Towards Automated Process Model Annotation with Activity Taxonomies: Use Cases and State of the Art

Michael Fellmann(✉)

Institute for Computer Science, University of Rostock,
Albert-Einstein-Str. 22, 18059 Rostock, Germany
Michael.Fellmann@Uni-Rostock.de

Abstract. In business process modeling, semi-formal models typically rely on natural language to express the labels of model elements. This can easily lead to ambiguities and misinterpretations. To mitigate this issue, the combination of process models with formal ontologies or predefined vocabularies has often been suggested. A cornerstone of such suggestions is to annotate elements from process models with ontologies or predefined vocabularies. Although annotation is suggested in such works, past and current approaches still lack strategies for automating the annotation task which is otherwise labor intensive and prone to errors. In this paper, first an example for use cases is given and then a comprehensive overview of the state of the art of annotation approaches is presented. The paper at hand thus may provide a starting point and basis for researchers engaged in (semi-)automatically linking semi-formal process models with more formal knowledge representations.

Keywords: Business process · Semantic annotation · Automatic matching

1 Introduction

In business process modeling, semi-formal modeling languages such as BPMN are used to specify which activities occur in which order within business processes. Whereas the order of the activities is specified using constructs of the respective modeling language, the individual semantics of a model element such as "Check order" is bound to natural language. As long as models are created and read by humans only and a commonly agreed (potentially restricted) language is used, the usage of the natural language is no serious limitation. However, if models have to be interpreted by machines, e.g. for offering modeling support, search on a semantic level, content analysis in merger and acquisition scenarios and for re-using implementation artifacts linked to process elements (e.g. web services), a machine processable semantics of modeling elements is required [1]. In the past, several approaches tried to formalize the semantics of individual model elements by annotating elements of ontologies or other predefined vocabularies that to some degree formally specify the semantics of a model element. However, such approaches up to date suffer from a major limitation: Annotation is a highly manual and tedious task. The user has to select suitable elements of an

W. Abramowicz (Ed.): BIS 2017, LNBIP 288, pp. 74–90, 2017.
DOI: 10.1007/978-3-319-59336-4_6

ontology by browsing the ontology or doing a keyword-based search in the labels of the ontology. Even if the system is capable of presenting some annotation suggestions, e.g. based on lexical similarity of labels, the user has to make sure that annotations match the appropriate context in the process model by inspecting the structure of the ontology that typically is organized in a hierarchy. For example, if the ontology contains two activities labelled with "Accept invitation", it is important whether this activity is part of the hiring process (where the applicant accepts e.g. a job interview) or the planning process for business trips (where the employee accepts an invitation of a business partner). In other words, the semantic context of an element that is to be annotated must be considered. Since no highly automated context-sensitive approach for process model annotation is available so far, this contribution is meant to facilitate developing, comparing and optimizing such approaches. To bootstrap systematic research in this direction, use cases for automated annotation approaches are described and existing annotation approaches are reviewed. With this, interest in a very promising research topic should be raised; both in regard to scientific outcome as well as practical usefulness.

The remainder is structured as follows. Section 2 provides use cases for automatic process model annotation. In Sect. 3, existing annotation approaches are reviewed. In Sect. 4, a conclusion and short outlook on research opportunities is provided.

2 Use Cases for Automated Annotation

In the following, application scenarios leveraging an automated process model annotation are presented.

Modeling Support. If process elements are automatically annotated with elements of an ontology or taxonomy containing a set of predefined activities, this knowledge can be exploited to help the modeler completing his or her modeling task. This is illustrated by Fig. 1 showing a process fragment (bottom) being automatically annotated with a task ontology (top). This knowledge can then be exploited to provide modeling suggestions (right). The advantage of using this knowledge is that the suggestions for the following model element are not only derived on basis of one (or more) previous model element(s). Rather, they can be based on the knowledge representation that is linked to the model element via annotation. For example, in the knowledge representation it may be specified that after offering the job, potential candidates should be selected. The key difference to approaches based on e.g. suggesting activities retrieved from similar models such as the work by Koschmider [2] is that in this way *normative knowledge* is used, i.e., how an enterprise *should* act. Besides modeling support, automated annotation also provides the basis for leveraging information from knowledge representations that may provide additional value. For example, the PCF taxonomy [3] contains key performance indicators for all of the activities it contains (in the industry independent version approx. 1000 activities). Also, information to enact a process in the workflow environment may be linked to the set of specified reusable activities. *All in all, new ways of modeling support and of providing additional assistance in the*

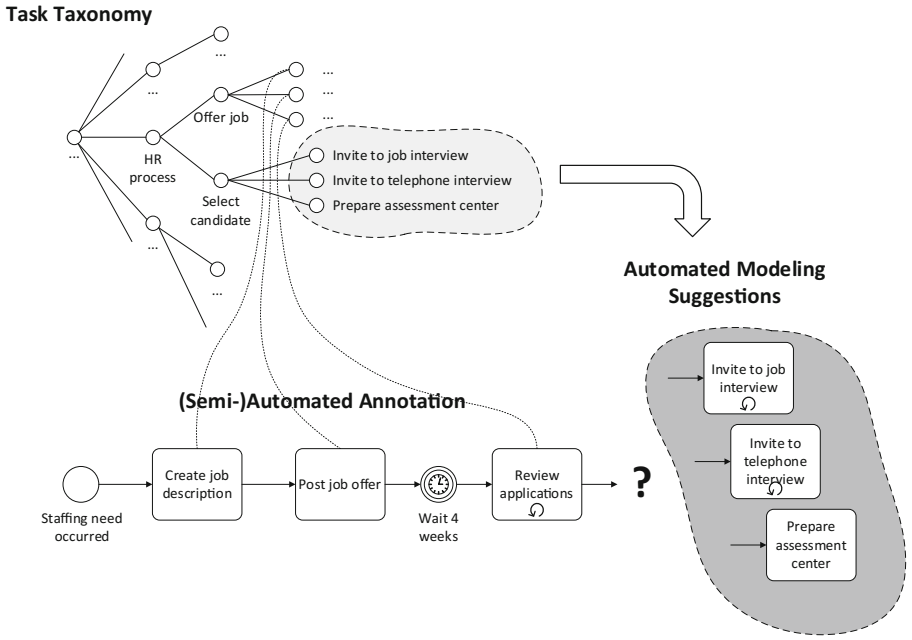

Fig. 1. Automated modeling suggestions

model-based design of process supporting information systems are possible due to an automatic process model annotation.

Process Retrieval. Current repositories are equipped mainly with keyword-based search mechanisms or rely on process query languages such as BPMN-Q [4]. These instruments allow searching the process space using natural language as well as structural and behavioral information. However, they lack to restrict search to broader content or topics of a process corresponding with the distinct functional areas in an enterprise, in short with the *business topic*. Although it may be possible to manually assign descriptors to models and in fact manual annotation approaches have been discussed recently [5], this imposes an extra effort on modelers having to focus on delivering high-quality models in a timely manner. Moreover, descriptors must be kept up to date if the model is adapted. Hence computing the business subject of a process model automatically based on activities that are annotated automatically creates an additional value. It can be re-computed from time to time to keep the information up to date.

How the automatic annotation of processes may improve the retrieval of processes from a repository is shown in Fig. 2. The user types in the keyword “review” in the search form (top). Since reviewing activities can occur in many contexts of the enterprise activities, the user specifies the category “Human resource management” which automatically shows up by typing in the special keyword “category” (much like keyword-search functionality in file explorers of common operating systems). Based on

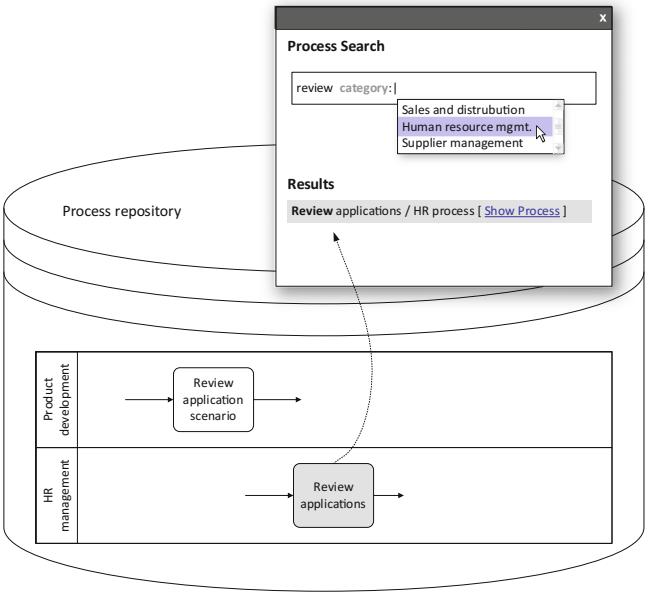

Fig. 2. Improved process retrieval

the automated annotation of processes, the activity "Review applications" is found that belongs to a process in the HR realm. *Hence with automated annotation, the retrieval of process knowledge on a semantic level can be improved.*

Process Analysis. Similar to process retrieval, current approaches for analyzing the contents of process models rely on keyword search or specialized query languages. Another way that is also common to analyze process models is to find similar process models, commonly referred to as *process model matching*. However, all these mechanisms have in common that an analysis is done in relation to what the user wants to know (which requires the user to know common terms in the business context) or what is available (when models are compared). However, in some situations of process analysis it may be favorable to introduce normative knowledge about which tasks *typically* occur in enterprises. With this, questions regarding the coverage of a process can be answered such as "Do we have a process for managing product quality?" which may be important for e.g. certain certification activities. Another example would be "In which area, we do not have yet specified processes?" or "Which of our processes are highly cross-cutting?" Fig. 3 illustrates how automated process model annotation may serve process analysis and comparison using normative knowledge.

At first, the user selects process models using a keyword search and adds models to the comparison (top). He or she subsequently inspects and compares the contents of the process model using a taxonomy of pre-defined business functions to guide this inspection (center). In more detail, the result of automatic annotation is displayed for each process model in a separate column. Each matching activity is displayed as a

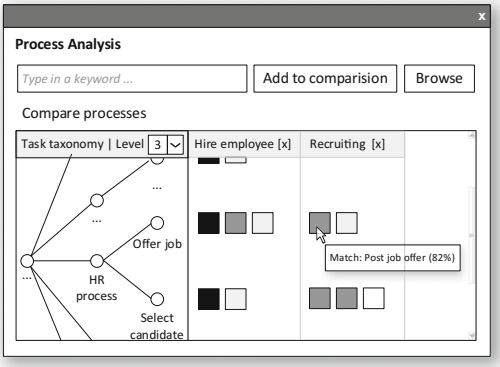

Fig. 3. Advanced process analysis

square that is saturated according to the matching score. Multiple squares are composed to a visualization that slightly resembles to well-known equalizer visualizations of audio-equipment. When the mouse is hovering over a square, matching score and other information can be shown such as a link to open the process model or other meta-information about the process. In order to zoom-in and -out, the user may also expand or reduce taxonomy levels (left).

Other visualizations that would be possible are histogram-like diagrams. *In this way, automated process model analysis that is enabled by exploiting annotation information is the basis for advanced analysis and visualization capabilities.*

3 State of the Art

Annotation in general has been discussed in the early stages of the Semantic Web movement [6]. In the following, annotation has also been explored in relation to enterprise modeling. For example, Boudjlida and Panetto describe annotation types in enterprise modeling [7]. The authors identify various semantic relations between an enterprise model and an element of an ontology and provide a schema for describing annotations. However, the authors also acknowledge that automation in annotation is largely missing: "However, an important feature is missing: it is the one that permits the automatic or the semi-automatic provision of the annotations." [7] Since no comprehensive overview of existing, manual annotation approaches for enterprise model is available so far, a structured literature analysis is conducted. With this, developers of automated annotation tools should be served with an overview that should inform and inspire the development of automated annotation procedures.

3.1 Selection and Analysis of Relevant Literature

For analyzing the literature, the literature data bases *EBSCO*, *Springer*, *ScienceDirect* and *Google Scholar* were examined. Different queries such as "`process model`" `AND annotation` or "`model annotation`" or "`semantic annotation`" `AND annotation` and variants of these queries were executed leading to 83 hits. The following inclusion and exclusion criteria were applied: Articles were excluded that use the term "annotation" to simply express that some additional information is written in the process model that has been generated automatically (i.e. to find semantic deficiencies). Further, works were excluded aiming at the semantic annotation of web services (e.g. by standards such as SAWSDL) or described by [8–12] or paper-based forms [13] since this is only slightly related to model annotation. Moreover, articles were excluded that describe high-level, general purpose annotation frameworks e.g. in the field of Semantic Web (annotation of web pages). Articles were included that sufficiently deal with business process modeling and that discuss annotation in sufficient detail. Regarding the latter aspect, this means not merely using/exploiting annotated process models that have been annotated somehow somewhere, but that are concerned with annotation itself.

In terms of completeness of the literature search, it can be assumed that most relevant papers have been identified since a high overlap between hits from databases and Google Scholar was found. Moreover, also all works in the area of process model annotation contained in the recent survey from [14] were retrieved. Hence it is likely that all important works were identified. For this reason, a forward- and backward search as requested e.g. from Webster and Watson [47] was not performed. Especially a backward search did not prove to be fruitful, since with this predominantly annotation tools of the semantic web community (such as OntoMat Annotizer etc., see [15, 16]) have been found that are not specific to process model annotation. If such approaches would be included, all the annotation work of the semantic web community (as an example list, see http://semanticweb.org/wiki/Tools) would be relevant. However, in the BPM community more focused approaches exist that leverage the process structure such as the works form Born et al. [17]. Hence it is more useful to more strictly look at the works from the BPM community that developed annotation techniques, which is done in the paper at hand.

3.2 General Overview on the State of the Art

In the following, the results of the literature analysis are presented (cf. Table 1). Relevant works are compared and reviewed by first giving a *Description of the overall approach*. Besides, a precise account on the notion of *Annotation concept* is given, that is, the specific approach the authors described, developed or implemented. In addition, approaches are compared in regard to whether they provide a (formal) definition of annotation (column *Def*) and the *Used technologies* such as e.g. lexical databases, string similarities etc. Moreover, approaches are compared in regard to two key characteristics. The first is their implemented or envisioned degree of automation (column *AU*). Symbol □ is used to indicate manual, ▣ for semi-automated and ■ for

Table 1. Results of literature analysis

Paper	Description of the overall approach	Annotation concept	Def.	Used technology	AU	CO
[18]	The authors suggest a mapping strategy and present a tool developed to map BPEL4WS to OWL-S. With the help of the strategy and tool, BPEL4WS-processes can be translated to OWL-S process descriptions	The mapping relation of a BPEL4WS process to an OWL-S ontology. In addition, the relation between concepts from the OWL-S profile ontology to domain ontologies	–	No information	□	no
[19]	Common modelling patterns are detected via an automatic semantic annotation of EPC process models. To automatically annotate the model elements, labels are decomposed using a lexical analysis and a pattern matching approach. If a suitable instance for annotation is missing in the ontology, then it will be created	Establishment of a semantic linkage from EPC functions and events to ontology instances	–	Lexicon (WordNet), term extraction, stemming	■	no
[17, 20, 21]	Execution-level business process modeling is supported that leverages a semantic annotation for process modeling and to automate process execution. Tool support aims at supporting the annotation by presenting the user only relevant annotation options. To do so, process	Establishment of a relation between model contents (e.g. actions, objects, states) and appropriate domain concepts or instances specified in an ontology	–	Term similarity and synonyms (no details provided). Analysis of the process context and structure	▣	yes

(*continued*)

Table 1. (*continued*)

Paper	Description of the overall approach	Annotation concept	Def.	Used technology	AU	CO
	structure and lifecycle information of the involved objects are considered					
[22]	The approach proposes to add security information to process models via annotation. The user is supported by suggestions provided by a "knowledge annotator"	A text attached to a BPMN element conforming to a specific syntax (annotation term, followed by a list of parameters)	–	Lexicon for synonym similarity (WordNet), path recognition	▣	no
[23–25]	Conceptual models are annotated to support e.g. benchmarking. Annotation support is based on the meta-modeling platform ADOxx and the integration of social network information to facilitate annotation is discussed	Adding properties of model elements or establishing relations to separate annotation models	–	No detailed information is provided	□	no
[26, 27]	The approach aims at an easy creation of domain specific ontology and semantic annotations. The latter are supported via automated suggestions. The computation of the suggestions is based on the semantic similarity between BPMN element labels and ontology concepts	Establishment of a relation between an activity of a BPMN model and an ontology concept	–	Lexicon for word sense hierarchies (WordNet), various lexical analysis techniques	▣	no
[28]	With Process SEER, a tool for semantic	Tasks in process models are	–	Using ontologies and Natural	□	no

(*continued*)

Table 1. (*continued*)

Paper	Description of the overall approach	Annotation concept	Def.	Used technology	AU	CO
	effect annotation of business process models has been developed. The tool requires analysts to describe the immediate effects of each task in natural language. These are then accumulated in an automated fashion	enriched by a structured description of their cumulative effects		Language Processing (NLP) is discussed to improve the approach		
[29–31]	Semantic annotations are discussed and an annotation framework for a range of applications is proposed such as systems Interoperability in a PLM environment	A semantic annotation relates an element of knowledge to one more ontology instances. It also captures an annotation relation type (e.g. subsumption) and the meta model element corresponding to the annotated element	✓	No information	☐	no
[32]	Organizational models are enriched through semantic annotation. A procedure to derive annotation suggestions is briefly sketched	A subject of annotation is related to an object by a predicate. Ontological annotation moreover means that the predicate and context are ontological terms and the object conforms to the ontological definition of the predicate	✓	Custom approach for ontology-based similarity calculation	☐	no
[33]	An ontological approach is developed to semantically	Linkage of the elements of a process model or	–	WordNet in conjunction with various syntactic,	▣	no

(*continued*)

Table 1. (*continued*)

Paper	Description of the overall approach	Annotation concept	Def.	Used technology	AU	CO
	annotate supply chain process models with a BPMN and SCOR ontology. The approach computes annotation suggestions that a user can select from a list	meta model with concepts from an ontology		linguistic and structural sim. measures		
[34–38]	A semantic annotation framework is proposed and applied in various settings such as for goal annotation or to increase the interoperability of process models. Automation is discussed predominantly in terms of translating a model to a pre-defined ontology based on the model constructs and meta-model information	Annotations of concrete process model elements are part of the more comprehensive PSAM (process semantic annotation model). Model annotation means to relate ontology concepts to model elements via pre-defined semantic relationships	✓	No detailed information is provided	☐	no
[16]	As part of the Pro-SEAT tool, semi-automatic annotation of goals for process models is implemented. Possible goal annotations can be deduced automatically based on the model annotation information	Relation between ontology concepts and model elements via pre-defined semantic relationships	✓	No detailed information is provided, apart from String match	▣	no
[5]	A model for semantically annotating business	CPSAM is a context-based process semantic	–	No information	☐	no

(*continued*)

Table 1. (*continued*)

Paper	Description of the overall approach	Annotation concept	Def.	Used technology	AU	CO
	process models is devised. The purpose of the model is to facilitate search, navigation and understandability of process models stored in repositories	annotation model for annotating business processes in a process model repository				
[39]	A framework and Wiki-based tool for the collaborative specification and annotation of business processes is provided. The tool provides a list of admissible annotations to the user	A relation between elements of a BPMN model and instances of a formal ontology	–	No information	▣	no
[40]	An approach for the automatic generation and annotation of capabilities based on the extraction of textual descriptions is developed	A semantic frame-based capability model for describing what an action (e.g. a task, or a service) achieves	–	Various NLP techniques from the CoreNLP library, WordNet	■	no
[41]	The sEPC ontology for EPC model serialization is presented and modelled in the WSML language. Competency questions serve to validate ontology development	Linking the sEPC-based process representation with elements from other ontologies	–	No automated approach	□	no
[42]	An approach for the annotation of the artefacts including process models is developed	Annotation is understood as the specification of concrete values for a set of common properties, given by the metadata defined in the ontology	–	No automated approach	□	no

(*continued*)

Table 1. (*continued*)

Paper	Description of the overall approach	Annotation concept	Def.	Used technology	AU	CO
[43]	Process models are annotated with their effects in order to apply a revision strategy that helps to obtain compliant process models from models that might be initially non-compliant	Descriptions of immediate effects of BPMN tasks provided in a formal form or derived from natural language (e.g. via Controlled Natural Languages - CNL)	–	No automated approach	☐	no
[44]	Artefacts such as process models are annotated to foster their reuse. The semantic annotation of processes is implemented using relations and concepts from a Business Ontology to describe processes or process fragments	The pairwise grouping of processes (or process fragments) with the elements "Business Goal", "Business Function", "Business Domain", "Business Role" and "Process Resource" via respective relations	–	No automated approach	☐	no
[45]	The semantic annotation of process models is introduced in order to provide for advanced querying of business process repositories	A correspondence between elements of a business process schema and concepts of a Business Reference Ontology. The relation is established in order to describe the meaning of process elements in terms of related actors, objects, and processes	–	No automated approach	☐	no
[46]	Annotations are introduced as a link between process	Annotations provide either formal definitions	(✓)	No automated approach	☐	no

(*continued*)

Table 1. (*continued*)

Paper	Description of the overall approach	Annotation concept	Def.	Used technology	AU	CO
	models and a reference ontology	of the entities involved in a process such as activities, actors, items (terminological annotations) or specify preconditions and effects for the activation of flow elements (functional annotations)				
[1]	An Ontology-based process representation is developed that is used to enrich model elements with machine processable semantics	Properties of ontology instances representing process elements that link to instances of classes from a domain ontology via defined properties	–	No automated approach	☐	no

automated approaches. The second key criteria is whether the approach accounts for the semantic context of a process model element (column *CO*), i.e. what previous activities lead to the activity or which activity are triggered by the activity. This criteria is important for the annotation of process models, since processes are essentially about the order of tasks executed in a business process. Consequently, the flow of activities is important for annotation. If for example an order is captured, checked and finally executed, it is highly unlikely that after order execution an activity such as "Confirm order" is relevant for annotation, even if it lexically matches an activity label such as "Confirm order fulfilment". So in essence, the criteria is about "knowing" the semantic context in which a process element occurs and considering this during automated annotation.

4 Conclusion and Outlook

In this study, general use cases that require an automated annotation approach have been presented. This underpins the relevance of such a research endeavor. Then a comprehensive overview on the state of the art in the literature was presented. A major

result of this overview is that annotation is rarely automated. Even if it is suggested in the research works, no automation seems to be implemented. Also, rarely prototypes are shown. Regarding the semantics of annotation, context information is (apart from one work) almost never used. This is a surprising research gap that exists even today – after almost one decade of research on semantic technologies applied to BPM that started with simple process model annotation proposals. Therefore, a research opportunity lies in developing (semi-)automated annotation approaches in order to first leverage existing standards such as PCF (cf. the use cases in Sect. 2) and second to make use of the wealth of semantic technologies (e.g. for search and matching of models on the semantic level) when process models have automatically been annotated. All in all, this contribution may be a starting point for developing more sophisticated (semi-)automatic approaches capable of linking semi-formal process models with more formal knowledge representations. With this, new use cases are possible shifting the automated interpretation of process models to a new and more semantic level. This contribution should encourage research towards this goal.

References

1. Thomas, O., Fellmann, M.: Semantic process modeling - design and implementation of an ontology-based representation of business processes. Bus. Inf. Syst. Eng. **1**, 438–451 (2009)
2. Koschmider, A.: Ähnlichkeitsbasierte Modellierungsunterstützung für Geschäftsprozesse, PhD-Thesis (2007)
3. APQC: Process Classification Framework (PCF), Version 5.2.0 (2010)
4. Awad, A.: BPMN-Q: A language to query business processes. In: Reichert, M. et al. (eds.) Proceedings of EMISA 2007, St. Goar, Germany, October 8–9, pp. 115–128 (2007)
5. Mturi, E., Johannesson, P.: A context-based process semantic annotation model for a process model repository. Bus. Process Manag. J. **19**, 404–430 (2013)
6. Bechhofer, S., Carr, L., Goble, C., Kampa, S., Miles-Board, T.: The semantics of semantic annotation. In: Meersman, R., Tari, Z. (eds.) OTM 2002. LNCS, vol. 2519, pp. 1152–1167. Springer, Heidelberg (2002). doi:10.1007/3-540-36124-3_73
7. Boudjlida, N., Panetto, H.: Annotation of enterprise models for interoperability purposes. In: International Workshop on Advanced Information Systems for Enterprises, 2008, IWAISE 2008, pp. 11–17 (2008)
8. Hau, J., Lee, W., Newhouse, S.: Autonomic service adaptation in iceni using ontological annotation. In: Proceedings of the 4th International Workshop on Grid Computing. IEEE Computer Society, Washington, DC, USA (2003)
9. Ringelstein, C., Franz, T., Staab, S.: The process of semantic annotation of web services. In: Cardoso, J. (ed.) Semantic Web Services - Theory, Tools, and Applications. Idea Publishing Group, USA (2007)
10. Xu, C., Liang, P., Wang, T., Wang, Q., Sheu, P.C.Y.: Semantic web services annotation and composition based on ER model. In: 2010 IEEE International Conference. on Sensor Networks, Ubiquitous, and Trustworthy Computing (SUTC), pp. 413–420 (2010)
11. Aljoumaa, K., Assar, S., Souveyet, C.: Publishing intentional services using new annotation for WSDL. In: Proceedings of the 12th International Conference on Information Integration and Web-based Applications & Services, ACM, New York, NY, USA, pp. 881–884 (2010)

12. Nie, H., Li, S., Lu, X., Duan, H.: From healthcare messaging standard to semantic web service description: generating WSMO annotation from HL7 with mapping-based approach. In: 2013 IEEE International Conference on Services Computing (SCC), pp. 470–477 (2013)
13. Kim, S.W.: Form annotation framework for form-based process automation. In: Haller, A., Huang, G., Huang, Z., Paik, H.Y., Sheng, Q.Z. (eds.) WISE 2011-2012. LNCS, vol. 7652, pp. 307–320. Springer, Heidelberg (2013). doi:10.1007/978-3-642-38333-5_33
14. Liao, Y., Lezoche, M., Panetto, H., Boudjlida, N., Loures, E.R.: Semantic annotation for knowledge explicitation in a product lifecycle management context: a survey. Comput. Ind. **71**, 24–34 (2015)
15. Reeve, L., Han, H.: Survey of semantic annotation platforms. In: Proceedings of the 2005 ACM Symposium on Applied Computing, pp. 1634–1638. ACM (2005)
16. Lin, Y.: Semantic Annotation for Process Models: Facilitating Process Knowledge Management via Semantic Interoperability (2008)
17. Born, M., Hoffmann, J., Kaczmarek, T., Kowalkiewicz, M., Markovic, I., Scicluna, J., Weber, I., Zhou, X.: Supporting execution-level business process modeling with semantic technologies. In: Zhou, X., Yokota, H., Deng, K., Liu, Q. (eds.) DASFAA 2009. LNCS, vol. 5463, pp. 759–763. Springer, Heidelberg (2009). doi:10.1007/978-3-642-00887-0_67
18. Aslam, M.A., Auer, S., Shen, J., Herrmann, M.: Expressing business process models as OWL-S ontologies. In: Eder, J., Dustdar, S. (eds.) BPM 2006. LNCS, vol. 4103, pp. 400–415. Springer, Heidelberg (2006). doi:10.1007/11837862_38
19. Bögl, A., Schrefl, M., Pomberger, G., Weber, N.: Semantic annotation of EPC models in engineering domains to facilitate an automated identification of common modelling practices. In: Filipe, J., Cordeiro, J. (eds.) ICEIS 2008. LNBIP, vol. 19, pp. 155–171. Springer, Heidelberg (2009). doi:10.1007/978-3-642-00670-8_12
20. Born, M., Dörr, F., Weber, I.: User-friendly semantic annotation in business process modeling. In: Weske, M., Hacid, M.-S., Godart, C. (eds.) WISE 2007. LNCS, vol. 4832, pp. 260–271. Springer, Heidelberg (2007). doi:10.1007/978-3-540-77010-7_25
21. Born, M., Hoffmann, J., Kaczmarek, T., Kowalkiewicz, M., Markovic, I., Scicluna, J., Weber, I., Zhou, X.: Semantic annotation and composition of business processes with maestro. In: Bechhofer, S., Hauswirth, M., Hoffmann, J., Koubarakis, M. (eds.) ESWC 2008. LNCS, vol. 5021, pp. 772–776. Springer, Heidelberg (2008). doi:10.1007/978-3-540-68234-9_56
22. Ciuciu, I., Zhao, G., Mülle, J., Stackelberg, S., Vasquez, C., Haberecht, T., Meersman, R., Böhm, K.: Semantic support for security-annotated business process models. In: Halpin, T., Nurcan, S., Krogstie, J., Soffer, P., Proper, E., Schmidt, R., Bider, I. (eds.) BPMDS/EMMSAD -2011. LNBIP, vol. 81, pp. 284–298. Springer, Heidelberg (2011). doi:10.1007/978-3-642-21759-3_21
23. Fill, H.-G.: Using semantically annotated models for supporting business process benchmarking. In: Grabis, J., Kirikova, M. (eds.) BIR 2011. LNBIP, vol. 90, pp. 29–43. Springer, Heidelberg (2011). doi:10.1007/978-3-642-24511-4_3
24. Fill, H.G., Schremser, D., Karagiannis, D.: A generic approach for the semantic annotation of conceptual models using a service-oriented architecture. Int. J. Knowl. Manag. 9 (2013)
25. Fill, H.-G.: On the social network based semantic annotation of conceptual models. In: Buchmann, R., Kifor, C.V., Yu, J. (eds.) KSEM 2014. LNCS, vol. 8793, pp. 138–149. Springer, Cham (2014). doi:10.1007/978-3-319-12096-6_13
26. Francescomarino, C., Tonella, P.: Supporting ontology-based semantic annotation of business processes with automated suggestions. In: Halpin, T., Krogstie, J., Nurcan, S., Proper, E., Schmidt, R., Soffer, P., Ukor, R. (eds.) BPMDS/EMMSAD -2009. LNBIP, vol. 29, pp. 211–223. Springer, Heidelberg (2009). doi:10.1007/978-3-642-01862-6_18

27. Di Francescomarino, C., Tonella, P.: Supporting ontology-based semantic annotation of business processes with automated suggestions. Int. J. Inf. Syst. Model. Des. **1**, 59–84 (2010)
28. Hinge, K., Ghose, A., Koliadis, G.: Process SEER: A Tool for Semantic Effect Annotation of Business Process Models. Presented at the September 2009
29. Liao, Y., Lezoche, M., Panetto, H., Boudjlida, N.: Semantic annotation model definition for systems interoperability. In: Meersman, R., Dillon, T., Herrero, P. (eds.) OTM 2011. LNCS, vol. 7046, pp. 61–70. Springer, Heidelberg (2011). doi:10.1007/978-3-642-25126-9_14
30. Liao, Y., Lezoche, M., Loures, E., Panetto, H., Boudjlida, N.: Formalization of semantic annotation for systems interoperability in a PLM environment. In: Herrero, P., Panetto, H., Meersman, R., Dillon, T. (eds.) OTM 2012. LNCS, vol. 7567, pp. 207–218. Springer, Heidelberg (2012). doi:10.1007/978-3-642-33618-8_29
31. Liao, Y., Lezoche, M., Loures, E.R., Panetto, H., Boudjlida, N.: A semantic annotation framework to assist the knowledge interoperability along a product life cycle. Adv. Mater. Res. **945**, 424–429 (2014)
32. Vazquez, B., Martinez, A., Perini, A., Estrada, H., Morandini, M.: Enriching organizational models through semantic annotation. Procedia Technol. **7**, 297–304 (2013)
33. Wang, X., Li, N., Cai, H., Xu, B.: An ontological approach for semantic annotation of supply chain process models. In: Meersman, R., Dillon, T., Herrero, P. (eds.) OTM 2010. LNCS, vol. 6426, pp. 540–554. Springer, Heidelberg (2010). doi:10.1007/978-3-642-16934-2_40
34. Lin, Y., Ding, H.: Ontology-based semantic annotation for semantic interoperability of process models. In: Mohammadian, M. (ed.) Proceedings of CIMCA-IAWTIC'06 -, vol. 01, pp. 162–167. IEEE, Washington, DC, USA (2005)
35. Lin, Y., Strasunskas, D.: Ontology-based semantic annotation of process templates for reuse. In: Halpin, T., Krogstie, J., and Siau, K. (eds.) Proceeding of 10th CAiSE/IFIP8.1/EUNO International Workshop on Evaluation of Modeling Methods in System Analysis and Design (EMMSAD05), Porto, Portugal, June 2005 (2005)
36. Lin, Y., Strasunskas, D., Hakkarainen, S., Krogstie, J., Solvberg, A.: Semantic annotation framework to manage semantic heterogeneity of process models. In: Dubois, E., Pohl, K. (eds.) CAiSE 2006. LNCS, vol. 4001, pp. 433–446. Springer, Heidelberg (2006). doi:10.1007/11767138_29
37. Lin, Y., Sølvberg, A.: Goal annotation of process models for semantic enrichment of process knowledge. In: Krogstie, J., Opdahl, A., Sindre, G. (eds.) CAiSE 2007. LNCS, vol. 4495, pp. 355–369. Springer, Heidelberg (2007). doi:10.1007/978-3-540-72988-4_25
38. Lin, Y., Krogstie, J.: Semantic annotation of process models for facilitating process knowledge management. Int. J. Inf. Syst. Model. Des. **1**, 45–67 (2010)
39. Rospocher, M., Francescomarino, C., Ghidini, C., Serafini, L., Tonella, P.: Collaborative specification of semantically annotated business processes. In: Rinderle-Ma, S., Sadiq, S., Leymann, F. (eds.) BPM 2009. LNBIP, vol. 43, pp. 305–317. Springer, Heidelberg (2010). doi:10.1007/978-3-642-12186-9_29
40. Gao, F., Bhiri, S.: Capability annotation of actions based on their textual descriptions. In: WETICE Conference (WETICE), 2014 IEEE 23rd International, pp. 257–262 (2014)
41. Filipowska, A., Kaczmarek, M., Stein, S.: Semantically Annotated EPC within semantic business process management. In: Ardagna, D., Mecella, M., Yang, J. (eds.) BPM 2008. LNBIP, vol. 17, pp. 486–497. Springer, Heidelberg (2009). doi:10.1007/978-3-642-00328-8_49
42. Furdík, K., Mach, M., Sabol, T.: Towards semantic modelling of business processes for networked enterprises. In: Noia, T., Buccafurri, F. (eds.) EC-Web 2009. LNCS, vol. 5692, pp. 96–107. Springer, Heidelberg (2009). doi:10.1007/978-3-642-03964-5_10

43. Ghose, A., Koliadis, G.: Auditing business process compliance. In: Krämer, B.J., Lin, K.-J., Narasimhan, P. (eds.) ICSOC 2007. LNCS, vol. 4749, pp. 169–180. Springer, Heidelberg (2007). doi:10.1007/978-3-540-74974-5_14
44. Markovic, I., Pereira, A.C.: Towards a formal framework for reuse in business process modeling. In: Hofstede, A., Benatallah, B., Paik, H.-Y. (eds.) BPM 2007. LNCS, vol. 4928, pp. 484–495. Springer, Heidelberg (2008). doi:10.1007/978-3-540-78238-4_49
45. Missikoff, M., Proietti, M., Smith, F.: Querying semantically enriched business processes. In: Hameurlain, A., Liddle, Stephen W., Schewe, K.-D., Zhou, X. (eds.) DEXA 2011. LNCS, vol. 6861, pp. 294–302. Springer, Heidelberg (2011). doi:10.1007/978-3-642-23091-2_25
46. Smith, F., Proietti, M.: Behavioral reasoning on semantic business processes in a rule-based framework. In: Filipe, J., Fred, A. (eds.) ICAART 2013. CCIS, vol. 449, pp. 293–313. Springer, Heidelberg (2014). doi:10.1007/978-3-662-44440-5_18
47. Webster, J., Watson, R.T.: Analyzing the past to prepare for the Future. MIS Q. **26**, 13–23 (2002)