Business Process Collaboration Using Semantic Interoperability: Review and Framework

Ruinan Gong[1], Qing Li[1], Ke Ning[2], Yuliu Chen[1], and David O'Sullivan[2]

[1] Department of Automation, Tsinghua University, Beijing, China
gongruinan@gmail.com
[2] Digital Enterprise Research Institute, National University of Ireland, Galway, Galway, Ireland
ke.ning@deri.org

Abstract. Business process collaboration is one of the most significant factors driving today's global business development. Researches and applications such as business process modeling, workflow interoperability, web service and ambient intelligence have been involved in this area. However, a holistic understanding is missing. To clarify the requirements and build a research foundation for business process collaboration, a conceptual model is provided in this paper. Then the state of the art and the future trend of business process modeling and process interoperability are reviewed based on this model. Furthermore, inspired by the novel semantic web technologies, a semantic agent based framework to facilitate business process collaboration is given.

1 Introduction

Today's enterprises have to establish cooperating partnerships to meet the challenges of changing market and high competition, which leads to inter-organization business process collaboration. In literature, research enhancing the efficiency and effectivity of process collaboration is usually divided into three aspects:

- *Information-based interoperability*, which is usually discussed from a view point of communication or interaction standards, such as TCP/IP, XML and SOAP etc.,
- *Resource-based coordination*, which focuses on the controlling and scheduling of the sharing resources such as employees, machines and inventory etc.,
- *Business rules-based collaboration*, which focuses on the mechanisms of process coordination, such as partnership trust and conformance assessment.

As a basis for discussion, a conceptual model for business process collaboration is developed in Section 2 to illustrate a general motivating scenario and to find out the underlying problems, which lead to conclusion that both process description model and performance model should be developed to meet the requirement of process collaboration.

R. Mizoguchi, Z. Shi, and F. Giunchiglia (Eds.): ASWC 2006, LNCS 4185, pp. 191–204, 2006.

Since business process modeling plays a fundamental role in process management, a brief review of business process modeling methods will be given in Section 3. So far, there has been no universally accepted process modeling standard that can satisfy all collaboration requirements, now the research trend is to reconstruct current process modeling methods by using an ontology that standardizes a shared vocabulary for communication and makes the semantics in the collaboration explicit.

Those approaches to facilitate business process collaboration, such as workflow interoperability, web service choreography and ambient intelligence, all involve semantic interoperability as a key factor. In section 4, we focus on the concept of interoperability and discuss the related research issues.

Currently, the semantic web technologies have become the most promising direction for integration and collaboration. Based on the above review and analysis, we believe semantic web technologies could help to enhance the efficiency and effectivity of process collaboration. So a framework of process interoperability based on semantic agent is given in Section 5. Key technologies such as process ontology and agent coordination rules are also discussed.

In a word, the aim of this paper is two-fold. On the one hand, it is to give an overview of recent research efforts and future trends related to business process collaboration; on the other hand, it is to propose our idea of using the semantic agent to facilitate business process collaboration in both application centric and human centric process environment.

2 Business Process Collaboration

Over the past ten years, under the huge competition pressure on cost, quality, service and time, the value of process management has been recognized by most enterprises. Many ideas, such as BPR (Business Process Reengineering), CPI (Continuous Process Improvement) or TQM (Total Quality Management) are discussed to show that process management can play a crucial role in creating sustainable competitive advantage.

The rapid development of the Internet and web infrastructures in the last few years has brought fundamental changes and enormous opportunities in the way business patterns are made available to both individuals and organizations. With the trend toward increasing globalization of manufacturing and outsourcing of functions to external partners, the challenge for the next years will be moving from intra-organization process management to inter-organizational process interaction, coordination and collaboration in the global supply chains.

2.1 A Conceptual Model of Business Process Collaboration

To describe the general situation of business process collaboration among different stakeholders, a basic conceptual model was created as Fig. 1.

Sets A and B represent two different processes: $A = \{a_1, a_2, \cdots, a_n\}, B = \{b_1, b_2, \cdots, b_m\}$, where a_i or b_j is an activity. We use different modeling forms

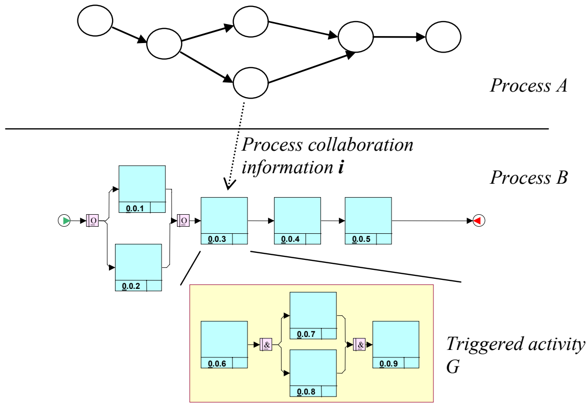

Fig. 1. Conceptual Model of Business Process Collaboration

to illustrate different processes because in industrial practice, various process modeling methods could be adopted by different modeling developers or users.

For the reason such as resource sharing or product assembling, process A and process B need to coordinate across manual or automated activities to achieve a common business goal. In this scenario, the running status of process B needs to be controlled or adjusted dynamically according to the running status of process A. Hence we must choose some key activities of process A, the information occurred by these activities would be treated as key performance indicators to control process B in a collaboration environment, which was called *Process Collaboration Information*, represented by set I, $I = \{i_1, i_2, \cdots, i_l\}$. By capturing and "translating" this information through specialized interface, process B could adjust its status of running automatically: For instance, trigger a set of activities G, to meet the collaboration requirement of both parties.

This conceptual model describes a most common situation of business process collaboration. It is specially pointed out that the concept of *Process Collaboration Information* is used to represent a general situation. In different collaboration environment (e.g. the degree of task automation, different process structures), collaboration information can be just one simple message about a single process entity, or can be composed by complex statistical performance indicates about the whole activity chain. Hence the main challenge for business process collaboration is *How to describe the process* and *How to construct Process Collaboration Information*.

2.2 Approaches to Business Process Collaboration

In the last decades, there has been a lot of research on business process modeling, software, architectures and standards to address business process integration in both academic and industrial areas. Thus interoperability among various process representation methods and heterogeneous process management systems has been an emerging need. From a modeling point of view, efforts can be carried out from two aspects as the conceptual model pointed out:

- *Process Description Model*. In essence, process description is a form of business knowledge that facilitates the understanding and communication of industrial users. There has been a lot of business process modeling techniques and tools (Section 3) which emphasize different perspectives for their own purposes. Hence in a collaboration environment, there must be a common business process description method and its schema language for distributed stakeholders to understand and communicate in a standard way[1].
- *Process Performance Model*. Given the complexity of business process, the process performance model is to represent the process performance indicators and their relationships, and more importantly, to provide the necessary information which helps collaboration and communication among different processes. In industrial practice, each process, especially in inter-organization environment, could be seen as separate profit and decision center, the conflict of single process goal and the whole collaboration goal should be solved on business level.

Furthermore, from a technical point of view, there must exist a standard description format and access protocols for both collaboration parties to publish their ability through a uniform interface, which is usually called workflow interoperability or web service choreography, so that process tasks can automatically be executed among potential partners with the help of functions provided by web service.

A number of initiatives is presently carried out worldwide by several academic and industrial research groups in some related areas to support business process collaboration for both human and automated tasks. One such trend is process integration by *Web Service* as a universal computing platform. In this area, process management is usually used together with another concept as *workflow* technology, of which the aim is "automation of a business process" [2]. The new research area merged into with workflow and web services merged, called workflow interoperability or web services choreography [3], aims at providing dynamic trading service (e.g., electronic purchase order) to business collaboration partners with universal description language and protocols.

On the other hand, not all process tasks are high structured and can be executed automatically by machine (e.g., human decision). Another research area is *Ambient Intelligence* (AmI), which is a human centered technology that is intuitive to the needs and requirements of the human actors. They are non-intrusive systems that are adaptive and responsive to the needs and wants of different individuals. AmI is a new paradigm in the area of information communication technology (ICT), context and context-awareness are central issues to AmI. There are many existing systems applying AmI/context aware technologies in the office, shopping store, house, hostel, museum, etc., but still very few systems exist at the moment to support the manufacturing collaboration environment. One of such systems is *iShopFloor* [4], which is an Internet-enabled agent-based intelligent system that provides an open architecture for distributed intelligent manufacturing process planning, scheduling, sensing, and control of the shop floor.

3 Business Process Modeling

Business process is defined [5] as “a structured, measured set of activities designed to produce a specified output for a particular customer or market”, and may be defined based on three dimensions as below: entities, objects and activities. Process models, which aim at a common understanding and analysis of business processes, play a crucial role in the implementation of any process improvement projects such as business process reengineering (BPR) or continuous process improvement (CPI). Literature review shows that process models should provide functions mainly covering two fields:

- *Description.* In essence, process representation is a form of business knowledge, to facilitate the understanding and communication of industrial users.
- *Analysis.* For the purpose of increasing process efficiency, not only representation is needed, models should also provide proper methods to analyze process and support process design/re-design, which are the core and most difficult task of BPR and CPI projects.

As process is usually defined as “a set of activities arranged in a specific order”, most current process modeling techniques describe processes in the form of activities and other process variables, such as entities, resources and objects, and their relationships, such as time series, logic and hypotaxis. These models, usually created by graphical modeling tools, including Petri Net[6], RAD[7], EPC[8], UML[9] and IDEF3[10] etc., have significant advantages on simplicity and descriptive ability. However, they fall short in analyzing capability to assist enterprise users with process designing and execution, mainly because of the following reasons:

- Graphical representation based on informal notation lacks mathematical accuracy and formal semantics, which makes it difficult to take effective analysis of process models, and difficult to communicate, share and reuse as well.
- Besides time series and logical relationship of activities, the underlying non-linear cause-and-effect relationship between process variables is seldom taken into consideration, which is important for disclosing the interrelationship between these controllable variables and performance improvement of process.

To meet the requirement of process collaboration among different stakeholders, process modeling methods should provide a common meta model and its associated schema language. The Process Specification Language (PSL) [11] has made significant effort to solve the problem. The goal of PSL is to create a process representation that is common to all manufacturing applications, such as scheduling, process modeling, process planning, production planning, simulation, project management, work flow, and business process reengineering. Based on the PSL ontology, different stakeholders can describe their business processes by using shareable terminology.

Motivated by those early efforts to standardize process description by ontology such as PSL, researchers try to extend it with domain knowledge added to enable a more widely collaboration integration, for instance, the project M3PE[3] developed a process ontology (m3po)[12] to incorporate and unify the different existing workflow meta models and workflow reference models. This project is still under developing and its next step is ontology mappings and validations from different existing workflow systems.

4 Process Interoperability

4.1 Definitions of Interoperability

Interoperability is a concept addressed very early during the design, development and enhancement of distributed systems. However, it is difficult to find a precise and general definition of interoperability. There exist different definitions of interoperability from different points of view.

- "Generally, the word 'inter-operate' implies that one system performs an operation on behalf of another." [13]
- "The ability to communicate with peer systems and access the functionality of the peer systems." [14]
- From the software engineering point of view, interoperability means: two cooperating software systems can easily work together without a particular interfacing effort.
- "The ability of two or more software components to cooperate despite differences in language, interface, and execution platform." [15]
- "The ability to integrate data, functionality and processes with respect to their semantics." [16] And "interoperable" is identified as a high degree of compatibility.

4.2 Semantic Interoperability

[13] defines a simplified interoperability framework to describe the interaction between two enterprises, as shown in Fig. 2.

- *Business layer*: includes business environment, business processes;
- *Knowledge layer*: includes organizational roles, skills and competencies of employees, knowledge assets;
- *ICT layer*: includes applications, data and communication components.

[3] http://m3pe.org

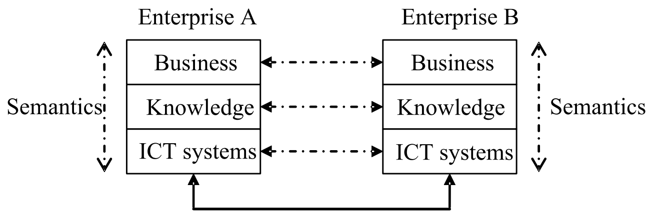

Fig. 2. Interoperability on all layers of an enterprise[13]

In the paper [17], a historical perspective and an overview of the interoperability is discussed as Fig. 3 shows. The *Remote Procedure Call* (RPC) and CORBA's *Interface Definition Language* (IDL) represent the early interoperability evolution. In the 90's, research has been focused on *signature level*, *protocol level* and *semantic level*. In an increasing order of complexity and difficulty, interoperability can be classified into four levels, which are physical, data, specification and semantic levels.

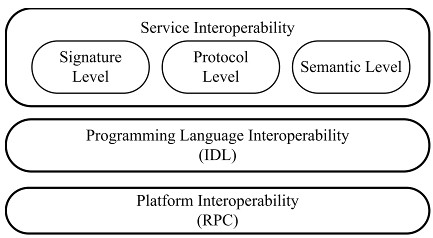

Fig. 3. Classic Levels of Interoperability[17]

According to [18], previous research in semantic interoperability can be categorized into three areas.

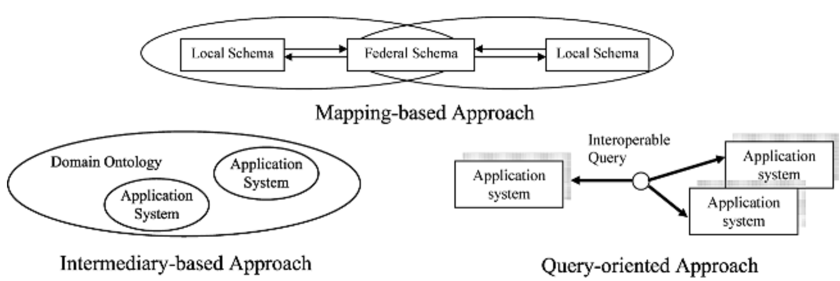

Fig. 4. Research Approach in Semantic Interoperability

– *Mapping-based*: construct mappings between different systems. The drawback of this method is that the mapping relationship is not designed to be independent of particular schemas and applications.
– *Intermediary-based*: use an ontology to share standardized vocabulary or protocols to communicate with each other. Its knowledge is domain-specific, but independent of particular schemas and applications.
– *Query-oriented*: based on interoperable languages, most of which are declarative logic-based language.

4.3 Workflow Interoperability Standards

Both standards for electronic data interchange and development of workflow systems have a longer history dating back to the 1970s , and process interoperability has been studied since the middle of the 1990. The latest research surge is emerging workflow management and web service into business integration scenario, which is called workflow choreography interface (or behavioural interface, abstract process, collaboration protocol profile, etc.)

A web service is a "software application identified by a URI, whose interfaces and bindings are capable of being defined, described and discovered by XML artifacts, and which supports direct interactions with other software applications using XML based messages via internet-based protocols."[19] Recent research in this area developed a lot of workflow interoperability and web services choreography standards, such as WSDL (Web Services Description Language)[20], SOAP (Simple Object Access Protocol)[21], UDDI (Universal Description, Discovery and Integration)[4] [22], WSFL (Web Services Flow Language)[23], BPEL4WS (Business Process Execution Language for Web Services). [24] and [25] have given a historical perspective of these standards.

5 A Process Collaboration Framework with Semantic Agent

With the emerging and rapid development of the semantic web, it is possible to adopt the novel semantic web technologies to help to enhance the efficiency and effectivity of process collaboration.

5.1 Semantic Web Technologies

The semantic web can be envisioned as an extension of the current web, which aims to make the web more understandable to computer programs, and allows data to be shared and reused across applications, enterprises, and community boundaries, easily.

There are two backbone technologies for the semantic web: RDF and OWL[26]. They, as web standards, provide a framework for asset management, enterprise integration, and sharing and reusing data on the web. These standard formats for

[4] http://www.uddi.org/

data sharing span different applications, enterprises, and community boundaries. All users - both human and machine - can share and understand the information available on the semantic web. The foundation of RDF[27] is built on a very simple model, but the basic logic can support large-scale information management and processing in a variety of different contexts. The assertions in different RDF files can be combined, providing far more information together than what they contain separately. RDF supports flexible and powerful query structures, and developers have created a wide variety of tools for working with RDF. OWL[28] provides a language for defining structured, web based ontologies. This delivers richer data integration and interoperability among descriptive communities. Many semantic web based information systems have been created[5], and have been successfully used in some industrial applications.

5.2 Application Scenario

The framework is developed to meet the requirement of project AMI-4-SME[6] in two main application scenarios: machine maintenance and shop floor control.

Machine Maintenance. Maintenance management is all about managing asset. It is defined as "the coordination, control, planning execution and monitoring of the right equipment maintenance activities of manufacturing operations"[29]. Maintenance is looked at from two perspectives, the first is providing the maintenance personnel with accurate and relevant realtime information on their machines in order to enable them to introduce and implement the appropriate strategies. The second perspective helps the staff carry out all necessary maintenance, both scheduled and unscheduled, in order to get the machines up and running in as quick a time as possible.

Combining the information coming in from the product tags with the machine sensors provides a vast amount of invaluable data. Detailed figures on machine utilization, mean time between failures, mean time between maintenance, equipment downtime, maintenance staff efficiency, overall equipment efficiency, and comparison of various maintenance strategies, to name but a few, can all be inferred from the collected realtime data. On the other hand, the maintenance technician, with the help of PDA, can get the information on the current state of the machine such as temperature, action that caused the failure, operator name etc. Details of the previous maintenance are also supplied to the maintenance technician.

Shop Floor. Shop-floor control is concerned with the efficient management and usage of resources at the lowest level of control on the shop floor of a manufacturing plant. The realtime information coming from the product manufacturing process provides exact locations for each of the batches of product. Should a certain machine fail then the batch location information can used to re-route

[5] Semantic Web Challenge. http://challenge.semanticweb.org
[6] http://www.ami4sme.org/

the effected batches as efficiently as possible in order to keep the impact of the machine failure to a minimum.

Information from various sources is used to control the processing of orders on the factory floor. It primarily relies on batch location information and also information from the employee roster, order book, stock room and others it controls how orders are routed through the factory and it also controls what workstations employees are working at. The data acquired from the tags and sensors can also be processed to provide the user with information on traceability, accountability and reliability. Traceability and accountability are of particular significance as they are necessary for meeting the guidelines laid down by standardization bodies i.e. ISO. Efficiency is useful in ensuring that the company is getting the most output of their assets.

5.3 Process Collaboration Framework Structure

Fig. 5 shows a process collaboration framework. Our idea is to transfer process collaboration information between different processes by semantic agents. All agents can access various business process management systems and capture information of different processes represented by process ontology.

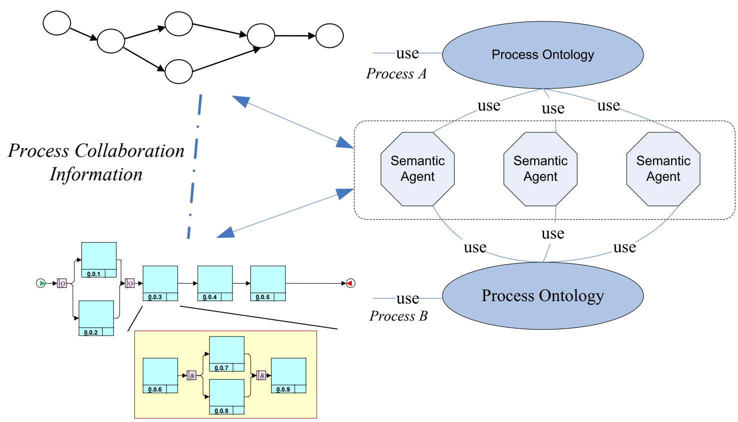

Fig. 5. Process Collaboration Framework Based on Semantic Agent

Ontology. Ontology is a general conceptualization of a specific domain in a both human and machine readable format. In general, it consists of classes, properties, relationships, and axioms. To realize interoperability and collaboration of different processes, it is necessary to build a formally and explicitly expressed process ontology, which can be classified into two categories:

– *Process Description Ontology* is to give formal semantics to traditional process modeling elements, such as entities, objects and activities, their relationships etc. For example, we can get details of some product by the statement:

```
<rdfs:Class rdf:ID="GetDesiredProductDetails">
<rdfs:subClassOf rdf:resource
        ="http://www.product.org/Process#AtomicProcess" />
</rdfs:Class>
```

PSL provides feasibility of extending its core ontology to represent most current process models with similarity-based ontology mapping. With Process Description Ontology, industrial users could get a common and formal understanding from their existing traditional process models and computers would be able to work cooperatively and efficiently in a collaboration environment.

– *Process Performance Ontology* is to express process performance for special collaboration partners with process domain knowledge added. For instance, in the maintenance scenario, the performance indicators such as mean time between failures, mean time between maintenance, equipment downtime, maintenance staff efficiency, and overall equipment efficiency will be given precise definition.

Semantic Interface. In this AmI scenario, process information could be collected by using three methods: *Tags, Machines Sensors,* and *PDAs* (Personal Digital Assistants).By applying tags (RFID, barcode, etc.) to the product component, the status of each production activity can be monitored in realtime throughout the whole production cycle. The type of tag used will be dependent on many factors such as the type of product, company size, complexity of production, production techniques etc. The production machinery is equipped with networked sensors which monitor the status of the machines (idle, off, processing product, failure). This information is available in realtime to the maintenance staff. Either maintenance or shop-floor staff having wireless PDAs equipped with tag readers could get information on particular product or machine to support their decision making. All the set of information sources and services needs to run the transaction protocol; for example, ontology searching, software-capability profiles, programming language, and the interoperation acts that will set up the semantic interfaces.

Agents and Rules. An agent is a software entity with intelligent properties, according to [30], the integration of agent technology and ontology will significantly affect the use of web services and the ability to extend programs to perform tasks for users more efficiently and with less human intervention. Agents act at the interface for the human-human and human-machine collaboration in business process integration. In this AmI scenario, different intelligent software agents (e.g., context agent, maintenance agent, production agent) work together to access heterogeneous information systems in anticipating user's requirements and thus avoid manual browsing for common information gathering tasks.

The shared process ontology allows for solving problems concerning heterogeneity of knowledge representation between distributed agents. On the other hand, intelligent agents that can automatically find any information requested by the user and can execute some intelligent issues like coordination, negotiation and agreement thus avoid inefficient or manual 'surfing'. With semantic agents any stakeholder will have instant access to all of distributed processes running at anywhere within the organization, regardless of format, structure, or location of the information.

With the help of *Process Performance Ontology*, it is possible to build a set of business rules (e.g., time, constraint, exception) to facilitate agent acting, reasoning, and coordinating with each other. The explicit description of process performance related information makes the process coordination feasible (e.g., resource conflict solving among different parts of the extended enterprise). This automated process reduces human intervention in process management, and thus enables them to focus on the most complex perspective. Ontology inference or reasoning, which can improve the efficiency of query and processing of innovation related instance data, will play the role in realizing the alignment analysis among different objects and rules, which could adopt Description Logic, FLogic or Horn Logic as theoretic foundation.

System Infrastructure. The key components of the system infrastructure include ontology server, rule base and web server as shown in Fig. 6. Through this infrastructure, Process Agents communicate with the Web Server to act and reference using the Process Ontology Database and the Process Rule Base, to realize collaboration between different processes.

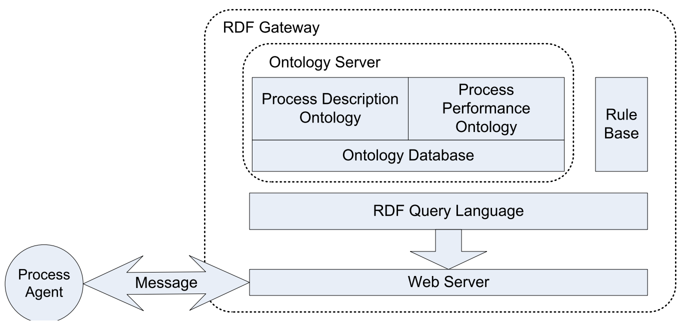

Fig. 6. System Infrastructure

RDF Gateway[31] is an ideal development environment for this infrastructure. It provides (1) RDF database to store Ontology in RDF triples, (2) the RDFQL language to query RDF and to execute server-side tasks, (3) certain inference capability (by RULEBASE command) to support RDFS and other customized rules, (4) the stand alone Web Server to communicate with Process Agents.

6 Conclusion

Business process collaboration plays a more and more important role in today's global manufacturing environment. Based on the conceptual model provided, we have discussed the requirements of business process collaboration, and reviewed some related research area, such as business process modeling and interoperability. These works have built a firm foundation for further research in this area.

Since the semantic web technologies have become the most promising direction for integration and collaboration, a business process collaboration framework based on semantic agents is provided. This framework needs to be further developed in detail. The further research issues include ontology mapping, agent design and coordination rules. The implementation work based on RDF Gateway is still going on. Our belief is that semantic web techniques could help to enhance the efficiency and effectivity of process collaboration.

Acknowledgements

This paper is based upon works funded by the European Union 6th Framework Specific Targeted Research Project (STREP) Ambient Intelligence for Systemic Innovation in Small to Medium Enterprises (AMI4SME). We would like to thank David Mulligan, Simrn Kaur Gill, Gearoid Hynes, Thai Vinhtuan and Fergal Monaghan for their key contribution of this research project. We also like to thank to Armin Haller and Eyal Oren for their introduction on project M3PE.

References

1. Dayal, U., Hsu, M., Ladin, R.: Business process coordination: State of the art, trends, and open issues. In The 27th VLDB Conference, Roma, Italy (2001)
2. Fischer, L.: The Workflow Handbook 2004. Future Strategies Inc. (2004)
3. Zhao, J.L., Cheng, H.K.: Web services and process management: a union of convenience or a new area of research? Decision Support Systems, 40(1) (2005) 1–8
4. Shen, W., Lang, S., Wang, L.: ishopfloor: an internet-enabled agent-based intelligent shop floor. IEEE Transactions on Systems, Man and Cybernetics, Part C, 35(3) (2005) 371–381 TY - JOUR.
5. Davenport, T., Short, J.: The new industrial engineering: Information technology and business process redesign. Sloan Management Review, 1990 Summer (1990) 11–27
6. Pinzon, L.E.: Petri Net Models. http://rutcor.ruters.edu/ pinzon/papers/rrr1/node15.html (2006)
7. Ould, M.A.: Business Process - Modelling and Analysis for Reengineering and Improvement. Wiley, New York (1995)
8. Scheer, A.W.: ARIS - Business Process Frameworks. Springer, Berlin (1999)
9. Fowler, M., Scott, K.: UML Distilled: A Brief Guide to the Standard Object Modeling Language. Addison-Wesley (2000)
10. KBSI: IDEF3 Process Flow and Object State Description Capture Method Overview - Process Description Capture Method.
11. Gruninger, M., Menzel, C.: The Process Specification Language (PSL) theory and applications. AI Magazine, 24(3) (2003) 63–74
12. Haller, A., Oren, E.: A process ontology to represent semantics of different process and choreography meta-models. Digital Enterprise Research Institute(DERI), Galway, Ireland (2006)

13. Chen, D., Doumeingts, G.: European initiatives to develop interoperability of enterprise applications-basic concepts, framework and roadmap. Annual Reviews in Control, 27(2) (2003) 153–162
14. Vernadat, F.: Enterprise modeling and integration: principles and application. Chapman & Hall, London (1996)
15. Wegner, P.: Interoperability. ACM computing surveys, 28(1) (1996) 285–287
16. IEC TC 65/290/TC (2002), Industrial process measurement and control
17. Strang, T., Linnhoff-Popien, C.: Service interoperability on context level in ubiquitous computing environments. In International Conference on Advances in Infrastructure for Electronic Business, Education, Science, Medicine, and Mobile Technologies on the Internet (SSGRR2003w), L'Aquila, Italy (2003)
18. Park, J., Ram, S.: Information systems interoperability: What lies beneath? ACM Transactions on Information Systems, 22(4) (2004) 595–632
19. W3C: Web services architecture requirements. (2003)
20. W3C: Web services description language (WSDL) 1.1. (2001)
21. W3C: Simple object access protocol (SOAP) 1.1. (2000)
22. Zimmermann, O., Tomlinson, M.R., Peuser, S.: Perspectives on Web Services : Applying SOAP, WSDL and UDDI to Real-World Projects. Springer (2003)
23. Leymann, F.: Web services flow language (WSFL 1.0). Technical report, IBM (2001)
24. Andrews, T., et al.: Business process execution language for web services version 1.1. IBM, BEA Systems, Microsoft, SAP AG, Siebel Systems (2003)
25. zur Muehlen, M., Nickerson, J.V., Swenson, K.D.: Developing web services choreography standards–the case of rest vs. soap. Decision Support Systems, 40(1) (2005) 9–29
26. Miller, E.: The WBC's Semantic Web Activity: an update. Intelligent Systems, IEEE [see also IEEE Intelligent Systems and Their Applications], 19(3) (2004) 95–97
27. RDF Primer. http://www.w3.org/TR/rdf-primer (2006)
28. OWL. http://www.w3.org/2004/OWL (2006)
29. de Vries, J.: Maintenance management. http://www.managementsupport.com (2000)
30. Hendler, J.: Agents and the semantic web. Intelligent Systems, IEEE [see also IEEE Intelligent Systems and Their Applications], 16(2) (2001) 30–37
31. RDF Gateway. http://www.intellidimension.com (2006)