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Defining a Methodology to Design and Implement Business Process Models in BPMN according to the Standard ANSI/ISA-95 in a Manufacturing Enterprise

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Abstract

Nowadays, extended enterprise requires flexible and adaptable platforms which enable technology and internal integration between ERP and MES levels of manufacturing industry. Under the EAI perspective, it is proposed the use of ESB and BPMS technologies to improve integration between business and manufacturing layers. In order to enable this integration, it should be considered standard ANSI/ISA-95 Enterprise/Control System Integration due to it defines an effective model for business integration/manufacturing. In this paper, in order to develop applications that allow the orchestration of information exchanges between ERP/MES, a methodology is defined to design BPMN process models according to the standard ANSI/ISA-95 because it enables B2M integration projects development.

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Keywords: Enterprise Integration; B2M Integration; ANSI/ISA-95 Standard; Business process modeling; BPMN

1. Introduction

Manufacturing company's challenges are driven by increasing flexibility, agility, efficiency and quality of their processes. For this reason, EU-Commission (2004) recommends to enhance the integration of processes in highly

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automated environments. This integration is especially necessary in collaborative contexts such as extended enterprise, where multiple companies share resources and services, and it is required an integration solution that allow to manage such collaboration in an effective way.

From a technological point of view, solution to be adopted in distributed system integration scenario must allow fast reconfiguration, offering an agile response to changes in the objectives of collaborating companies. For this, in recent years, with the rise of Web technologies and widely usage of service-oriented architectures (SOA), enterprises are wrapping their applications with Web services layers. Standards such as SOAP (Simple Object Access Protocol) and REST (Representational State Transfer) are used to invoke services, WSDL (Web Services Description Language) to describe them, and UDDI (Universal Description, Discovery and Integration) to be registered. In addition, an Enterprise Service Bus (ESB) can be used as a communication facilitator among distributed systems to allow Enterprise Application Integration (EAI), as it is introduced by Manouvrier and Ménard (2010). Additionally, effective coordination and cooperation are needed in order to have a high level of integration. To achieve the goal of orchestrating tasks effectively, the potential of Business Process Management Systems (BPMS) to automate integration processes and invoke available web services should be considered.

Integration projects of Enterprise Resource Planning (ERP) systems and Manufacturing Execution Systems (MES) are complex. From an internal point of view and in order to facilitate understanding among all participants in the integration project, Camarinha-Matos and Afsarmanesh (2003) suggest the adoption and the use of reference models and the target system modeling (As-Is and To-Be). In recent years, to meet this need for modeling enterprise systems and their business processes, many methodologies and languages have been developed, which cover all perspectives required to model whole system (i.e. information, functional, behavior). But among all of them, Business Process Modeling Notation (BPMN) has drawn the attention of enterprise engineers, since it allows the definition of workflows in a simple and flexible way, and also facilitates processes automated execution using workflow engines embedded within BPMS.

Focusing on manufacturing domain, different works can be found in the literature about process modeling using BPMN. Zor et al. (2010, 2011) suggest several modeling patterns and propose a BPMN extension, but these patterns do not use reference models and an implementation guideline is not provided. In contrast, these aspects have been addressed by Ricken and Vogel-Heuser (2010), who propose functional modeling of a MES using BPMN and taking as a reference the ANSI/ISA-95 Enterprise - Control System Integration standard (2000, 2001, 2005) to define system requirements. This standard has also been used by He et al. (2012) as a basis for the development of a manufacturing data management tool, which adopts the Business to Manufacturing Mark-up Language (B2MML) (WBF, 2011) for exchange of information based on the ANSI/ISA-95 specification. All these contributions confirm the trend to consider the use of standard specifications, i.e. B2MML, as references in the implementation of Business to Manufacturing (B2M) integration solutions.

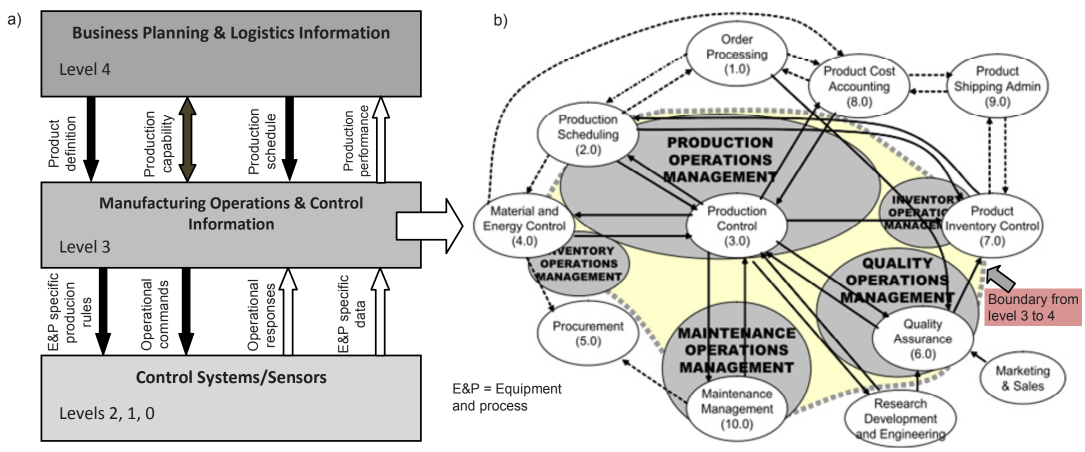

Fig. 1. (a) Functional model ANSI/ISA-95; (b) Manufacturing operations management model.

The ANSI/ISA-95 standard is one of the initiatives that have had wider acceptance in recent years, due to it specifies a complete functional model (Fig. 1b) to integrate the business and manufacturing layers, and defines the information to be exchanged between levels 3 and 4 of the proposed automation pyramid (Fig. 1a).

Taking into account previous considerations, in order to contribute to the integration of enterprise and manufacturing processes in a unified way, this paper proposes a methodology to design and implement BPMN process models according to the standard ANSI/ISA-95. The conceptual framework that suits our proposal and the adopted modeling languages and technologies is discussed in section 2. Proposed methodology is described in section 3. In section 4, a use case is shown to illustrate the application of the methodology. Finally, results and conclusions are presented.

2. Proposal conceptual framework

The methodology will be deployed in a distributed scenario adopting a technological solution like presented in Fig. 2a is implemented, in order to improve the internal integration and communication among different organizational member units of the extended enterprise.

The proposed technological solution follows SOA based architecture. The core component of this EAI solution is an ESB. All integrated sub-systems (ERP and MES) offer access to their specific functionality through web services layers, using widely accepted protocols such as REST, SOAP and WSDL (Fig. 2a). In order to facilitate communication among these heterogeneous systems, the ESB will perform the necessary transformations on exchanged information messages when services use different transport formats to send the same content type. In addition, the ESB acts as a single access point to all registered services, providing robustness against possible changes in network topology when services availability varies along the system run time.

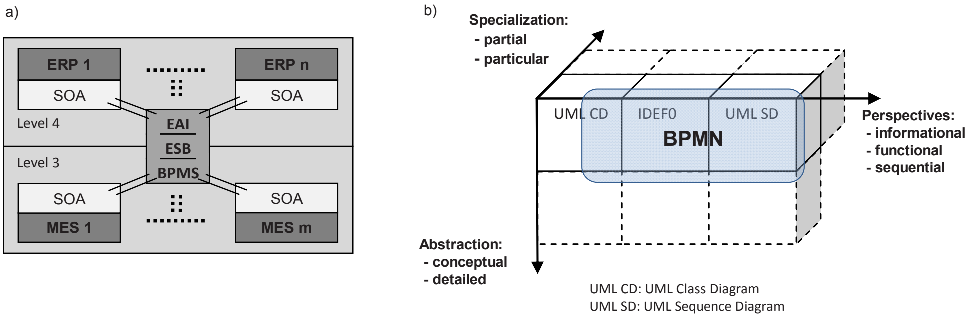

Fig. 2. (a) Technological integration model between ANSI/ISA-95 levels 3 and 4; (b) Methodology modeling perspectives and techniques related to BPMN.

To define workflows that coordinate services invocation, ESBs traditionally use the Business Process Execution Language (BPEL) which is based on XML standards and its execution can be automated using an embedded workflow engine. However, the use of XML based notation makes these workflows difficult to be modified directly. There is a need to count on the help of a graphical notation to facilitate this task. BPMN has a graphical notation that provides all the necessary expressiveness and BPMN modeled workflows can be translated to BPEL in order to be executed. In response to BPMN adoption and popularity, many BPMS have appeared supporting direct execution of BPMN models offering ESB capabilities to allow web services invocation following the SOA philosophy. Therefore, the adoption of this kind of solution allows us to isolate ourselves from the MES and ERP systems integration technological complexity, and to be focused on the logic that should be used to orchestrate services in distributed manufacturing contexts.

BPMN is a process modeling technique that covers many of the views that are required to obtain a fairly comprehensive model (informational, functional and behavioral). But, in the outline of an integration team it is proposed the use of other complementary modeling techniques, which will help integration team to have a complete overview of the system, obtaining better understanding and facilitating their work. Taking into account suggestions about modeling techniques selection done by Noran (2003) and Letsholo et al. (2012), whom locate modeling techniques in the Zachman framework, it is decided to complement BPMN with IDEF0 and UML sequence diagrams. As is shown in Fig. 2b, the appropriate adoption of these techniques facilitates the development of all project phases, from conceptual to detailed modeling.

Just like when any other enterprise modeling framework is applied, it is required a good management of the knowledge about the system to be integrated. Using recognized standards as reference, it is possible to define partials models which are suitable for an extended enterprise dedicated to discrete manufacturing of different product families. The use of these partial models facilitates to define particular models for a concrete integration scenario in a unified way.

The definition of partial functional and information models will be based on the ANSI/ISA-95 specification, which is widely accepted in industrial and academic fields, and it standardizes the manufacturing operations found on MES and the information exchange established with ERP system.

3. Description of the methodology to design and implement BPMN models based on ANSI/ISA-95

The proposed methodology allows the definition of manufacturing specific BPMN models which can be executed in the technological environment defined in the previous section. The starting point is the definition of *partial* models inspired in ANSI/ISA-95 specification, which are later adapted to the scenario under study. The methodology concludes using learned lessons to improve these adapted *partial* models (Fig. 3).

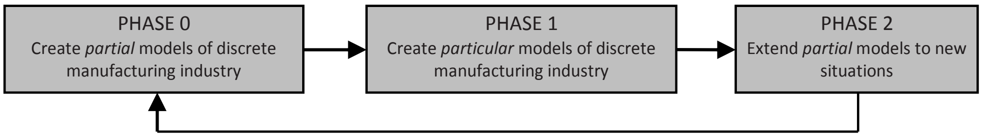

Fig. 3. Proposed methodology phases.

Following the three phases of the proposed methodology are introduced.

3.1. PHASE 0: Partial modeling

In order to facilitate understanding of the whole process, it is suggested to define some preliminary models as a previous step to elaborate *partial* BPMN models according to ANSI/ISA-95 specifications. Following, the required steps to define these preliminary models at different levels are explained.

Functional modeling of ANSI/ISA-95.

It is important to have a conceptual reference model to help to the implementation team to identify the activities and information which are essential in each project scope. To do this, a *partial* functional model is defined, which describes the activities and information flows specified by ANSI/ISA-95 standard. After analyzing different modeling methodologies and languages, IDEF0 is chosen to model a first approximation of the functional requirements of the system, according to the detailed level required by the integration team.

A joint read of ANSI/ISA-95 part 1 (Models and terminology, 2000) and part 3 (Activity models of manufacturing operations management, 2005) is done focused on discover relationships between information models provided in part 1 and activity models described in part 3. This way, all the information flowing through the activities of the company is identified. ANSI/ISA-95 standard identifies the main manufacturing operations management related activities as shown in Fig. 1b. A boundary is represented to differentiate between activities at level 3 and activities at level 4. Only a few activities are carried out at both levels. A preliminary IDEF0 functional model is defined, covering all level 3 activities and their communications with some of the level 4 activities.

Sequence modeling of ANSI/ISA-95

Information about the order in which different activities are carried out in manufacturing process provides a temporal behavior perspective about their execution. UML sequence diagrams are proposed for this purpose. These diagrams show which message transfers take place and how communication evolves among the different actors involved to carry out each activity. The *partial* UML diagrams defined in this step detail all information exchange between level 3 and 4 of the company, taking into account the activities and objects previously identified in *partial* IDEF0 diagrams.

BPMN based process modeling of ANSI/ISA-95

Finally, activities, objects and message exchange sequences identified on previous models are incorporated to *partial* process modeled using BPMN notation. It is possible to count on the help of *partial* BPMN models as templates to be applied on each type of company where the integration project is carried out. This fact greatly facilitates to obtain *particular* BPMN models customizing the most adequate *partial* template.

Taking into consideration ANSI/ISA-95 levels, BPMN models are developed using a top-down modeling approach representing main identified activities (IDEF0 functional diagrams), and how related task execution is coordinated according to the identified information exchange sequences (UML sequence diagrams). Information exchanged within these *partial* BPMN models refers to data models specified in B2MML, also based on the standard.

In order to improve reusability, BPMN models are modeled using a componentization strategy dividing the complete model in different sub-processes focused on separate ANSI/ISA-95 management operations or complex activities. These sub-processes form a set of modeling blocks that can be reused to define *partial* and *particular* BPMN models more easily. This way, all models share the same standard based terminology and modular decomposition.

3.2. PHASE 1: Particular modeling

The next step of the methodology is to create *particular* models from the *partial* ones. Existing *partial* models should be taken as a reference to particularize them in the context of each use case. This particularization can be achieved by the following steps.

Company analysis and adaptation of IDEF0 models

The first step is to define the *particular* IDEF0 model of the company under study, taking into consideration the *partial* IDEF0 model of the ANSI/ISA-95 developed in Phase 0. To make this adaptation is necessary to establish the project scope (involved company areas and functions). Once the key activities that should be included in the study are determined, their current situation is analyzed. To carry out this analysis, it is proposed to form a multidisciplinary and inter-company team who develop a current (As-Is) functional model (IDEF0) of the company. Finally, using this model and taking into account the desired final state that is expect to reach with this integration project, the *particular* IDEF0 model (To-Be) is defined.

Analysis of transactions and adaptation of sequence diagrams

The second step is to adapt the *partial* UML sequence diagrams to the analyzed case. The integration team define the current sequence model (As-Is) taking into consideration the *particular* IDEF0 (As-Is) model and the collected information about the flow of current information exchange. Using these sequence diagrams and taking into consideration the *particular* IDEF0 (To-Be) model as a reference, *particular* UML sequence diagrams (To-Be) are modeled in order to define clearly the information exchanges that is desired to occur within the extended enterprise.

Adaptation of BPMN models

Taking into account the overview provided by *particular* IDEF0 models and *particular* sequence models (As-Is and To-Be), obtained in the previous steps, and the *partial* BPMN model of the ANSI/ISA-95 (To-Be) as a template, *a particular* BPMN model (To-Be) is defined. These *particular* BPMN models are more easily modeled reusing all the *partial* sub-processes already modeled requiring to customize only *particular* behavior.

3.3. PHASE 2: Extension and/or adaptation of partial models

In this last phase of the methodology, improvement and/or extension of *partial* models is done to take advantage of learned lessons on each use case. If some new aspects are identified, which are not covered by the initial *partial* models used as references, these models are modified in order to be improved. This way, knowledge base used in Phase 1 is expanded to be applied in future implementations.

4. Use case

In order to test the presented methodology, it is carried out a pilot experience of a B2M distributed integration on a hypothetical extended enterprise that belongs to the ceramic cluster of Castellón. This enterprise is made up by a production company of ceramic tiles (company A) which has its own production plant and sells some products that requires some grinding operations, which are performed by another grinding specialized company (company B). The scope of the integration project covers the management of production operations, maintenance operations and inventory operations located at the MES level in company B and their integration with the ERP of company A. On this paper, it is shown the work carried out by the integration team in the development of Phase 1 of the methodology focused on Production Operations Management.

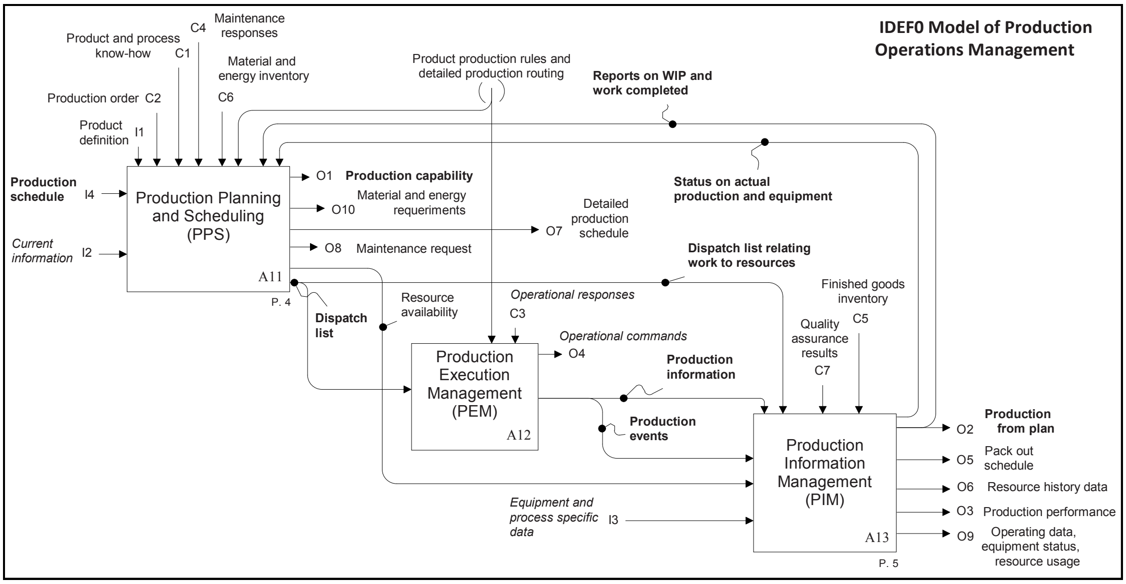

Fig. 4. Particular IDEF0 model (To-Be).

To develop *particular* BPMN models, the integration team counts on the help of three *partial* diagrams developed according to the ANSI/ISA-95 standard (functional, sequential and process diagrams), obtained as a result of Phase 0 of the methodology. Taking these as reference, the integration team have several meetings with the technical staff of the involved companies to model IDEF0 diagrams (As-Is), which show production activities and the flow of information required to be exchanged between the companies. Afterwards, *particular* IDEF0 model (To-Be) is determined, as is shown in Fig. 4.

To show the sequence of activities execution that have been identified in the IDEF0 model (Programming Planning and Scheduling - PPS, Production Execution Management - PEM, Production Information Management - PIM) of the level 3 of company B and with the level 4 (ERP) of company A, *partial* UML sequence diagrams is defined (Fig. 5).

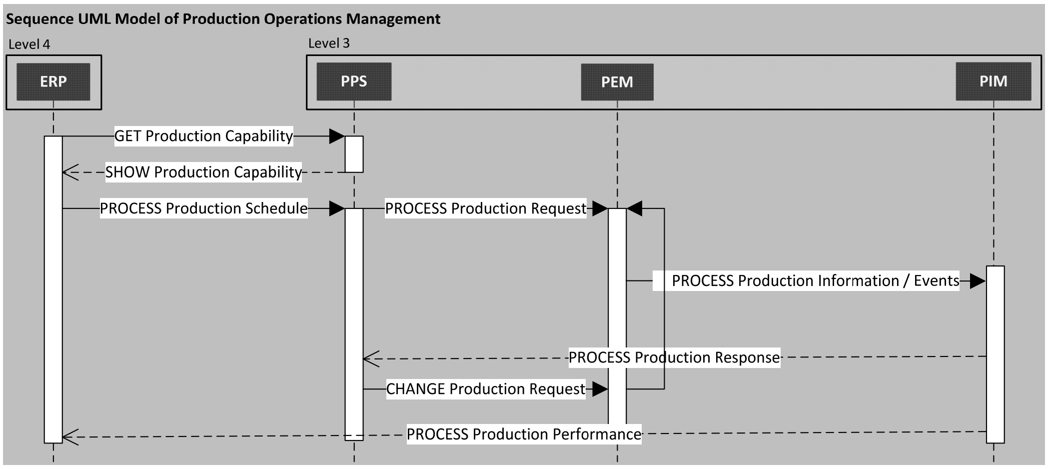

Fig. 5. Particular UML sequence diagram (To-Be).

As a last step, the *partial* BPMN model is adapted to *particular* one (To-Be) taking into account the activities and the sequences described in the previous models. The execution of this *particular* model could be automated by the supporting technological system to enable the required integration between the companies of the extended enterprise (Fig. 6).

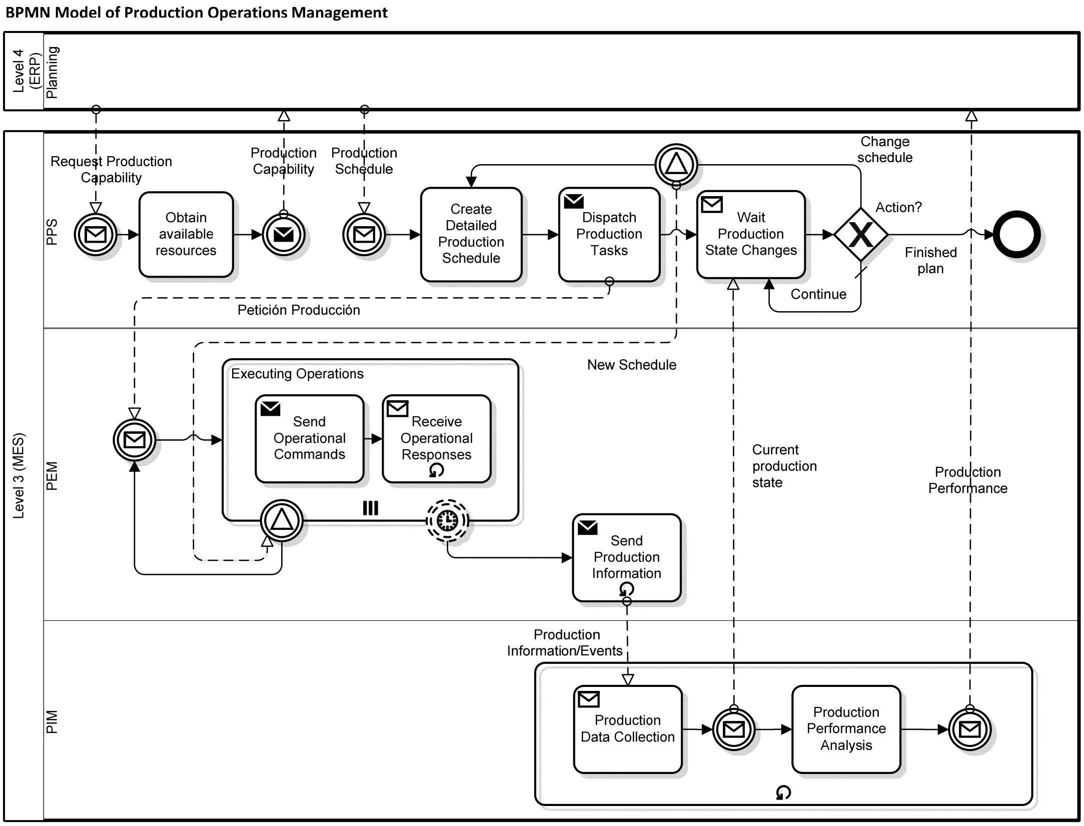

Fig. 6. Particular BPMN model (To-Be).

5. Results and conclusions

The proposed methodology has proven its adequacy to define coordination and cooperation *partial* and *particular* models to be applied to facilitate integration in typical distributed scenarios of extended manufacturing enterprise. The use of ANSI/ISA-95 standard also facilitates the development of this kind of integration projects, due to it provides a unified reference framework, which is used to define the models of the B2M operations addressed by the proposed methodology. To obtain these models, the use of BPMN notation is proposed in combination with other complementary modeling techniques such as IDEF0 activity diagrams and UML sequence diagrams. Thereby, the work of the integration team is facilitated, improving understanding of the current system (As-Is) and allowing to define the desired system (To-Be). This fact was corroborated during the development of presented pilot experience.

After facilitating the information management, coordination and cooperation required by the integration between levels 3 and 4 of the ANSI/ISA-95 standard, in future works, more attention will be given to the integration between levels 3 and 2. The consideration of including other standards such as OPC Unified Architecture (OPC UA) will be evaluated for the exchange of information in these levels, and the possibility of extending its application to all levels of the ANSI/ISA-95 standard.

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