A Standards Framework for Value Networks in the Context of Industry 4.0

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***Abstract*—The German initiative Industry 4.0 will involve amongst other issues networking and integration of several different parties (e.g., manufacturing companies, suppliers, customers, sub-contractors) through value networks. This initiative underpins that this collaborative partnership will only be feasible if standardization and open standards are available. For this purpose a reference architecture is needed to provide a technical description of these standards. In this context interoperability plays a major role for the seamless exchange of data and information among partners in these value networks. Interoperability involves the interaction of different systems and their users. Information modeling is a key concept for providing interoperability. In this paper, we present a standards framework that highlights how existing standards intertwine to establish value networks in an Industry 4.0 context.**

Keywords*—*electronic data interchange, system integration, value networks

I. Introduction

Horizontal integration through value networks and its vertical integration in networked manufacturing systems are key issues for the implementation of an end-to-end engineering across the entire value chain [1]. For realizing a *horizontal integration through value networks*—we need appropriate language constructs to describe business relationships between companies taking their different business views into account. At the same time, we need a fundamental understanding of activities and information flows within manufacturing companies to enable a seamless *vertical integration of networked manufacturing systems*. However, seamless information flows between the horizontal layer (business partner networks) and the vertical layer (from an ERP system to a Manufacturing Execution System and deeper) are very limited [1]. Furthermore, IT systems still tend not to cross company or factory boundaries.

From a technical as well as an economic perspective an *end-to-end digital integration* is a key issue to realize smart factories. This integration will enable all levels of a manufacturing company (enterprise level, shop floor control level, and shop floor level) to be connected to each other through a global information system with customers, suppliers, and other external participating parties. The potential of a flexible end-to-end integration is huge. In contrary to existing interorganizational systems, it has to accommodate individual, customer-specific criteria in the design, configuration, ordering, planning, manufacture and operation phase. This will enable last-minute changes to be incorporated as well as very low production volumes (single-piece workflow). The realization of this ambitious goal requires appropriate interfaces for integrating the individual subsystems. However, it is still common practice that IT systems exchange information through extensive interfaces, but can only utilize specific pieces of that information. The situation is further worsened by the problem that many different interfaces introduce dependencies whose management can become complex and hard to achieve. Thus, the system complexity will rise drastically.

Even though the industry starts years ago with the vertical integration and networked manufacturing systems, there is still a fundamental need for further research. In the course of an academic lecture at TU Vienna, the CEO of Infineon Technologies Austria AG—the Austrian subsidiary of a Top 20 semi-conductor company—points to the fact that vertical integration is already successfully implemented. However, the dynamic integration of business partners (e.g., sub-contractors, suppliers, customers) to form a value network on the fly is still a very challenging open issue in their research agenda. Modeling can act as an enabler for managing this integration. Models are representations of real and hypothetical scenarios that only include those aspects that are relevant to the issue under consideration. The working group of the German initiative states that *"the use of models constitutes an important strategy in the digital world and is of central importance in the context of Industry 4.0"* [1]. For this purpose appropriate language constructs are required to formally describe the increasing functionality, increasing product customization, dynamic delivery requirements, and the rapidly changing forms of cooperation between different companies in order to provide end-to-end transparency.

In this paper, we focus on the *horizontal integration* of different partners building a value network. Thereby, we also consider the integration of the value network into a company of the network. We intend to deliver a standards framework for this purpose. This framework considers already existing standards that provide data models and information flow models for various aspects of system integration to form a network of businesses. Our proposed standards framework presented in this paper is the backbone for the research project *InteGra 4.0* funded by the Austrian Research Promotion Agency (FFG) under the project ID 849944.

II. Open-edi

Exchanging business data between ERP systems by electronic means has been realized in industry for some decades. It is based on the concepts known as *electronic data interchange (EDI)*. Although the economic advantages of EDI are well understood and, in particular, large corporations are able to realize substantial benefits, we still see some limitations with respect to the vision of Industry 4.0. Traditional EDI is only efficiently used in long term business partnerships and usually only between a limited number of partners—leading to an extranet of dedicated business partners. This is mainly due to the fact that the cost of establishing an EDI partnership is tremendous. It requires first a detailed bilateral business agreement which is followed by a technical agreement to implement it. Despite the existence of EDI standards (see also subsection IV-D), these implementations are by no means standardized and are characterized by bilateral interpretations of the standards and additional agreements on business semantics, transport protocols, security mechanisms, etc. However, for successful Industry 4.0 implementations we need a high flexibility with respect to (i) building company networks on the fly, also allowing partners dynamically joining in and leaving the network and (ii) allowing for ad-hoc communications within the network.

Open-edi [2] is an ISO standard that intends to break up rigid structures and to lower the barriers to interorganizational systems by minimizing the need for private interchange agreements and maximizing interoperability. Open-edi provides a so-called reference framework identifying different classes of necessary standards for interorganizational systems. The reference model is independent of any information technology implementations, any business content, any business activities, and any participating parties. It rather provides a framework for the identification, development, and coordination of existing and emerging standards.

A key concept of the Open-edi reference framework is the differentiation of standards for the *business operational view (BOV)* and the *functional service view (FSV)* as presented in Figure 1. The BOV is a perspective on interorganizational business transactions focusing on aspects regarding the making of business decisions and commitments among parties. Accordingly, BOV addresses the semantics of business data in business transactions and their data exchanges as well as rules—operational conventions, agreements, and mutual obligations—for business transactions. BOV-related standards have to provide tools and rules by which business experts who understand the operating aspects of a business domain may create interorganizational business scenarios.

The FSV is a perspective on interorganizational business transactions focusing on the IT aspects ensuring the interoperability of IT systems. Accordingly, the FSV addresses the mechanistic needs of Open-edi, such as functional capabilities, service interfaces and protocols. The FSV delivers technology to design and build IT systems supporting the business needs (of the BOV) that potentially support the execution of interorganizational business transactions.

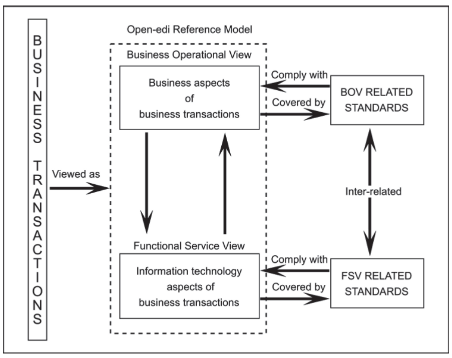

Fig. 1. Open-edi Reference Model [2]

It follows that Open-edi envisions the cooperation of different experts, e.g., business domain experts supported by information analysts as well as IT specialists and telecommunication experts. The communication between these types of experts has to be supported by models. Models are considered as essential means to reach an agreement on the business semantics before agreeing on specific data structures, data representations, and protocols. Models also serve as a tool to reconcile and coordinate different representations used in different industry branches. Accordingly, models describing the roles, the business scenarios, and the semantics of information bundles represent the cornerstones of the Open-edi idea. Open-edi models must consider both the external and the internal behavior of networking parties. Those models must consider all aspects that are critical to ensure interoperability. In other words, the models must deal with the interoperability issues of internal systems as well as those with external partners.

III. A Standards Framework for Industry 4.0

In our approach, we built up on the ideas of Open-edi as described in the previous section. Open-edi does not specify any particular standards, but it provides guidelines for the identification, development, and coordination of existing and emerging standards. Accordingly, we use these guidelines for identifying appropriate standards, as presented in Figure 2, for the horizontal integration in the dedicated context of Industry 4.0. In particular, we see three different dimensions in the identification of appropriate standards. The first dimension is the differentiation between the strategic/tactical and the operational layer. The second dimension distinguishes between the internal and the external aspects of the horizontal integration. The internal aspects describe the integration of a partner's local systems, whereas the external aspects describe its interaction with partners in the value network. The third dimension separates between the business operational view (BOV) and the functional service view (FSV) as described in Open-edi.

In the dedicated context of horizontal integration in interorganizational systems, we do not need to go into all the details of the strategic layer and the tactical layer. However, it is essential to understand the main business function by which an enterprise creates value. Any of these business functions is either realized by value exchanges with partners in a value network or by a value creation within the company. Thus, we require a language for the identification of these types of business functions on the strategic/tactical layer.

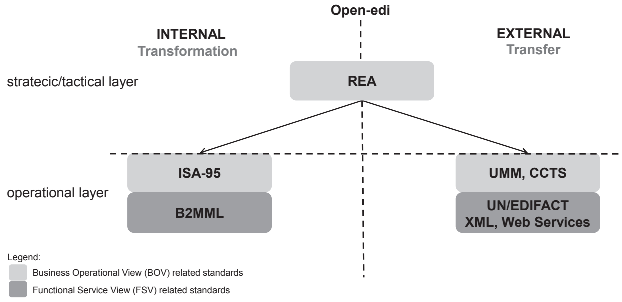

Fig. 2. Standards Framework 4.0

This requirement is exactly met by the Resource-Event-Agent (REA) ontology which is an international standard ISO 15944-4 for a business ontology. It is certainly a BOV standard that covers (on purpose) both the internal and the external aspects. Without going into the operational aspects there is no need for a corresponding FSV standard on the strategic/tactical layer.

On the operational layer, we have to take a different modeling approach for the external and the internal business functions (as identified by REA). For the external business functions, we have to describe the business scenarios between the participating parties. These scenarios cover both the flow of interactions between the parties and the information bundles exchange between them in any of these interactions. An international standard for describing the flow of interactions amongst business partners is UN/CEFACT's modeling methodology (UMM) [3]. The candidate language for describing the information bundles and customizing them to the dedicated needs of a particular value network is the Core Component's Technical Specification (CCTS) [4] that started off during ebXML and is now maintained by UN/CEFACT. Both, UMM and CCTS are independent of the type of communication used and, thus, are considered as BOV standards. Evidently, the models specified by means of UMM and CCTS have to be translated into a IT solution, be it a traditional EDI standard like UN/EDIFACT or an XML-based document format. The communication may be based on Web Services, AS2 or other protocols.

When aiming for a horizontal integration, the internal business functions are of secondary interest. Nevertheless, we need to understand the internal behavior to a certain extent for a purposeful definition and exposition of the interoperability aspects. For example, if an internal business function (e.g. product assembly) requires a material (e.g. tire) that is acquired by an external business function (e.g. tire procurement), it is the internal business function's requirements that usually drive the external business function. In the context of Industry 4.0, we see the various models of ISA-95 as appropriate to describe the internal business functions. ISA-95 is certainly a BOV standard, and its XML serialization called B2MML may be used on the FSV layer.

IV. Standards within the Framework

A. *Resource - Event - Agent Business Ontology*

Analyzing economic phenomena on which companies base their business lead to business models, which are defined by Timmers [5] as *"an architecture for the product, services and information flows, including a description of various business actors and their roles"*. A business model defines "how" a company creates value. Porter [6] specifies this competitive strategy by introducing the concept of a *value chain*. A value chain examines all of a company's business functions, and defines how they are connected.

The *Resource Event Agent business ontology (REA)* is a domain ontology to conceptualize any kind of business model. REA was developed by William McCarthy [7] [8] for the conceptualization of business functions which are in REA *transfers* (value exchange) and *transformations* (value creation) of the present, the past, and the future. *Resources* are transferred or transformed by business functions. Resources can be goods, semi-finished products, material, rights, labor, physical assets or services which agents have control of and which should be monitored or controlled in a business environment. An *event* is considered as a class of phenomena reflecting transfers or transformations of resources by participating agents. *Agents* are persons, companies, or organizational units capable of having control over resources, who/which participate in transfers and transformations.

The *REA value chain* is based on Porter's definition [6]. It is built by a number of value activities which correspond to the main business functions. A *value activity* takes some resources as input and creates some resources as output. From an economic perspective it is important that the output is considered to be of higher value than the input. On a high level of abstraction there are two ways to create additional value by an activity. Firstly, one may use and/or consume some input resources in order to produce some output (e.g., a finished good),—this is called *transformation*. Secondly, in a trading relationship with external business partners one may receive resources (e.g., material, equipment, transport service, rights, labor, etc.) and give resources (e.g. cash) in return,—this is called *transfer*. *Resource flows* tie the value activities together. The *duality* concept presents the core economic principal of REA. A duality constitutes that it is impossible to get something for nothing that is to say "there is no free lunch". The duality concept applies to transfers and transformations and consists of two parts: the *decrement entity set* covers events executed some agents leading to a decrease of some resources. It is compensated by the *increment entity set* that covers events executed by some agents leading to an increment of some (other) resources.

Initially, REA has its roots in the accounting discipline and is based on strong concepts of the literature economic theory [9]. Its declarative semantics is used to describe concepts and relationships involved in business transactions and scenarios. In previous work [10], we developed a domain specific language (DSL) for the REA business ontology, which we named REA-DSL. This language provides a formal definition of REA concepts by means of the Object Management Group's (OMG) meta-modeling architecture called Meta Object Facility (MOF). In present work [11] [12], we have continued our work by extending the REA-meta model to link the value activities of a manufacturing company with appropriate services and products provided by other companies.

B. *ISA-95*

The *International Society of Information* (ISA) released a multi-part international standard—ISA-95 [13]—for global manufacturers (i.e., a manufacturing company with decentralized, networked production plants) for specifically developing automated interface between enterprise systems (ERP layer) and control systems (MES layer). Based upon this standard the norm ISO/IEC 62264 was established. ISA-95 can be applied in all industries, and in all sorts of production processes like batch processes, continuous processes, and repetitive processes.

ISA-95 is built on top of UML and comprises five parts, each of which concentrates on specific aspects of the integration issue. Part 1 consists of standard terminology and object models, which can be used to decide which information should be exchanged. The basic data to be exchanged are information flows for the sectors personnel, material, equipment/physical asset, and process segment. These sectors are defined as *object models*. They constitute basic building blocks by which information flows are constructed. The *process segment* is a logical group of equipment/physical asset, personnel, material required to carry out a specific function in a production process (e.g, mixing, sawing, etc.). Part 2 consists of the attributes of every object that is defined in Part 1. The objects and attributes of Part 2 can be used for exchanging information between different systems (e.g., ERP, MES). Part 3 defines production activities and information flows at the shop floor control level. It offers a guideline for describing and comparing the production levels of different sites in a standardized way. Part 4, which is entitled *"Object Models and Attributes of Manufacturing Operations Management"* forms the basis for the design and the implementation of interface standards and make sure of a flexible lapse of the cooperation and information exchange between the different MES activities. Part 5 defines business-to-manufacturing transactions and manufacturing-to-business transactions that may be used in relation to the objects that are exchanged between the enterprise level and the shop floor control level, as defined in the models of Part 1 and Part 2. Part 5 introduces models that provide descriptions of the transactions and explanations of the required transaction processing behavior. This part has the intent of providing insight into the level of work required to construct information messages in business-to-manufacturing transactions. There exists an XML serialization of ISA-95,—the *Business To Manufacturing Markup Language (B2MML)*. In other words, B2MML defines XML schemas that are exact equivalents of the ISA-95 meta model.

Figure 3 presents the 31 important information ows for manufacturing control as described in the *functional enterprise control model* presented in Part 1. This model contains 12 functions. ISA-95 describes step by step the tasks of each of these functions. The functions shown in rectangles (e.g., research, development and engineering, marketing, sales) are external entities and as such they are not described in the

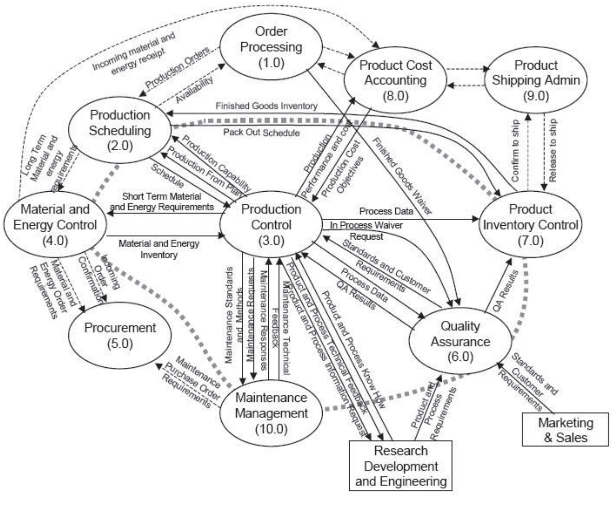

Fig. 3. ISA-95: Functional Enterprise-control model [IEC 62264-1]

functional enterprise control model. These entities are components outside the boundaries of this model that send data and receive data from the functions. The basic data to be exchanged are information flows which are defined for the object models presented in Part 2. ISA-95 groups the 31 information flows between ERP and MES into four categories: (i) production capability information, (ii) production definition information, (iii) production schedule information, and (iv) production performance information.

C. UN/CEFACT'S UMM and Core Components

When enterprises exchange goods and services in a value network their collaboration is based on the exchange on business documents. Conceptual models describing these business collaborations do not only describe the static structure of the business document types, but also capture the flow of business document exchanges between business partners. The United Nation's Centre for Trade Facilitation and Electronic Business (UN/CEFACT) took up the endeavor to develop such business collaboration models. This work resulted in UN/CEFACT's *Modeling Methodology (UMM)* [3]—a choreography language describing the interactions in a peer-to-peer manner—and the *Core Components Technical Specification (CCTS)* [4] for modeling the business documents.

UMM is a UML profile for designing business interfaces and their behavior that each partner must provide in order to collaborate. It provides the business justification for the interfaces in a collaborative environment. Thus, a primary vision of UMM is to capture the business knowledge that enables the development of low cost software supporting companies of any size to engage in interorganizational collaboration. UMM focuses on developing a global choreography of interorganizational business processes and their information exchanges.

UMM consists of three main views: Firstly, the *business requirements view* provides a framework for elaborating on the business processes and main actors in a certain business domain. Secondly, the *business choreography view* identifies and describes a flow of business document exchanges. This choreography is built by a composition of a number of business transactions each representing a single business documents exchange with an optional response. Thirdly, the *business information view* describes the static structure of the business documents. UMM does not mandate a specific approach to model the business documents. Nevertheless it recommends UN/CEFACT core components to be used in the business information view.

Core components are reusable building blocks for assembling business documents. The *Core Components Technical Specification (CCTS)* defines the meta-model of the core component approach. Thereby, CCTS distinguishes between core components, which are context independent, and business information entities, which are context-specific. The idea is to define the basic building blocks of business documents first on a context independent level.

If a certain industry wants to use a core component in order to assemble a business document with it, the core component is taken and tailored to the context-specific needs of the industry. In terms of CCTS, a core component thereby becomes a business information entity. Note that a business information entity may only be derived from a core component by restriction. Therefore, a business information entity only contains elements, which have previously been defined in the underlying core component. Since all business information entities are derived from the same core components, a common semantic basis between all business information entities is given at any time. The core components, which form the basis for business information entities are standardized by UN/CEFACT as well. In the *Core Components Library (CCL)* the reusable building blocks (core components) are defined in an unambiguous manner. A common semantic data model that is independent of any particular syntax solution is a promising option to provide a bridge between different EDI standards. Furthermore, we argue for a balanced approach that delivers (i) all-encompassing core components providing semantic alignment between different messages and at the same time (ii) business information entities limiting the components to the specific needs of the business context of the message. Accordingly, we consider UN/CEFACTs Core Components to be the most advanced approach towards an implementation neutral BOV standard for business documents.

D. Business Document Standards

A conceptual business document modeling approach as described in the previous subsection allows the specification of business documents independent from any particular transfer syntax. Consequently, these business documents serve as a basis for generating transfer syntax artifacts. For this purpose, UN/CEFACT provides the *XML Naming and Design Rules (NDR)* specifying rules and guidelines for generating XML schemas based on conceptual business document models. However, UN/CEFACT XML schemas are certainly not the only option to be used on the FSV. One may consider other popular XML schemas for business document standards such as the Universal Business Language (UBL) or an industry specific standard such as PapiNet in the paper industry. Despite of the growing importance of XML, most document exchanges in industry are still based on UN/EDIFACT and X12. Therefore, a transformation to these traditional EDI standards is still required to comply with legacy systems. An overview of the state-of-the-art in business document standards covering a number of potential languages on the FSV is provided in [14].

V. Conclusion and Future Work

In this paper, we have introduced a standards framework for the purpose of horizontal integration in the context of Industry 4.0. We base our work on Open-edi as reference framework to identify and integrate existing standards. We use REA on the strategic/tactical level to identify the main business functions and classify them into external (transfer) and internal (transformation) functions. On the operational layer, the internal business functions are further detailed by ISA-95 specifying internal models for value creation inside the company. B2MML is the candidate language to express ISA-95 on this implementation layer. In addition, we use UMM to further elaborate the external business functions on the operational layer. UMM is used for designing business interfaces and their behavior that each partner has to provide for collaboration. The documents exchanged between these interfaces are modeled by means of CCTS and have to be expressed in an XML-based business document standard or a traditional EDI standard.

The presented standards framework builds the groundwork for our research project *InteGra 4.0* funded by the Austrian Research Promotion Agency which aims for a universal model-driven industrial engineering framework spanning over production chains and value networks. In this project, we will realize seamless information flows by an alignment of the mentioned standards. For this purpose we will provide transformation rules between the standards based on their semantic overlaps.

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