A Comparison of XML Interchange Formats for Business Process Modelling

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Abstract: This paper addresses heterogeneity of business process metamodels and related interchange formats. The different approaches towards interchange format design and effects of interchange format specification are presented first. In particular *completeness* is identified as an important design criterion for interchange formats. Afterwards the superset of metamodel concepts is extracted from 15 currently available XML-based specifications for business process modelling. Furthermore, these concepts are used as a framework for comparing the completeness of 15 specifications.

1 Introduction

Heterogeneity of Business Process Modelling (BPM) techniques is a notorious problem for business process management. Although standardization has been discussed for more than ten years (cf. e.g. [Ho94]), the lack of a commonly accepted interchange format is still the main encumbrance to business process management (see e.g. [De03]). Such a commonly accepted interchange format is needed to move business process models between tools of different vendors. Beyond that, the reason why interchange is still a problem can be attributed to the different perspective of business analysts and system engineers [zMR04].

Recently, various new specifications for Web Service based Business Process Modelling and Web Service composition have been proposed. At least in the short run, they contribute to a further increase of heterogeneity of XML interchange formats for business process modelling. Yet, the interrelation of these formats is too little understood. This paper tries to identify the superset of high-level concepts covered in metamodels of the various proposals. We propose to use this classification as a framework for comparing the *completeness* of BPM interchange formats. It might serve as a first step towards a reference model for BPM that unifies the different perspectives on BPM.

The rest of the paper is structured as follows. Section 2 gives an overview of interchange formats, their rationale, and general design criteria. Completeness is identified as an important criterion for interchange format design. Section 3 introduces a framework for comparison of different XML interchange formats for BPM based on concepts extracted from the metamodels of 15 BPM specifications. In Section 4 these specifications are compared to the framework in order to assess their completeness. In Section 5 related work is discussed before Section 6 concludes the paper with an outlook on future research.

2 Interchange Format Specification

The specification and standardization of interchange formats is a wide-spread strategy in order to achieve inter-operability of applications (see e.g. [Ko92]). In essence, an interchange format defines the structure of a file via a grammar or a schema that represents data relevant for a certain application domain. Independent software components can then consume data files that other applications produce. As a consequence, a standardized interchange format provides for a simple integration of applications (see e.g. [HW04]).

According to a survey on experience reports of interchange format design projects, three general effects of interchange format standardization can be distinguished: a pragmatic effect, an economic effect, and an effect of conceptual consolidation [Me04].

- The *pragmatic effect* established inter-operability between heterogeneous applications of the same or related domains. This simplifies collaboration between people that work with different applications. A common interchange format avoids discontinuity of media and re-entering of data. Furthermore, the interchange format can be used as an intermediary format for translations between multiple applications reducing the number of translation programs from $O(n^2)$ to $O(n)$ (see e.g. [WHB02]).
- The *economic effect* refers to positive network effects in competition between software vendors. Positive network effects caused by the standardization of an interchange format might leverage competition, because interchangeability of application data reduces vendor lock-in. It becomes cheaper to change the vendor or to buy complementary software that uses the same interchange format [Cr84]. This might motivate the development of new tools. Moreover, the specification of an interchange format might even create a market: multimedia applications are a good example for this case (cf. e.g. [Ko92]).
- The *effect of conceptual consolidation* is triggered by the standardization process of an interchange format. In order to be successful the interchange format has to reflect at least the commonly used concepts of a certain domain. Accordingly, the specification of an interchange format may be regarded as a special kind of reference modelling that leverages the explication of concepts and consolidation of terminology of a given domain [OMGM+98].

The specification of interchange formats involves three interrelated aspects: metamodel, serial representation, and mappings between both (see Figure 1, grey area).

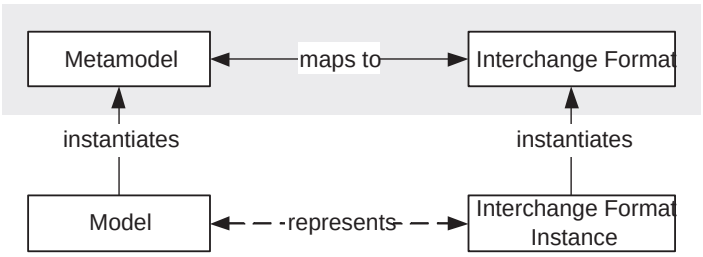

Figure 1: Metamodel, Mappings, and Interchange Format.

The *metamodel* is used to define the modelling language for a certain domain [KK02]. Various techniques are available for the definition of metamodels including e.g. entity-relationship-diagrams [Ch76], UML class diagrams [OM04], graphs (cf. [Wi02]), or XML Schema [BLM+01, BM01]. In order to build the foundation of an interchange format a respective metamodel should meet the design criteria simplicity, completeness, generality, unambiguity, and extensibility.

- *Simplicity* refers to freedom of complexity [SDSK00] in order to provide a compact metamodel that is easy to understand for domain experts.
- On the other hand, *completeness* demands that a sufficient set of concepts is included in order to provide the expressive power that is needed for representing all relevant aspects of the domain (cf. e.g. [Cr84]).
- *Generality* has to be offered by the interchange format to be applicable in all scenarios that are relevant to the domain (cf. e.g. [Cr84]). Especially those concepts should be taken into account that are included in existing tools (see e.g. [Eu86]).
- Moreover, the interchange format has to offer an *unambiguous* view on the domain. Precise terms need to be chosen and related semantics have to be defined formally. By this means an interchange format might prove valuable for the consolidation of terminology in the respective domain (see e.g. [OMGM+98]).
- *Extensibility* belongs to the most prominent criteria (see e.g. [Cr84, Ko92, SDSK00]). It provides for the inclusion of additional information in a predefined way. This is especially desirable, because future developments, new requirements, and changing technology might motivate unanticipated revisions of the format in a priori unknown directions. Extensibility grants a smooth integration of such new aspects.

Models complying to the metamodel of an interchange format need to be expressed in a *serial representation*. Such a serial representation may follow a byte encoding, a plain text encoding, or XML [BPSMM00]. The structure of the serial representation is defined via a schema. Furthermore, XML-based techniques like RDF [Be04], or GXL [Wi02] can be customized for business process modelling as well. A serial representation of an interchange format should meet the design criteria of readability, ease of implementation, platform independence, efficiency, free availability, and support of standards (cf. [Me04]).

The identity of metamodel and serial representation is important in order to avoid loss of information [SDSK00]. Formally, this implies that isomorphic *mappings* between them must be available. Different approaches are used to specify metamodel, interchange format, and respective mappings.

- *Interchange Format Only:* Some interchange formats like BPEL4WS [ACD+03] provide only an XML Schema. This schema can be regarded as a metamodel. Thus, no mappings need to be defined between metamodel and interchange format.
- *Mappings Only:* Another approach is taken by XMI [OM03]. In order to offer an interchange format for UML models, the XMI specification defines production rules (mappings) from the Meta-Object Facility (MOF) [OM02] meta^{2}model of UML to XML and XML Schema representation. Actually, XMI does not define the interchange format for UML models, but the production rules to derive an interchangeable representation of those models. As a consequence, XMI defines a set of interchange formats that correspond to a set of UML (meta)models.
- *Joint Specification:* Frequently, the joint specification of a metamodel and a respective interchange format is given. For example, the Petri Net Markup Language (PNML) [BCvH+03] defines a metamodel via a UML class diagram and an XML interchange format via a schema. The Graph eXchange Language (GXL) [Wi02] provides for the definition of both the metamodel and the interchange format using only one technology.

Although the interchange format should be isomorphic to the metamodel, actual software applications and tools most frequently use a proprietary internal model which is similar, but not identical to the standardized metamodel. Accordingly, the import and export of interchange format compliant files would be a homomorphic mapping to and from the proprietary model. Therefore, it is important for a metamodel to meet the design criteria of completeness. An interchange format is more likely to gain acceptance when a complete set of modelling concepts is supported. The following section aims to identify the superset of concepts used in various metamodels of BPM interchange formats which is then used as a framework for comparing the different approaches.

3 Metamodel Concepts of Business Process Modelling Proposals

Recently, Business Process Modelling has become subject of various specification and standardization efforts. Different consortia including Object Management Group (OMG), Organization for the Advancement of Structured Information Standards (OASIS), Business Process Management Initiative (BPMI), United Nations Centre for Trade Facilitation and Electronic Business (UN/CEFACT), World Wide Web Consortium (W3C), and Workflow Management Coalition (WfMC), as well as individual software vendors and academic groups have or will propose metamodels and related interchange formats for Business Process Modelling. From the analysis of 15 specifications we gathered the following list of 13 high-level metamodel concepts.

1. *Task I/O:* In this paper we use the term task to refer to basic units of work whose temporal and logical relationships are modelled in a process. The input and output (I/O) of these tasks may be modelled using simple or XML complex types.

2. *Task Address:* The address specifies where or how a service can be located to perform a task. The address can be modelled directly via a URI reference of a service or indirectly via a query that identifies a service address.

3. *Quality Attributes:* When a set of potential services is generated via a query, quality attributes may be used to identify the "best" service.

4. *Task Protocol:* The protocol defines a set of conventions to control interaction with a service performing a task. Web Services use SOAP as a protocol.

5. *Control Flow:* The control flow defines the temporal and logical relationships between different tasks. Control flow can be specified via directed graphs, block-oriented nesting of control instructions, or process algebra.

6. *Data Handling:* Data handling specifies which variables are used in a process instance and how the actual values of these variables are calculated.

7. *Instance Identity:* This concept addresses how a process instance and related messages are identified. Correlation uses a set of message elements that are unique for a process instance in order to route messages to process instances. The generation of a unique identifier which is included in the message exchange is an alternative approach.

8. *Roles:* Roles provide for an abstraction of participants in a process. Roles are assigned to tasks and users to roles. A staff resolution mechanism can then allocate tasks of a process instance to users.

9. *Events:* Events represent real-world changes. Respective event handlers provide the means to respond to them in a predefined way.

10. *Exceptions:* Exceptions or faults describe errors during the execution of a process. In case of exceptions dedicated exception handlers undo unsuccessful tasks or terminate the process instance.

11. *Transactions:* ACID transactions define a short-run set of operations that have all-or-nothing semantics. They have to be rolled back when one partial operation fails. Business transactions represent long-running transactions. In case of failure the effects of a business transaction are erased by a compensation process.

12. *Graphic Position:* The graphical presentation of a business process model contributes to its comprehensibility. The attachment of graphical position information can be an explicit part of the metamodel.

13. *Statistical Data:* Performance analysis of a business process builds on statistical data such as costs or duration of tasks.

4 A Comparison of Business Process Modelling Proposals

The 13 metamodel concepts gathered in the previous section are now taken as a benchmark to compare the completeness of the 15 business process modelling interchange format proposals. The interchange formats are used in at least four different areas of application:

- *Composition:* Composition refers to the definition of the internal implementation of executable business processes. Web Service composition defines executable business processes that are built from a set of Web Services.
- *Choreography:* Choreography defines externally observable behavior of a business process. Web Service choreography refers to the correct content and order of messages that two parties exchange in a business process.
- *Business Analysis:* Business analysis refers to the presentation of business processes to managers. It builds on visualization of processes and annotation with statistics.
- *Formal Analysis:* This application refers to the verification of different formal quality criteria. These include e.g. soundness [vdA00].

Figure 2 gives an overview of the findings. A plus sign indicates that the concept mentioned on the left hand side of the row is included in the metamodel of the proposal mentioned at the top of the column. A minus sign denotes that the concept is not included. The question marks in the first column are a hint that the metamodel of BPDM is still in progress of specification while this paper is written. The figure shows that none of the specifications addresses all of the 13 concepts. BPEL4WS, BPMN, and WSFL yield the best results each lacking only three concepts. In this context it is important to mention that plus signs for a concept do not imply that the languages offer similar primitives to capture a high-level concept. Although control flow is the only concept supported by all specifications, there may be huge differences in the set of control flow primitives available in different language (cf. [vdAtHKB03]). We will now discuss each proposal in detail.

1. *BPDM:* OMG's Business Process Definition Metamodel (BPDM) [Ko03] is still in progress of development. BPDM will be MOF compliant. Accordingly, the respective BPDM interchange format will rely on XMI production rules. The specification process of BPDM is expected to take the remainder of 2004 [Ha04].
2. *BPEL4WS:* Business Process Execution Language for Web Services (BPEL4WS or BPEL) [ACD+03] has moved from a consortium of major software vendors to OASIS. BPEL is specified as an interchange format only via an XML Schema. BPEL models tasks as calls to Web Services whose input and output are specified by messages and whose address is identified via Uniform Resource Identifiers (URI) of WSDL port types. SOAP is used as the communication protocol. Control flow of BPEL can be modelled block-oriented or graph-oriented, data handling is expressed via variables and related operations. The identification of process instances is achieved via correlation sets. Roles of process participants are defined via so-called partner link types. Furthermore, BPEL supports handling of events and faults

	BPDM	BPEL4WS	BPML	BPMN	BPSS	EPML	OWL-S	PNML	UML Act.D.	WS-CDL	WSCI	WSCL	WSFL	XLANG	XPDL
Task I/O	?	+	+	+	+	-	+	-	+	+	+	+	+	+	+
Task Address	?	+	+	+	-	-	+	-	-	+	+	+	+	+	+
Quality Attributes	?	-	-	-	+	-	+	-	-	-	-	-	+	-	-
Protocol	?	+	-	+	-	-	+	-	-	+	+	+	+	+	-
Control Flow	?	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Data Handling	?	+	+	+	-	-	-	-	+	+	-	-	+	-	+
Instance Identity	?	+	+	-	-	-	-	-	-	-	+	-	+	+	-
Roles	?	+	+	+	+	-	+	-	+	+	+	-	+	+	+
Events	?	+	+	+	-	+	-	-	-	-	-	-	+	+	+
Exceptions	?	+	+	+	+	-	-	-	+	+	+	-	+	+	+
Transactions	?	+	+	+	+	-	-	-	-	+	+	-	-	+	-
Graphic Position	?	-	-	+	-	+	-	+	+	-	-	-	-	-	-
Statistical Data	?	-	-	-	-	-	-	-	-	-	-	-	-	-	+

Figure 2: Overview of BPM Interchange Formats.

as well as compensation of transactions. BPEL can be used to describe executable Web Service composition as well as Web Service choreography.

3. *BPML:* The Business Process Modeling Language [Ar02] proposed by BPMI is very similar to BPEL [MM03]. As the main difference BPML allows to specify multiple processes in one XML document and related communication between those processes. Furthermore, BPML is not tied to WSDL. Accordingly, the communication protocol is left to a BPML compliant implementation.

4. *BPMN:* The Business Process Modeling Notation [Wh04] also developed by BPMI wants to unify the different graphical notations for business processes. The specification also provides a mapping to BPEL. Therefore, its metamodel reflects most of BPEL's concepts except correlation. Additional specifications will define a BPMN metamodel based on MOF. This will permit serialization with XMI production rules for XML interchange.

5. *BPSS:* The Business Process Specification Schema [CCK+01] is part of OASIS and UN/CEFACT's work on ebXML. It includes a metamodel and XML Schema for Web Service choreography. Accordingly, it does not address implementational aspects like data handling or process instance identification. It supports the definition of roles, exceptions, and transactions in an inter-organizational message exchange.

6. *EPML:* The Event-Driven Process Chain (EPC) Markup Language (EPML) [MN04] is an academic proposal. It captures the control flow elements of EPCs. Further

aspects can be defined via extensions. As EPML aims to facilitate graphical model interchange it includes graphical position information for each EPC object.

7. *OWL-S:* OWL-Services (OWL-S) [APS+03] is an academic proposal for a service metamodel represented in OWL. OWL-S builds on an (input-output-preconditions-effects) quadruple to describe services. It also allows the definition of resources that we categorized as roles in Figure 2. OWL permits the definition of so-called groundings which is similar to a WSDL binding to a protocol and related endpoints.

8. *PNML:* The Petri Net Markup Language [BCvH+03] is an academic proposal for an XML interchange format for Petri Net models. It supports the basic Petri Net syntax elements and can be extended to represent arbitrary Petri Net types. The eXchangeable Routing Language (XRL) [No03] is based on PNML and can be executed on a dedicated infrastructure.

9. *UML 2 Activity Diagram:* Activity Diagrams of Unified Modeling Language (UML) [OM04] can be exchanged using XMI. Their metamodel includes concepts to model input and output of tasks, control flow, data handling, roles, exceptions, and graphical information.

10. *WSCDL:* W3C's Web Service Choreography Description Language [KBR04] is up to now only available as a working draft. It builds on WSDL and SOAP and provides different algebraic control flow primitives. It also supports data handling, role definition, as well as exception and transaction modelling.

11. *WSCI:* W3C's Web Service Choreography Interface [AAF+02] provides a set of extensions to WSDL in order to describe process behavior of message exchanges. Beyond input and output message types, WSDL bindings, and correlation WSCI also supports roles, exception handling, and transactions.

12. *WSCL:* Hewlett-Packard's Web Service Choreography Language [BBB+02] defines a minimal set of concepts in order to describe Web Service choreographies including message types, protocol, and service location. The specification contains a metamodel and a related XML Schema.

13. *WSFL:* IBM's Web Services Flow Language [Le01] is one of the predecessors of BPEL. It includes most of the concepts despite transaction support, graphical position information, and statistical data. Control flow in WSFL is modelled via directed graphs.

14. *XLANG:* Microsoft's XLANG [Th01] is the second predecessor of BPEL. It defines WSDL extensions to describe process behavior of a Web Service similar to WSCI. Additionally, it provides means for defining message correlation, roles, event and exception handling as well as transaction declaration.

15. *XPDL:* XML Process Definition Language [Wo02] is a standardized interchange format for business process models proposed by WfMC. It includes various concepts like task input/output and address, control flow, data handling, roles, events, and exceptions. It is also the only specification that addresses process statistics like durations and costs.

5 Related Work

A lot of work on business process model interchange formats and related metamodels is dedicated to the comparison of only two or three proposals. Examples include comparisons of BPEL and BPML [MM03]; DAML-S (predecessor of OWL-S) and BPEL [MM02]; and XPDL, BPEL, and BPML [Sh02]. Other approaches define metamodels or lists and use them as a framework for comparison (see e.g. [BKKR03], [SAJ+02], [RG02], or [zM04]). Our approach complements this work by providing a list of concepts that are extracted from actual specifications. To our best knowledge our list of XML-based business process modelling specifications is exhaustive at the time this paper is written. It extends the list of proposals gathered at the XML4BPM workshop [NM04] or those listed on Cover Pages [Co03]. Another approach is taken by [vdAtHKB03] who identify workflow patterns for control flow semantics. A similar approach needs to be taken for each of the high-level metamodel concepts identified in this paper in order to build the foundation of a reference model for business process management. This will be subject to future research.

6 Outlook

In this paper we presented a framework for comparing XML-based business process modelling specifications that builds on the superset of concepts extracted from the metamodels of 15 BPM specifications. Furthermore, we applied this framework to compare the 15 BPM specifications. With our work we aim to contribute to a better comparison of heterogenous approaches towards BPM which may finally result in a BPM reference metamodel and a related general interchange format for BPM. Yet, the high-level metamodel concepts identified in this paper need further in-depth analysis similar to the workflow pattern analysis reported in [vdAtHKB03]. Such analysis will be subject to future research.

References

[AAF+02] Arkin, A., Askary, S., Fordin, S., Kawaguchi, K., Orchard, D., Pogliani, S., Riemer, K., Struble, S., Takacsi-Nagy, P., Trickovic, I., and Zimek, S.: Web Service Choreography Interface (WSCI) 1.0. W3C Note 8 August. World Wide Web Consortium. 2002.

[ACD+03] Andrews, T., Curbera, F., Dholakia, H., Goland, Y., Klein, J., Leymann, F., Liu, K., Roller, D., Smith, D., Thatte, S., Trickovic, I., and Weerawarana, S.: Business Process Execution Language for Web Services, Version 1.1. BEA Systems, IBM Corp., Microsoft Corp., SAP AG, Siebel Systems. 2003.

[APS+03] Ankolenkar, A., Paolucci, M., Srinivasan, N., Sycara, K., Solanki, M., Lassila, O., McGuinness, D., Denker, G., Martin, D., Parsia, B., Sirin, E., Payne, T., McIlraith, S., Hobbs, J., Sabou, M., and McDermott, D.: OWL-S: Semantic Markup for Web Services (Version 1.0). OWL Services Coalition. 2003.

[Ar02] Arkin, A.: Business Process Modeling Language (BPML). BPMI.org. 2002.

[BBB+02] Banerji, A., Bartolini, C., Beringer, D., Chopella, V., Govindarajan, K., Karp, A., Kuno, H., Lemon, M., Pogossiants, G., Sharma, S., and Williams, S.: Web Service Conversation Language (WSCL) 1.0. W3C Note 14 March. World Wide Web Consortium. 2002.

[BCvH+03] Billington, J., Christensen, S., van Hee, K. E., Kindler, E., Kummer, O., Petrucci, L., Post, R., Stehno, C., and Weber, M.: The Petri Net Markup Language: Concepts, Technology, and Tools. In: W. M. P. van der Aalst and E. Best, eds., *Applications and Theory of Petri Nets 2003, 24th International Conference, ICATPN 2003, Eindhoven, The Netherlands*. volume 2679 of *Lecture Notes in Computer Science*. pp. 483–505. 2003.

[Be04] Beckett, D.: RDF/XML Syntax Specification (Revised). W3C Recommendation 10 February. World Wide Web Consortium. 2004.

[BKKR03] Bernauer, M., Kappel, G., Kramler, G., and Retschitzegger, W.: Specification of Interorganizational Workflows - A Comparison of Approaches. In: *Proceedings of the 7th World Multiconference on Systemics, Cybernetics and Informatics*. pp. 30–36. 2003.

[BLM+01] Beech, D., Lawrence, S., Moloney, M., Mendelsohn, N., and Thompson, H. S.: XML Schema Part 1: Structures. W3C Recommendation 02 May. World Wide Web Consortium. 2001.

[BM01] Biron, P. V. and Malhorta, A.: XML Schema Part 2: Datatypes. W3C Recommendation 02 May. World Wide Web Consortium. 2001.

[BPSMM00] Bray, T., Paoli, J., Sperberg-McQueen, C. M., and Maler, E.: Extensible Markup Language (XML) 1.0 (Second Edition). W3C Recommendation 6 October. World Wide Web Consortium. 2000.

[CCK+01] Clark, J., Casanave, C., Kanaskie, K., Harvey, B., Clark, J., Smith, N., Yunker, J., and Riemer, K.: ebXML Business Process Specification Schema Version 1.01. UN/CEFACT and OASIS. 2001.

[Ch76] Chen, P.: The Entity-Relationship Model - Towards a Unified View of Data. *ACM Transactions on Database Systems (TODS)*. (1):9–36. 1976.

[Co03] Cover, R.: Standards for Business Process Modeling, Collaboration, and Choreography. Website (last modified: November 20, 2003). Cover Pages. http://xml.coverpages.org/bpm.html. 2003.

[Cr84] Crawford, J. D.: An electronic design interchange format. In: *Proceedings of the 21st Conference on Design Automation, 25-27 June 1984, Albuquerque, United States*. pp. 683–685. 1984.

[De03] Delphi Group: BPM 2003 – Market Milestone Report. White Paper. 2003.

[Eu86] Eurich, J. P.: A Tutorial Introduction to the Electronic Design Interchange Format. In: *Proceedings of the 23rd ACM/IEEE Design Automation Conference, June 1986, Las Vegas, NV, United States*. pp. 327–333. 1986.

[Ha04] Harmon, P.: The OMG's Model Driven Architecture and BPM. Newsletter 5. Business Process Trends. http://www.bptrends.com/publicationfiles/05-04 NL MDA and BPM.pdf. May 2004.

[Ho94] Hollingsworth, D.: The Workflow Reference Model. TC00-1003 Issue 1.1. Workflow Management Coalition. 24 November 1994.

[HW04] Hohpe, G. and Woolf, B.: *Enterprise Integration Patterns*. Addison Wesley. 2004.

[KBR04] Kavantzas, N., Burdett, D., and Ritzinger, G.: Web Services Choreography Description Language Version 1.0. W3C Working Draft 27 April 2004. World Wide Web Consortium. April 2004.

[KK02] Karagiannis, D. and Kühn, H.: Metamodelling Platforms. Invited Paper. In: K. Bauknecht and A. Min Tjoa and G. Quirchmayer, eds., *Proceedings of the 3rd International Conference EC-Web 2002 - Dexa 2002, Aix-en-Provence, France*. volume 2455 of *Lecture Notes in Computer Science*. pp. 182–196. 2002.

[Ko92] Koegel, J. F.: On the Design of Multimedia Interchange Formats. In: *Proceedings of the 3rd International Workshop on Network and Operating System Support for Digital Audio and Video, 12-13 November 1992, La Jolla, California, United States*. pp. 262–271. 1992.

[Ko03] Koethe, M. R.: Business Process Definition Metamodel. Request for Proposals (bei/2003-01-06). Object Management Group. 2003.

[Le01] Leymann, F.: Web Services Flow Language (WSFL). IBM Corp. 2001.

[Me04] Mendling, J.: A Survey on Design Criteria for Interchange Formats. Technical Report JM-2004-06-02. Vienna University of Economics and Business Administration - Department of Information Systems. http://wi.wu-wien.ac.at/˜mendling/publications/TR04-Interchange.pdf. 2004.

[MM02] McIlraith, S. and Mandell, D.: Comparison of DAML-S and BPEL4WS. Stanford University. http://www.ksl.stanford.edu/projects/DAML/Webservices/DAMLS-BPEL.html. September 2002.

[MM03] Mendling, J. and Müller, M.: A Comparison of BPEL4WS and BPML. In: Tolksdorf, R. and Eckstein, R., eds., *Proceedings of Berliner XML-Tage*. pp. 305–316. 2003.

[MN04] Mendling, J. and Nüttgens, M.: Exchanging EPC Business Process Models with EPML. In: Nüttgens, M. and Mendling, J., eds., *XML4BPM 2004, Proceedings of the 1st GI Workshop XML4BPM – XML Interchange Formats for Business Process Management at 7th GI Conference Modellierung 2004, Marburg Germany*. pp. 61–80. http://wi.wu-wien.ac.at/˜mendling/XML4BPM/xml4bpm-2004-proceedings-epml.pdf. March 2004.

[NM04] Nüttgens, M. and Mendling, J., eds.: *XML4BPM 2004, Proceedings of the 1st GI Workshop XML4BPM – XML Interchange Formats for Business Process Management at 7th GI Conference Modellierung 2004, Marburg Germany*. http://wi.wu-wien.ac.at/˜mendling/XML4BPM/xml4bpm-2004-proceedings.pdf. March 2004.

[No03] Norta, A.: Web Supported Enactment of Petri-Net Based Workflows with XRL/flower. Technical report. Eindhoven University of Technology. http://tmitwww.tm.tue.nl/staff/anorta/XRL/documentation/ATPN04.pdf. 2003.

[OM02] OMG, ed.: Meta Object Facility. Version 1.4. Object Management Group. 2002.

[OM03] OMG, ed.: XML Metadata Interchange (XMI). Version 2.0. Object Management Group. May 2003.

[OM04] OMG, ed.: Unified Modeling Language. Version 2.0. Object Management Group. 2004.

[OMGM+98] Ohno-Machado, L., Gennari, J. H., Murphy, S. N., Jain, N. L., Tu, S. W., Oliver, D. E., Pattison-Gordon, E., Greenes, R. A., Shortliffe, E. H., and Barnett, G. O.: The GuideLine Interchange Format. *Journal of the American Informatics Association*. 5(4):357–372. July 1998.

[RG02] Rosemann, M. and Green, P.: Developing a meta model for the Bunge-Wand-Weber ontological constructs. *Information Systems*. 27:75–91. 2002.

[SAJ+02] Söderström, E., Andersson, B., Johannesson, P., Perjons, E., and Wangler, B.: Towards a Framework for Comparing Process Modelling Languages. In: Banks Pidduck, A., Mylopoulos, J., Woo, C. C., and Özsu, M. T., eds., *Proceedings of the 14th International Conference on Advanced Information Systems Engineering (CAiSE)*. volume 2348 of *Lecture Notes in Computer Science*. pp. 600–611. 2002.

[SDSK00] St-Denis, G., Schauer, R., and Keller, R. K.: Selecting a Model Interchange Format - The Spool Case Study. In: *Proceedings of the 33rd Annual Hawaii International Conference on System Sciences (HICSS-33), 4-7 January, 2000, Maui, Hawaii*. 2000.

[Sh02] Shapiro, R.: A Comparison of XPDL, BPML and BPEL4WS. Draft version 1.4. Cape Visions. http://xml.coverpages.org/Shapiro-XPDL.pdf. 2002.

[Th01] Thatte, S.: XLANG: Web Services for Business Process Design. Microsoft Corp. 2001.

[vdA00] van der Aalst, W. M.: *Business Process Management*. volume LNCS 1806. chapter Workflow Verification: Finding Control-Flow Errors Using Petri-Net-Based Techniques, pp. 161–183. Springer Verlag. 2000.

[vdAtHKB03] van der Aalst, W. M. P., ter Hofstede, A. H. M., Kiepuszewski, B., and Barros, A. P.: Workflow Patterns. *Distributed and Parallel Databases*. 14(1):5–51. July 2003.

[Wh04] White, S. A.: Business Process Modeling Notation. Specification. BPMI.org. 2004.

[WHB02] Wüstner, E., Hotzel, T., and Buxmann, P.: Converting Business Documents: A Classification of Problems and Solutions using XML/XSLT. In: *Proceedings of the 4th International Workshop WECWIS*. 2002.

[Wi02] Winter, A.: GXL – Overview and Current Status. In: *Proceedings of the International Workshop on Graph-Based Tools (GraBaTs), Barcelona, Spain*. 2002.

[Wo02] Workflow Management Coalition: Workflow Process Definition Interface – XML Process Definition Language. Document Number WFMC-TC-1025, October 25, 2002, Version 1.0. Workflow Management Coalition. 2002.

[zM04] zur Muehlen, M.: *Workflow-based Process Controlling*. Logos Verlag. 2004.

[zMR04] zur Muehlen, M. and Rosemann, M.: Multi-Paradigm Process Management. In: *Proc. of the Fifth Workshop on Business Process Modeling, Development, and Support - CAiSE Workshops*. 2004.