurs="unbounded" />
                <xsd:element name="OPCUAServerConfig" type="opcua:ApplicationConfiguration" minOccurs="0" maxOccurs="1" />
                <xsd:element name="OPCUAClientConfig" type="opcua:ApplicationConfiguration" minOccurs="0" maxOccurs="1" />
        </xsd:sequence>
</xsd:group>
```

Figure 5. Enhancement of the Equipment Schema of B2MML [8] with OPC UA and AutomationML elements

structure of the individual information blocks, or to adapt them. This paper does not deal with the interoperability and transformation of the treated information models; these mechanisms remain unaffected by this concept. Nevertheless, their necessity can be reduced, because in the presented concept every stakeholder normally gets the needed data in the suitable format (Fig. 6).

IV. Integration of Information Models from AutomationML and OPC UA into B2MML

B2MML provides so-called extension points for the extension of all main classes such as process segments or resources (*Equipment*, *PhysicalAsset*, *Personnel*, and *Material*). These are used to include additional information structures in the model or in the corresponding submodels.

The following demonstrates how this mechanism is used to extend B2MML with the information models of OPC UA and AutomationML. The first step is to import the basic information models, i.e., the XML schemata of AutomationML (CAEX) and OPC UA, into the B2MML schema (Fig. 4). Then the partial models, into which corresponding data are to be inserted, can be extended accordingly. Figure 5 shows the extension of the B2MML equipment model by an AutomationML information and an OPC UA configuration.

It should be noted that, in the case of AutomationML, external references can be used to link the contents of other (XML) files. If this option is used, the schemas of these models and the referenced files must also be included. In the case of the PLCopen XML and COLLADA, these are the corresponding schemas found in [5] and [6].

There are two requirements for enabling communication for this extended B2MML schema: Both communication partners must have implemented (i) the transaction functionalities defined in [15] and (ii) the B2MML XML-schema extensions as described above. In case of AutomationML the *ChangeMode* attribute of AutomationML [16] and the transaction concept of B2MML have to be combined and synchronized. Table I shows the resulting affiliation.

For each transaction of a B2MML element including CAEX code, the appropriate AutomationML *ChangeMode* parameter has to be set. The following example illustrates how this extension can be used in practice, and which advantages result from it.

V. Application Example: Information on Planning, Simulating, and Executing a Production Process Restructuring with Equipment Replacement

The described application case deals with a process restructuring in a process chain. The process shall be changed from injection molding to 3D printing within an automated production process for the manufacturing of an element made from plastic. During the restructuring, as little interference as possible shall be made in the production flow of the other processes running. For this purpose, following questions must be answered and work steps carried out.

- What is the actual status of the plant (Monitoring: OPC UA)?
- Which operations and processes as well as interrelated processes are affected (ERP: B2MML)?
- Which resources are affected, deleted, or required (ERP: B2MML)?
- Estimation of the effort required for the necessary modifications (plant engineering data: AutomationML)
- Execution (plant data: AutomationML, personnel planning: B2MML)
- Commissioning, monitoring, quality control (Monitoring: OPC UA, Quality criteria: B2MML)

It can be recognized that production process restructuring affects all levels of automation. By means of the extensions of B2MML by OPC UA and AutomationML elements, the required data can be communicated directly in the required form. This can be performed between the necessary functional components at the various levels using a service-based approach on top of the transaction mechanisms of B2MML (Fig. 3) [15].

Figure 6 shows a simplified representation of the production process restructuring as described above. In particular, the organizational sequence of the action, in combination with the data required in the respective work steps is explained. On a customer request ("Customer Order"), a feasibility check is carried out with regard to the product and the production line. This leads to a review of the processes involved, which include references to the required equipment.

Figure 6, Listing 1 shows this *ShowProcessSegment* information. The equipment can now be called up via the references in the *EquipmentSegmentSpecifications*.

Figure 6, Listing 2 shows the content of the *ShowEquipment* transaction response for injection molding machine with its plant planning data in AutomationML, the OPC UA configuration data, and its test specification properties. A GET call [15] to the *EquipmentcapabilityTestSpecificationID*s allows the corresponding properties of the injection molding machine to be queried.

Figure 6, Listing 3 shows the content of the *ShowEquipment* transaction response for the 3D printer with its plant design data in AutomationML, the OPC UA configuration data, and its test specification properties. By a GET call [15] of the *EquipmentcapabilityTestSpecificationID*s, the corresponding properties of the 3D printer can be queried and compared with those of the injection molding machine.

TABLE I. AFFILIATION OF B2MML AND AUTOMATIONML COMMUNICATION CONCEPTS

B2MML	AutomationML	
Sync (Change)	Change	PUBLISH
Sync (Delete)	Delete	PUBLISH
Sync (Add)	Create	PUBLISH
Get	State	PULL
Show	State	PULL
Confirm, Cancel, Acknowledge, Process, Respond, Change		PUSH

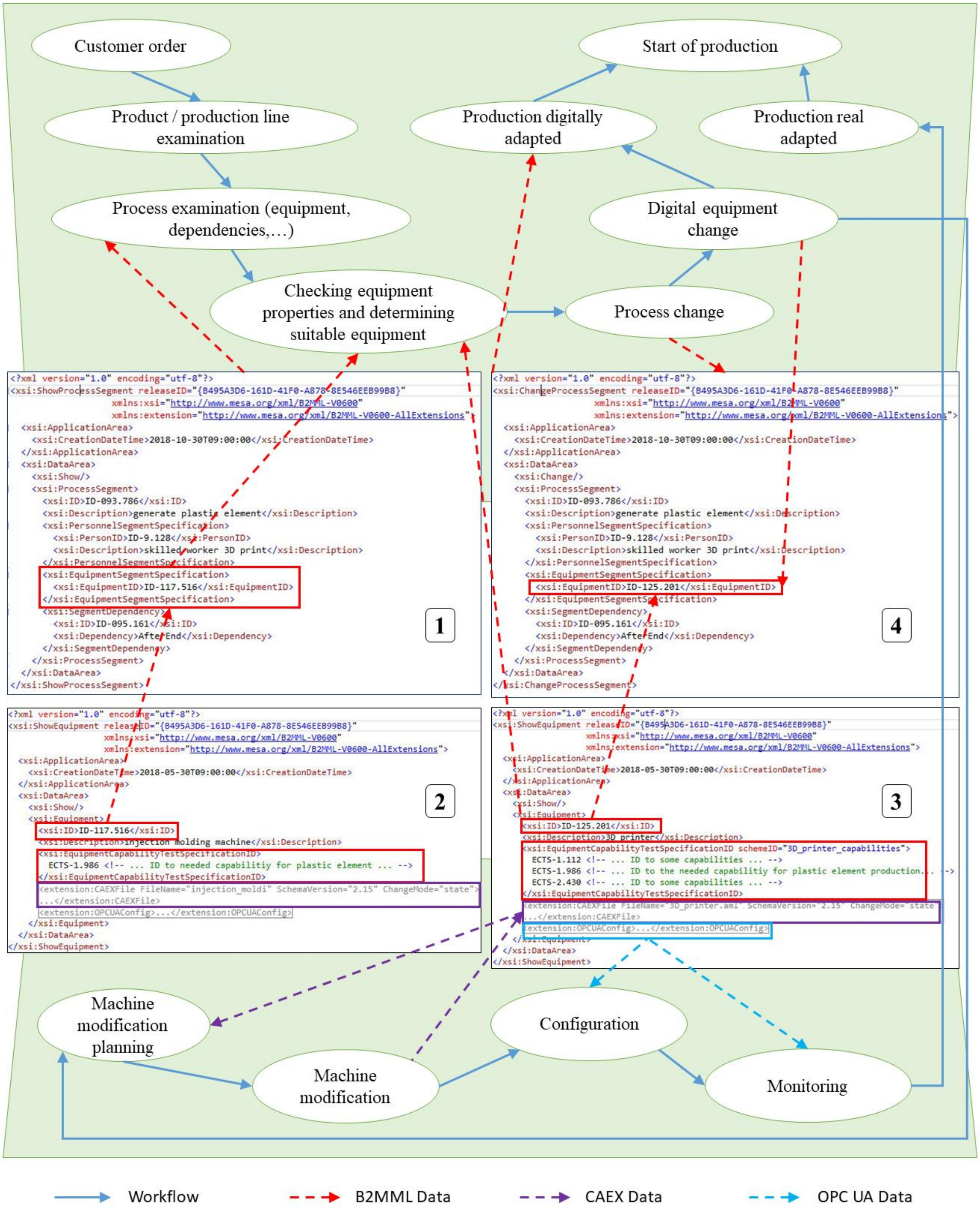


Figure 6. Application Example

Since the printer meets the required property, the process can be restructured. With this information, the process can now be updated with new *EquipmentSegmentSpecification* using the *ChangeProcessSegment* transaction [15] by entering the ID of the 3D printer for the required equipment. This means that the new equipment including communication functionalities (OPC UA configurations and hardware plans (AutomationML)) are technically updated for the restructured process (Fig. 6, Listing 4).

Furthermore, the required connection and installation information (AutomationML and OPC UA) are available simultaneously with the *EquipmentSegmentSpecifications* of the 3D printer (Fig. 6, Listing 3). In addition, the corresponding personnel with required capabilities was assigned to the process segment in the *PersonnelSegmentSpecification* at the same time.

When using the OPC UA-Companion specifications for ISA-95, the corresponding elements would have to be transformed to B2MML in order to make them readable for a B2MML-based ERP system. Equivalent to this, the B2MML information would have to be transformed into AutomationML for an AutomationML-based system or into B2MML for a B2MML-based system. Manual activities would be necessary to complete the allocation of the resources [14], if the Companion specifications were not used.

VI. DISCUSSION

As explained in the previous sections, AutomationML, OPC UA, and B2MML provide mechanisms for extending or integrating and using other information models. For the concept presented, the variant of using the extension of B2MML with AutomationML and OPC UA via the appropriate extension points was chosen. This has the advantage that, on the one hand (usually), no data transformation is necessary. All data is contained in the data package in the required information model. On the other hand, the transaction specifications of B2MML for AutomationML information [1] and OPC UA information can also be used for the enterprise level. Finally, the communication specifications of OPC UA for the MES and production level are also available. The Companion specifications of OPC UA and AutomationML remain unaffected and can be used without restrictions [17].

VII. CONCLUSION

It was shown how the information models OPC UA and AutomationML can be integrated by means of the extension mechanisms of B2MML and how they can be used together as data formats in a service-oriented MOM implementation. The transaction mechanisms of IEC 62264 are used here. At the same time, the scope of information provided by OPC UA and AutomationML is available without restriction. A limitation in the application of the concept results from the fact that B2MML transactions only allow queries via IDs. For an application between companies or independent company structures, these would have to be extended by mechanisms, which access other parameters by semantic means, e.g., the description elements (Fig. 2) [8].

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