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A process-oriented service infrastructure for networked enterprises

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ABSTRACT

The *networked enterprise* is a short-term partnership of business organizations aimed at sharing the partners' services without restrictions on size or organizational structure. Our approach considers two software solutions developed for supporting the creation and maintenance of such business collaborations in interoperable networks. The first one addresses a business alliance formation based on combining competences, processes and services of several organizations into a single value chain. Our emphasis is mainly on the interoperability and security of the provided services. The second approach focuses on the collaboration between large enterprises with rich IT ecosystems and SMEs with poor or missing IT infrastructure. Interoperable data sharing is supported by light-weight semantics, while standard inter-SME communication is enriched to grant authentication among partners. Alternatives for enabling technologies for service orchestration, process modelling, and event routing are investigated for the solutions. Based on the evaluation results obtained from pilot testing of the system prototypes, we discuss the implications of the technologies on quality indicators such as usability, performance, and business applicability.

1. Introduction

The concept of *networked enterprises* became popular in the last decade as a progressive method enabling flexible business collaboration (Bughin and Chui, 2010). This approach for outsourced and distributed resources, coordinated toward a well-defined business goal, has been identified as advantageous for *small and medium-sized enterprises* (SMEs), since it supports supply chain management (Mentzer et al., 2007), facilitates logistics integration between networked companies (Marcuta and Marcuta, 2013), and helps to increase the competitiveness of cooperating SMEs in the global market. To proceed from theory to implementation though, the overall solution has to cover organizational and technological aspects of companies' integration.

From the organizational perspective, the management of collaboration among several organizations is recommended to follow best practices and methodologies, such as Six Sigma, PRINCE2, related ISO standards, and so on. In the IT industry, the ITIL standard (ITIL, 2014) is well adopted and widely used.

Technological aspects of collaboration among networked enterprises are handled by installing advanced infrastructure with contemporary *information and communication technologies* (ICTs). They include web services orchestrated into process chains, employing standardized data exchange protocols and interfaces, and can be applied in line with the Web 2.0 paradigm (Bughin and Chui, 2010). Other advanced technological approaches supporting business collaboration networks include the utilization of business process models managing collaboration workflow, the enterprise service bus for control and monitoring a flow of events, semantic knowledge representation structures facilitating service orchestration, and adapters and enablers of interoperable information exchange between alliance partners and their legacy applications.

We emphasize the technological aspects of IT infrastructure supporting the creation and maintenance of networked enterprises. We view the organizational aspects as methodology drivers and performance indicators. Our findings in this area are demonstrated for solutions developed within two independent but highly related R&D projects, SPIKE and VENIS. Both were accomplished under the 7th Framework Programme (FP7) of the European Union (EU). The architecture, implementation details, and functionality of these systems are presented together with the results of experimental evaluation of pilot applications. We focus on identification, analysis, and investigation of influences that combinations of technology frameworks and approaches may have on performance, usability, business applicability and quantitative or qualitative cri-

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teria of software solutions enabling business collaboration for networked enterprises.

2. Motivation and challenges

A number of business cases (Barchetti et al., 2012; Solaimani et al., 2015; Yam et al., 2007) indicate that the lack of efficient collaboration technologies, trust and guidelines has a notable impact on the exploitation of new business opportunities. This is especially obvious in the area of component and device manufacturers (typically SMEs), where limited access to collaboration systems, cooperation models and know-how lead to a situation where suppliers serve one major client instead of providing their services to a larger customer base. Today, business is especially open to subcontracting, outsourcing and other forms of cooperation, but the lack of flexibility and limited abilities to adapt internal processes of organizations to new requirements are often showstoppers for developing new partnerships and products.

To overcome these difficulties, software solutions that enable efficient and flexible maintenance of business alliances are expected to be accessible for a wide range of business organizations, especially SMEs with limited resources for advanced and expensive IT infrastructure. This implies that systems supporting business alliances need to be built on open standards and frameworks, with a preference for open source components. Moreover, the systems must provide interfaces to a wide range of data repositories, information systems, and communication platforms commonly used by SMEs and businesses of various types. These assumptions have also driven the conceptual design of the systems developed within the SPIKE and VENIS Projects, as we will shortly discuss in greater detail.

2.1. Infrastructure for short-term business alliances in the SPIKE Project

The concept of a *short-term business alliance* has two main distinguishing characteristics. It is a mutually agreed upon partnership of organizations aimed at sharing the partners' business services without restrictions on organizational size or structure. These partnerships usually tend to be temporary to accommodate the changing business environment. Further, ad hoc process-oriented collaboration is often required, both on the level of individual employees and working teams. These conceptual specifications formed the functional requirements in the SPIKE Project, which started in 2008 and lasted till 2011 as a joint effort of several European SMEs and universities. The projects did R&D work for a prototype solution enabling previously unacquainted companies to establish and manage short-term business alliances.

The formation of a business alliance is based on the combination of competences, resources and services of several organizations into a single value chain to serve customers with a jointly developed product or service. The organizations conduct joint production and combine their forces by outsourcing or partnering with other service providers in the scope of a networked enterprise. Fig. 1 illustrates the structure of three layers to describe them, as proposed in the SPIKE Project (Broser et al., 2009).

The purpose and composition of each of the proposed layers is as follows:

- The *Networked Enterprise Layer* of a business alliance shares skills, knowledge, expertise, capabilities, and high-level services between the companies in mutually beneficial collaboration.
- The *Conceptual Layer* models shared artefacts and processes in a value chain, with related process models, and information support and semantic knowledge representations and structures.
- The *Service Layer* consists of tools and technologies enabling an implementation of the value chain processes. It includes low-level services of various types, such as standardized web services, custom online e-services for accessing data, and manual tasks, from the partners.

A platform that enables the creation and management of such business alliances was designed and developed as a prototype in the SPIKE Project (Furdik et al., 2011a). It focused on the conceptual layer, by emphasizing secure and interoperable access to services. Key aspects, such as the federation of identities, the security model for services, and the orchestration and composition of low-level services based on semantically-annotated business process models have been investigated. We will discuss the solutions that were developed in more detail later in this article.

Due to the limited project budget and its early lifecycle phase of development, only a prototype system was implemented, and many of the features to scale it for commercial use are in the planning phase only. They mostly are related to support schemas and operational models, which depend on a business case and platform configuration for integrated processes, services, and needs-based customization.

2.2. The paradigm of virtual organization in VENIS

To overcome the limitations of the SPIKE Project and to proceed with a solution for networked enterprises, the research team decided pursue additional outcomes in another EU FP7 Project, VENIS (Laclavik et al., 2012), which was implemented in 2011–2015. The general objectives of the VENIS Project were similar to those of SPIKE: to increase interoperability in service provision, data exchange, and communication between companies cooperating in a business network. The VENIS project, however, was more focused on networking and interoperability between *large enterprises* (LEs) and *medium and small enterprises* (SMEs). It did so according to the *virtual organization paradigm* (Mowshowitz, 2003), which is based on:

- A distributed and secure *repository* to share the information contained in the file systems, databases, ERPs, CRMs, and other legacy applications of the enterprises, connecting IT Infrastructures of various size companies (from LEs to SMEs).
- A set of light-weight *web services* to enable integration of the information exchanged in joint work, based on legacy e-mail systems and boosted by semantic annotation and search.
- A distributed *process engine mechanism*, able to link and execute business processes in the value chain defined for the networked enterprise, to assist the work and create novel synergies in the joint production supply chains.

An overall goal of the VENIS Project was to develop a platform that helps to reduce interoperability barriers between LEs and SMEs at the technical, semantic and organizational levels. To achieve, the project implements light-weight approaches supporting interoperable information storage and exchange.

At the technical level, the challenge was to achieve interoperability on the top of protocols for e-mail and web applications, with web service adapters for various legacy applications. In contrast to the SPIKE solution, which was solely based on WSMO platform (Fensel et al., 2010), the approach adopted in VENIS is compatible with many contemporary IT infrastructures. It relies on RESTful web services and e-mail messaging for tasks such as document management including tagging and search, creation of collaborations, and notifications about the activities of collaboration members. At the semantic level, VENIS focuses on the sharing

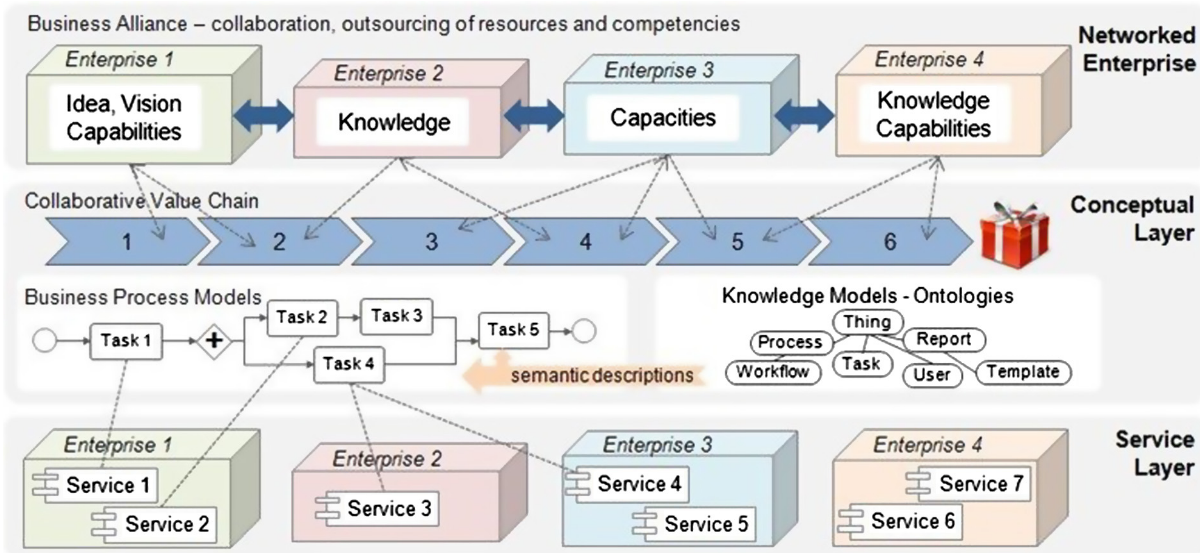

Fig. 1. Business alliance layers in the SPIKE Project.

and reuse of tags and annotations that can be automatically extracted from human-readable collaboration artefacts (Laclavik et al., 2012). This approach goes beyond the static knowledge representation models used in the SPIKE Project (Furdik et al., 2011a), and brings more flexibility and adaptability to the solution. Support for business process modelling and execution in VENIS is similar to the approach of semantic process models applied in SPIKE; however, instead of the obsolete BPMO framework (Cabral et al., 2009), a more progressive jBPM technology base has been utilized.

Descriptions of the architecture, modules, and functionality of both systems are provided in the following two sections. The prototypes were deployed in various industry environments and tested on a set of pilot applications. The testing and evaluation procedure for SPIKE and VENIS, together with results obtained from industry evaluators, are presented and discussed in Sections 3 and 4. A deeper analysis of the outcomes and evaluation results are discussed related to the issues of interoperability, supply chain management, and semantic business processes in Section 5.

3. Spike for networked enterprises

The SPIKE platform is a technical infrastructure for networked enterprises. It is focused on short-term, product-oriented business alliances, and helps to set up and maintain such collaborations in an efficient way, making the process easier and better structured. It supports loosely-coupled alliances: collaborators may cooperate in one project, but compete in others. This type of ad hoc co-operation requires a process-guided approach for controlling the interactions and information exchange between alliance members. This is achieved in SPIKE by employing formal business process models of the alliance value chain, while the execution framework consists of a business process engine, Semantic Service Bus, and components enabling secure access to inner services provided by collaboration participants. To support these features, the conceptual and service layers of the overall business alliance schema include building blocks that cover the functionality of the user interface, the processing of semantically-enhanced business models, and secure access to low-level services.

The building blocks of the SPIKE platform are depicted in Fig. 2. The Portal UI module, built upon the Liferay Portal CE solution (LiferayCE, 2011), provides a single access point for service providers and platform users. It is constructed as a web-based portal that enables an integration of external applications via Java portlets compliant with the JSR-268 specification (Oracle, 2014).

The business logic for handling connected services in accordance with respective process models, and representing the alliance value chain, is presented in the Semantic Process and Secure Mediation modules that implement the semantically-enhanced enterprise service bus, security framework, and related components. The Semantic Process module contains a formal representation of the value chain workflow in the form of business process modelling notation (BPMN, BPEL, or BPMO (Cabral et al., 2009)). It is deployable to a built-in workflow engine that controls its execution. Further, it provides the Portal UI with integration points enabling it to include legacy applications via portlets into the process, and exhibiting basic graphical user interfaces that feed inputs to and visualize outputs from individual steps of the overall workflow.

The Secure Mediation module serves as an adaptable semantic interface between the process models and the connected low-level services provided by various alliance partners. It allows flexible orchestration and composition of services without having to re-model and re-deploy the business process model. Each of the connected services is represented by a semantic description, which forms a virtual service access point and represents a virtual service interface for inner platform components. The virtual service interfaces are marked by the IF label in Fig. 2.

Low-level services are connected to the platform by means of respective binding components (the BC mark in Fig. 2), which enable both static and dynamic binding to process model tasks. The implementation of Secure Mediation is based on *enterprise service bus* (ESB) principles (Chappell, 2004) enhanced with features of semantic orchestration and mediation. In addition, security capabilities for authentication, authorization and access control to individual services are provided on top of the virtual services (Fritsch and Pernul, 2010). The security infrastructure, which is based on the Shibboleth framework (shibboleth.internet2.edu), was employed for implementing features such as the single sign-on and federation of identities between the external online services (Fernandez et al., 2009).

Individual low-level services are represented inside the Service Adapters module. Static service binding, presented in Fig. 2 by the chain IF1 – VS1.1 – S1.1, enables external services or applications

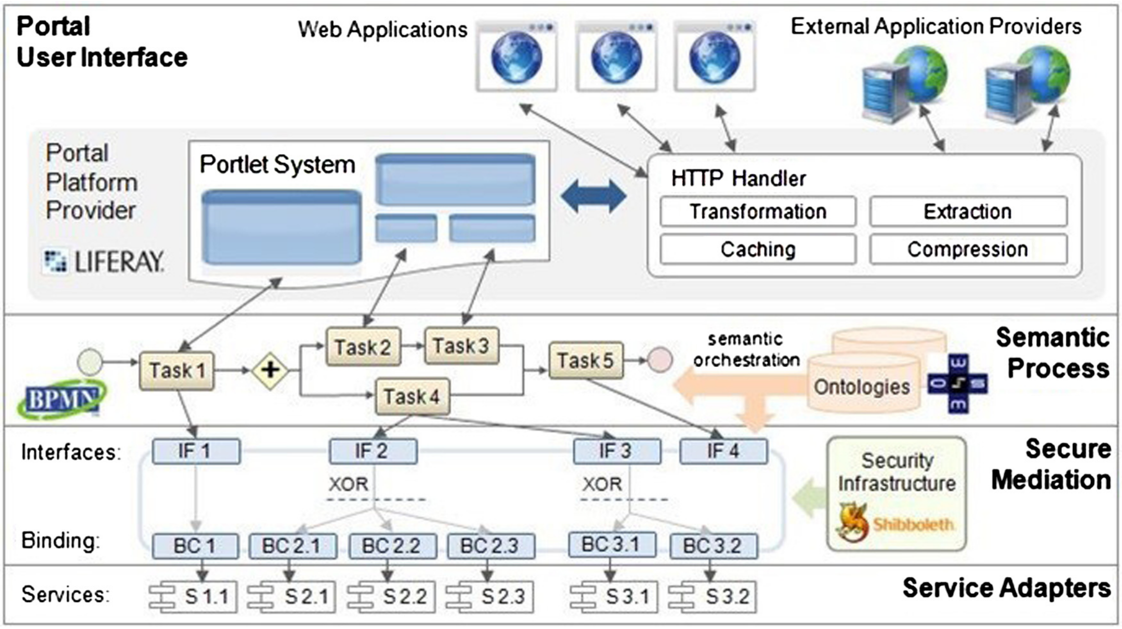

Fig. 2. SPIKE system architecture and interactions among the building blocks.

to integrate into the SPIKE portal without any association to the business process model. A more sophisticated example of flexible and dynamic service allocation is illustrated by the chain IF3 – VS3.1/VS3.2 – S3.1/S3.2. In general, the Service Adapters module acts as a pool of all applications and services that are available to networked companies for forming and modelling business alliances.

3.1. Semantic service bus and ontologies

The interoperability of heterogeneous services from business alliance partners is addressed by SPIKE through a common semantic knowledge model, which enables service orchestration and mediation during the operation of business process models. The semantic infrastructure of SPIKE has been implemented via the WSMO and WSMO-Lite framework (Fensel et al., 2010), with reuse of existing ontologies such as BPMO, vCard and CORE (Furdik et al., 2009). The implementations of different ontologies are specified in three logical groups: process, system, and domain ontologies. The aim is to support interoperability at different levels: in abstract business processes, for low-level services, and with respect to domain-specific entities. Detailed descriptions of developed ontologies can be found in Furdik et al. (2011a).

The main purpose of the semantic knowledge base in the SPIKE platform is to support dynamic selection of services for tasks in a specified alliance workflow (Vitvar et al., 2008). This is achieved through semantic annotation for services and workflow elements in the business process models, which can then be semantically-matched and mediated (Furdik et al., 2011b). For services of all supported types (i-web services, online services in the cloud environment, and *human tasks* involving off-line services performed asynchronously by human actors, the SA-WSDL standard was adopted to support service discovery and data mediation.

SA-WSDL is a light-weight semantic framework, which coexists well with other existing and widely-used technologies for web services, such as XSD and WSDL. This approach allows the gradual semantic annotation of services whenever needed, and it paves the way for migrating legacy applications to modern semantically-enriched service-oriented architectures. Fig. 3 shows how SA-WSDL extends XML-based WSDL service descriptions, operational capabilities, and XSD messages with WSMO and WSML semantic annotations. Consequently, XSD and WSDL service description elements can be linked to ontology concepts and then matched with similar semantic characteristics of workflow elements. This is supported by a built-in XSLT transformation mechanism for the *lifting* (changing XML data produced be a web service from that representation to another semantic version) or the *lowering* of data (changing the data back from the semantic version to its XML representation) (Fritsch et al., 2011). This feature is employed for the dynamic binding and resolution of services routed by the service bus implemented in SPIKE.

The Semantic Service Bus is a central communication and messaging infrastructure of the SPIKE system, designed in line with ESB principles (Christudas, 2008). All data exchanged between alliance partners during the collaboration workflow are funneled through some of the service bus components depicted in Fig. 4. The interface for both providers and consumers includes a set of Binding Components supporting standard communication protocols (HTTP, SOAP, JDBC, or UDDI), which normalize the sent or received service messages to a common XML-based data format.

The Normalized Message Router, which is built on top of the *Java Business Integration Framework* (JBI), forms the central messaging backbone of the service bus and provides data routing capabilities between the components. The application logic required for service composition, orchestration, semantic resolution, transformation, mediation, and monitoring is included in the functional modules asynchronously controlled by the Service Messages Engine component.

The mechanism for processing service calls in the Semantic Service Bus is depicted in Fig. 5.

Service requests can be invoked externally by an alliance partner or internally via a task of the operating business process model. Thereafter, data sent by the Service Requester (1) are transformed from a protocol-specific format into the common XML representation by an appropriate Binding Component (2). A normalized service message is then sent via the Message Router to the next component, the Interceptor (3), which enriches the message with security attributes required for authorization and authentication

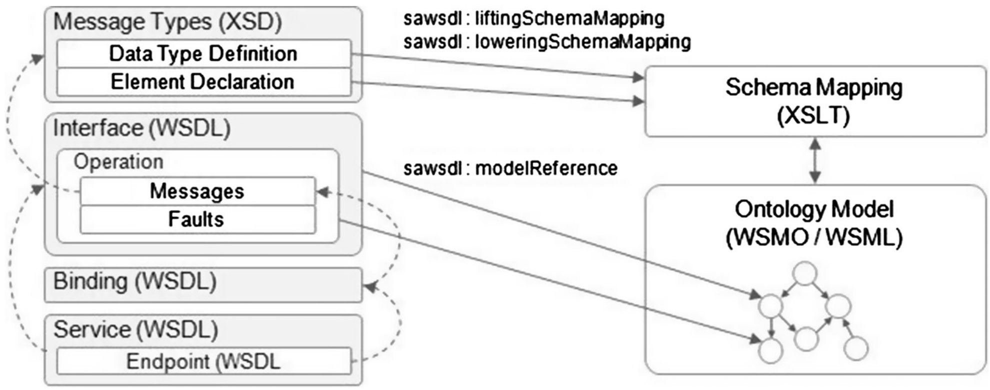

Fig. 3. Semantic annotation of services by SA-WSDL.

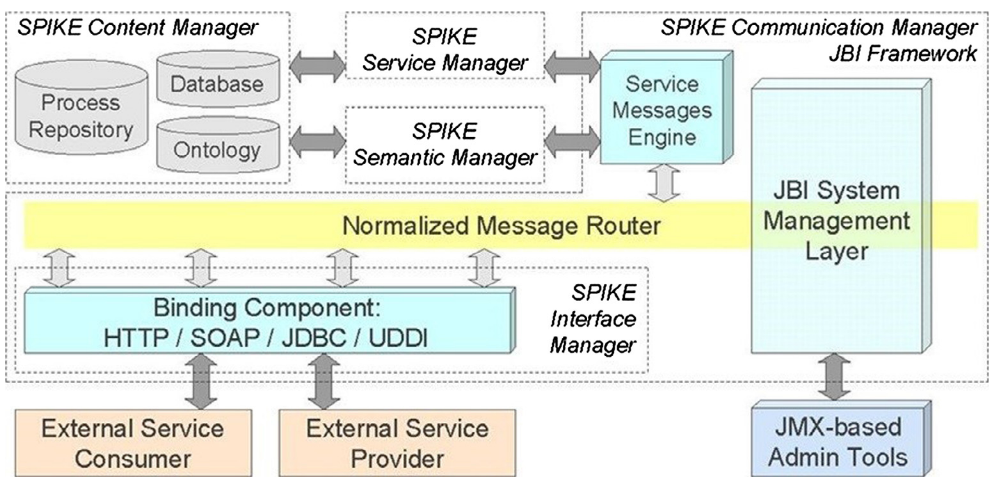

Fig. 4. Semantic service bus and related functional subsystems.

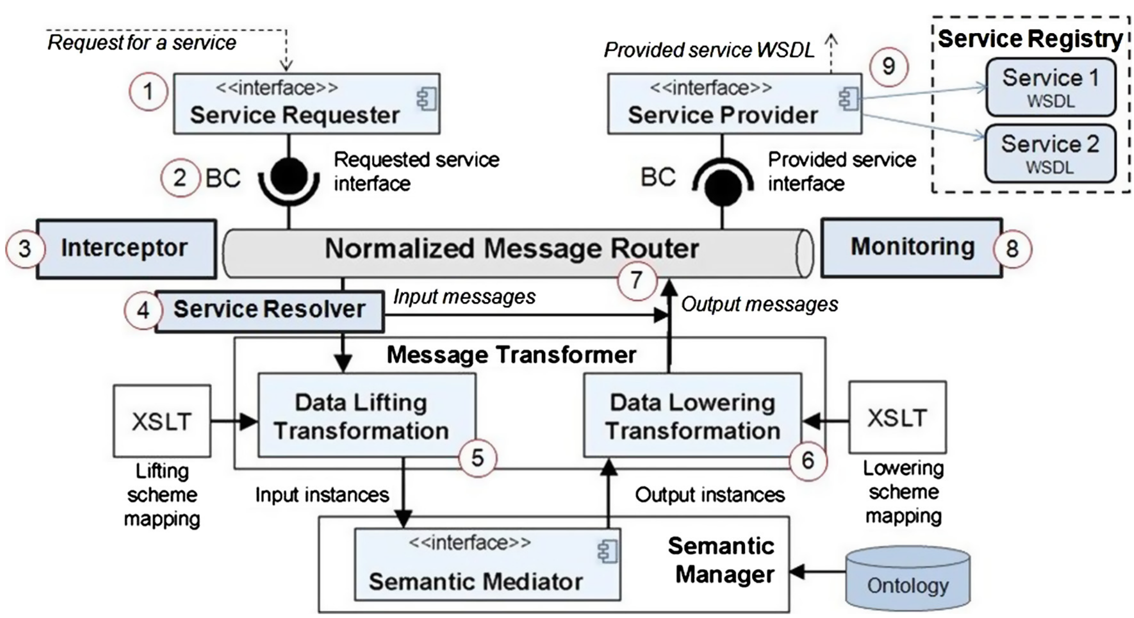

Fig. 5. Routing and semantic transformation of service messages.

in subsequent processing. The resulting SA-WSDL construct, which corresponds to the virtual interface of the requested service, is then forwarded via the message router to the Service Resolver (4).

If the service request is statically bound to a single WSDL, then the corresponding target service is selected from the Service Registry of the Alliance (7), and is returned so it can be invoked. However, dynamic binding is applied in most cases. So the requesting message specifies the target service by its semantic characteristics only. The SA-WSDL of a target service is wrapped into a SOAP message and sent by the Service Resolver to the Message Transformer component, which forwards the interface to the lifting procedure (5). The SA-WSDL description contains definitions of required service properties, which are annotated with the *sawsdl:liftingSchemaMapping* attributes that point to the instances of ontology concepts. (See Fig. 3 again.) These semantic instances are retrieved from the ontology and used for semantic mediation and resolution of candidate services by means of the reverse XSLT transformation (6). Invocation of both statically-bound and semantically-resolved services is tracked through a Monitoring action (8) before the actual service interface via proper communication protocol is provided (9). By this procedure for service routing and mediation, the SPIKE platform enables flexible integration of heterogeneous services provided by network alliance partners based on a predefined workflow.

3.2. Testing SPIKE on pilot applications

A prototype of the SPIKE platform, equipped with the Semantic Service Bus, portal system, security infrastructure and other components that we have described, was completed in November 2010. After that, in early 2011, the prototype was tested and validated on a set of pilot applications installed on the premises of the project partners in Austria and Finland. The focus of the two Austrian pilots, supervised by the partner companies, Infineon Technologies GmbH and addIT Dienstleistungen GmbH, was on several key features, including identity federation, single sign-on, and the integration of the Siemens DAMEX legacy application into the web portal provided by SPIKE (Broser et al., 2010).

The collaboration value chain as whole, including the process workflow of service-based communication and interoperable data exchange between the business alliance partners, was tested via an integrated pilot installed on the premises of the Citec Information Oy Ab company in Finland. This application was designed to create intraorganizational and interorganizational technical documentation services so they could be provided in a collaborative manner. The SPIKE system was employed for managing and automating the supplier's tasks in the documentation management process and related sub-processes, such as document flow control, verification of the outputs provided by suppliers, and monitoring of communication between the customer company and its suppliers. The main goal was to demonstrate and evaluate whether the semantic annotation of business processes and support services could make the information flow more robust, error-free and cost-efficient.

The application of the SPIKE system has been investigated in terms of its maturity and the suitability of the semantic technology that is used, in combination with the portal and service bus architecture, to maintain the workflow of technical documentation development within the networked enterprise. Besides the WSMO platform, Intalio's BPMS Community Edition (www.intalio.com) was also assessed as an alternative for handling the design and execution of the business process models.

Evaluation of all of the pilot applications was accomplished in accordance with the information quality criteria defined by Wang et al. (2005). The criteria, which essentially represent different quality dimensions, fall into four main categories: intrinsic, contextual, representational, and accessibility quality. Indicators, such as accuracy, believability, timeliness, completeness, interpretability, accessibility, and response time were evaluated by users who acted as assessors of the system solution. They assigned satisfaction degrees on a 0, 1 and 2 scale for each of tasks and functional use cases that were performed. To obtain global and comparable results across the assessors, additional quantitative evaluation was done via a hierarchical weighting of application cases, use cases, and tasks related to the use cases.

Fig. 6 gives an overview of the results that we obtained from the evaluation of all of the pilot applications. The listed use cases, which correspond to different phases of collaboration in the business alliance, have been performed and evaluated separately for each of the pilots. The perceived values of the quality indicators, as specified by the industry evaluators in comparisons with the stated requirements and expectations, were aggregated for each of the collaboration phases. The resulting average values are presented in the "Measures" column. The "Weight" column contains percentage scores for the relative importance of the collaboration phases from the perspective of the industry users. Finally, the "W (M)" column presents values with a weighted measure. It can be interpreted as a relative performance contribution for the various collaboration phases based on the overall perceived quality of the SPIKE system.

The numbers in the table indicate that the inner phases of the alliance collaboration, especially the Resource Management and Collaboration Phase, were given weights relative to the other quality dimensions at 30%, which indicated that they were the most important, and were assess to both be greater than 90% in terms of their raw quality measure. However, Collaboration Setup and Collaboration Extension and Reduction were perceived as being less successful, with ratings from 60% to 85%. The overall value of 89.33%, obtained by summarizing of the weighting of the measures, can be interpreted in straightforward way. It is that the SPIKE approach is adequate and fulfils most of business users' requirements that were indicated as being necessary. The applied technology of the Semantic Service Bus, together with the set of pre-defined ontologies, security infrastructure, and the other components that were implemented seem to support the collaborative processes within the network enterprise quite well. Lower evaluation results for the setup and adjustment to a collaboration initiative indicate, however, that there are some limitations in terms of configuration difficult, and the lack of flexibility and scalability of the SPIKE prototype.

The evaluation outcomes and findings are useful bases for evidence to identify improvements that may be needed to take SPIKE beyond the prototype level. Although the concept of semantically-supported service orchestration proved to be successful, and assessing its capability to facilitate the collaboration of enterprises in a business alliance, there were still plenty of functionalities requested by user partners. In particular, they suggested further improvements that should be included. They are: improved usability and intuitiveness of the user interface, easier adaptability and more flexible configuration mechanisms, open interfaces for external legacy applications, and integration of content management systems with a change management support.

Concerns related to the technology centered on the WSMO platform, which became obsolete; it needed to be replaced with OWL and RDF or other more widely-used semantic standards. The requirements of flexibility and scalability require an adaptable semantic representation, to support the adjustment of the structure of its knowledge in accordance with the continuously updated repository of documents and artefacts exchanged in the collaboration. The same principles of adaptability and standardization apply to business processes modelling tools. And, together with the related process execution engine, these should support the newest BPMN standard instead of BPEL, which is harder to implement for non-technical users. Modelling and configuration tools, as well as other types of end user console that are employed need to be more intuitive, simpler to use and easier to learn. To summarize, the SPIKE evaluation showed the importance of increasing usability, flexibility and adaptability when new enhancements of a software platform for networked enterprises are being made.

Use Cases	Measured	Weight	W(M)
Collaboration Setup	75,70%	20%	15,14%
Resource Management	92,50%	30%	27,75%
Collaboration Phase	99,80%	30%	29,94%
Adjust Collaboration	85,00%	10%	8,50%
Extend/Reduce Collaboration	60,00%	5%	3,00%
Finish Collaboration	100,00%	5%	5,00%
TOTAL:		100,00%	89,33%

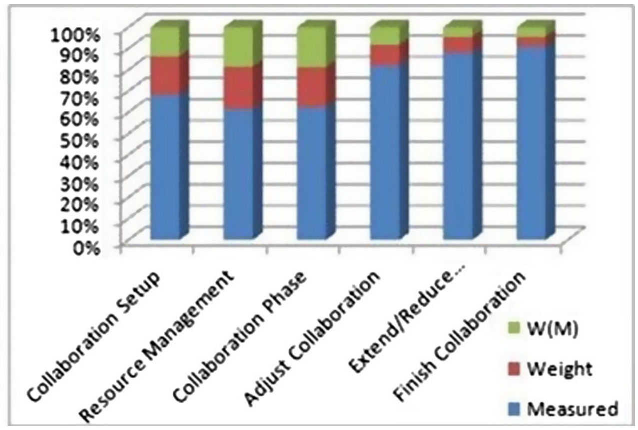

Fig. 6. Assessment results for the evaluation of the SPIKE system.

4. extensions toward interoperable data exchange in venis

The findings that emerged from the evaluation of the SPIKE prototype have been taken into account in the next EU R&D project, VENIS, which addresses the same capabilities of software platforms to support interoperable business alliances. The overall objective of the VENIS Project is to implement a light-weight platform, called the VENIS Services for the Interoperability of enterprises (VSI), which focuses on interoperability and collaborations between the LEs with rich IT ecosystems and SMEs with poor or missing IT infrastructure.

The list of challenges in Table 1 suggest that the solution offered by the VENIS platform has to be more adaptive relative to the existing IT and organizational status of both LEs and SMEs, while providing the right answers to the key requirements. The VENIS approach is based on the following kinds of actions:

- using existing services, to preserve past investments;
- connecting different enterprises through the use of data adaptors and distributed processes; and
- managing information exchanged through indexing, semantic search, and process synergy.

Table 1
LE and SME collaboration challenges and the VENIS approach.

Challenge	Solution	VENIS approach
Dispersion of exchanged information with the risk of data loss	Shared repository, able to keep track of the entire information exchanged	Shared virtual information space containing collaboration artefacts and working procedures. Notification service is included. (VENIS Virtual Common Repository layer)
Information exchange suffers from poor IT infrastructure of SMEs	User time required for interoperability mediation needs to be reduced	Semantic annotations are used to extract business objects and are used to provide a recommendation system reducing the time for manual interoperability mediation. (VENIS Distributed Data Sharing layer)
Manual handling of information in SMEs	Smart and user-friendly navigation in the exchanged data	Automatic extraction of information from collaboration artefacts – human readable textual data – for process recommendation and semantic search. (VENIS Distributed Data Sharing layer)
Difficulty to link LE working procedures with those in SMEs	Light-weight process support for SMEs facilitating actual work	Distributed event-based management of procedures for processes across LEs and SMEs. (VENIS Business Process Handler layer)

4.1. VSI architecture and interfaces

The high-level architecture of the VSI that is expected to satisfy the interoperability and collaboration needs between LEs and SMEs is shown in Fig. 7. The VSI, which is deployed as an instance of the VENIS system platform, and consists of three functional blocks. They are:

- *Legacy Application Adapters.* The data contained in the legacy applications (ERP, CRM, DMS, CMS, MRP, etc.) are stored in structured files with a proprietary format, database records, and human readable documents, among others. The adapters are software modules that able to retrieve and store data that go from and to the LEs legacy applications, and create human readable documents for the SME employee.
- *Repository Services.* Based on the Virtual Common Repository (VCR), these services allow sharing of files across VENIS users by means of upload and download capabilities, accompanied with Security Services for authorization, creation of tokens to access the files, and other activities. VCR is connected with external legacy applications, including ERP, CRM, DMS, CMS, MRP, etc., by a set of dedicated Adapters that enable the retrieval of data from and the storage of data to the LEs legacy applications. This enables them to create human-readable documents for SME employees. The invocation of Repository Services is moderated by the adapters and controlled by means of a user GUI.
- *Data Services.* Based on e-mail messages that are received, Data Services implement an interaction with an SME user. The Mail Transport Agent (MTA) module provides an e-mail handling facility to strip attachments and store them in the VCR, generating notifications for e-mail events, and so on. Indexing and retrieval of stored information is provided by the Search Engine module utilizing a light-weight semantic approach with free schema annotations and user tagging (Laclavik et al., 2012). The Data Service layer offers a web-based user interface, the

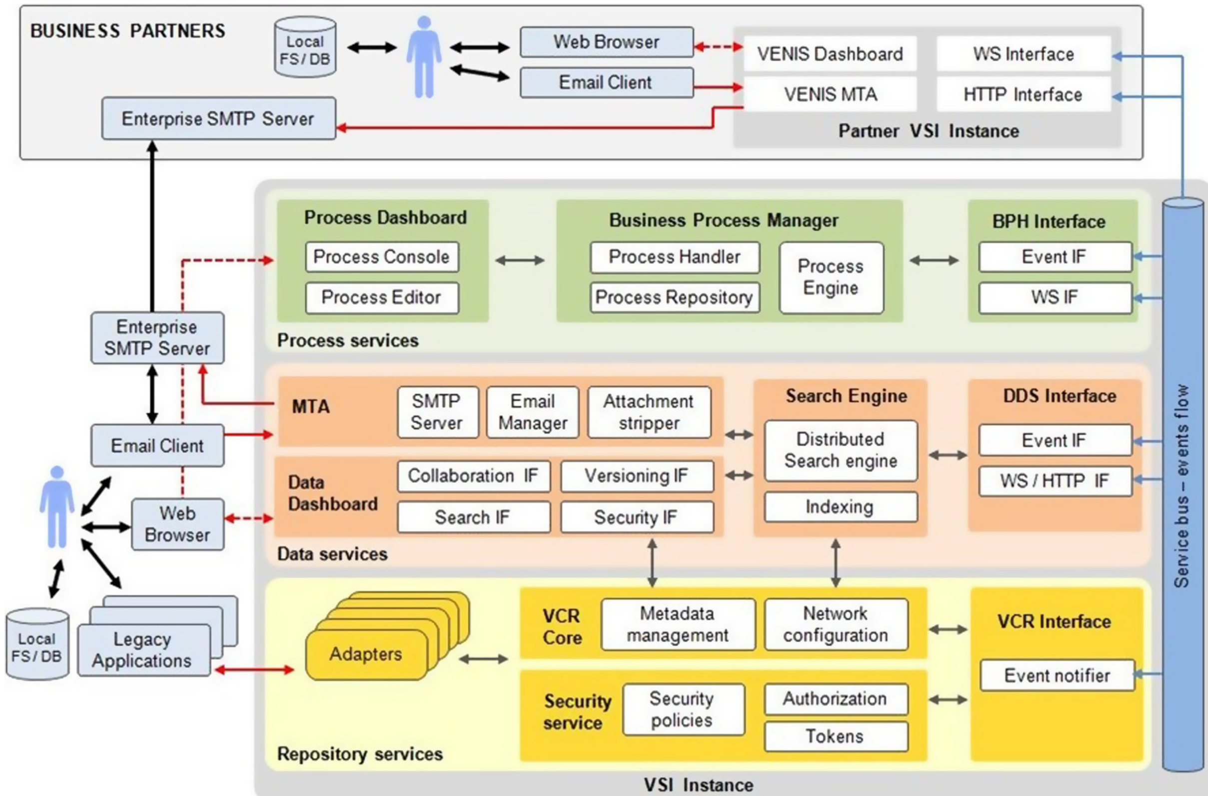

Fig. 7. VSI architecture and interfaces.

Data Dashboard, which enables users to interact with the inner VSI services and access shared information stored in the repository.

- *Process Services*. These support the modelling, configuration and execution of business procedures inside the VSI. The Business Process Manager is built on the jBPM core engine and is fully integrated with the data elements of VSI, such as stored documents, email messages, notifications or events. As such, the Process Services layer enables the system to define a standard BPMN 2.0 business process in which tasks, triggers, or other elements are dynamically connected with VSI data objects. During its execution, such a business process is capable of control and effectively managing collaboration and interoperable information exchange between LE and SME partners.

All three VSI layers are equipped with interfaces that are connected to the Service Bus. Similarly, as in the SPIKE system, the VSI Service Bus acts as a communication and messaging component that collects the events produced by the inner services of Repository, Data and Process layers, and creates a shared event flow so that events are routed and handled by any layer according to the principles of the publisher and subscriber model (Eugster, 2007).

In addition to that, VSI provides an external HTTP and web service interface which propagates the generated events to other VSI instances deployed on in the various LE and SME environments. This way, the VENIS system enables a network of VSI nodes to be establishr that mediate an interoperable connection with the Les' and SMEs' infrastructures. They include: SMTP e-mail servers, file systems, databases, and legacy applications. The VSI network is defined and configured autonomously on each of VSI instances by XML settings stored in VCR Core module of Repository services layer.

From the deployment point of view, a VSI instance can be installed both on LE and SME sides in order to support interoperability of information exchange and different levels of collaboration controlled by business process models defined inside the networked VSI. Other deployment schemes, where VSI is delivered by a VENIS system provider and configured individually for each of the collaboration partners, are possible as well.

4.2. Data interoperability in the VENIS Project

The VENIS system supports data elements such as e-mail messages with attachments and the most common formats of text-based documents (PDF, DOC, DOCX, and TXT files). Other types of information objects can be included by means of adapters to provide connectivity with data resources and legacy applications. Within the scope of VENIS Project, there are adapters for MySQL databases, XSL and XLSX files, the Liferay Portal, the Signavio process modeler, and the Seapine TestTrack: all of these have been developed. The kinds of data objects that are supported can then be stored in the VSI repository and are available to the members of VENIS collaboration based on appropriately defined security policy.

However, interoperability in VENIS goes beyond the compatibility of heterogeneous data objects at the technology level. Semantic interoperability is addressed by applying light-weight semantics based on tags or annotations, which has been successful on Web 2.0 and social network sites. The repository services of VSI enable attachment tags and metadata annotations to data objects and documents either manually or automatically via an annotation API using information extraction and automatic tagging methods, implemented as REST and SOAP services.

VENIS relies on light-weight semantics instead of more complex and formal models, such as EDI, CoreComponents or Semantic web standards. Simpler models such as annotations and graphs are a better choice in applications that include the involvement of users (Laclavik et al., 2011). The method VENIS uses is based on simple key-value pair annotations extracted from emails and attachments. They enable building trees of annotations that can be extracted from an email message or a document, and comparing them against connecting trees from multiple documents. This forms simple semantic networks suitable for visualization and search. Semantic trees are automatically transformed (Marin et al., 2011) to CoreComponent standard to achieve semantic interoperability. The problem has been that the CoreComponent XML that is generated was incomplete because of the use of automatic information extraction. In addition, it was difficult for SMEs to handle the CoreComponent documents. Pattern-based and gazetteer-based approaches for information extraction and existing tools such as GATE are used instead, and these have been tested in several enterprise use cases. The results of the testing suggest that customization can be accomplished in a reasonable amount of time (Laclavik et al., 2011), although involvement from human experts is still needed. In VENIS, we are able to deliver an information extraction mechanism so that the customization is accomplished by user interactions and learning (Dlugolinsky et al., 2012).

Users can interact with the VENIS network by means of standard email clients or via the Data Dashboard. This is a web-based console that offers a graphical user interface to enable uploads, downloads, semantic searched and other facilities for managing the VSI repository. Fig. 8 depicts two ways of user access to the information artefacts shared when collaboration occurs. Using the Data Dashboard, collaboration members can upload documents with supported formats into the shared space of the VSI repository, organize the documents into folders, annotate them with semantic metadata, and share the uploaded documents among selected partners within the collaboration. Moreover, data objects from external repositories, such as databases, file systems, or legacy applications connected to the VSI instance via respective adapters, are automatically uploaded to the repository and are available for further sharing. When such documents are marked as shared in the Data Dashboard, an e-mail message with a unique token is generated, so the document is accessible and ca be distributed to collaborating organizations.

The flows of documents and other shared data objects are controlled in VENIS by means of business process models that can be defined by the Process Dashboard module of the VSI Process Services layer. (See Fig. 7 again.) The process modeler, implemented as a customization of the jBPM 6.2 toolkit (www.jbpm.org), is integrated into the VSI web console and functionally connected with VCR, MTA, and other VSI modules.

Events, which can be generated by inner VSI components or received from networked VSI instances, are recognized by the Business Process Handler (BPH) interface, and then can serve as triggers for invoking business process tasks. An example of such an event-driven triggering is presented in Fig. 9, where the *newCollab* event fires the signal element. Consequently, if this type of event is received during the process run, the task of notifying collaboration members is executed.

Tasks, as basic elements of a business process model, can handle all types of data objects stored in repositories of networked VSI instances. For example, the process model tasks can be defined as directives for sending some documents to users via email, as requests for uploads or data to the shared repository, as requirements of some, even offline activities, and so on. This way, the embedded process model, together with semantic search and other VENIS system capabilities, enables managing partial sequences of tasks or, if needed, the whole life cycle of the networked enterprise

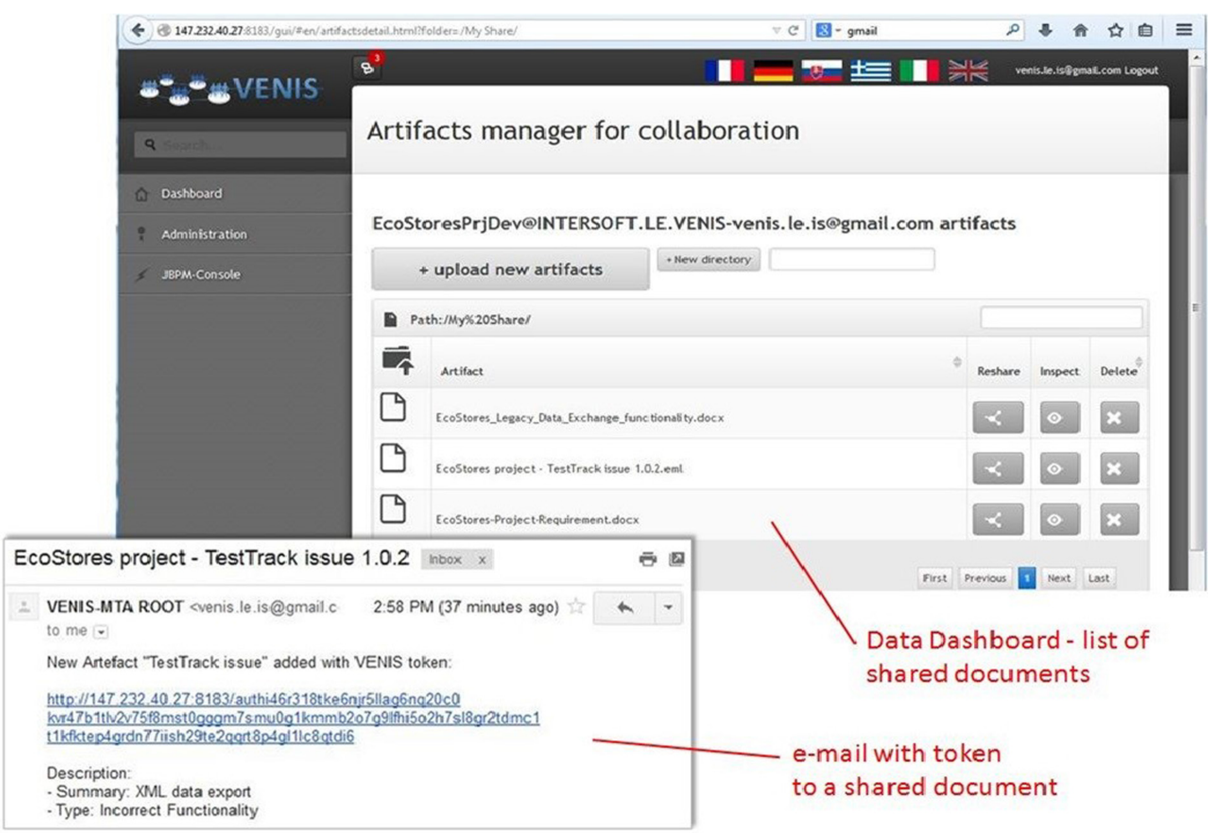

Fig. 8. Accessing documents by e-mail token and from the data dashboard.

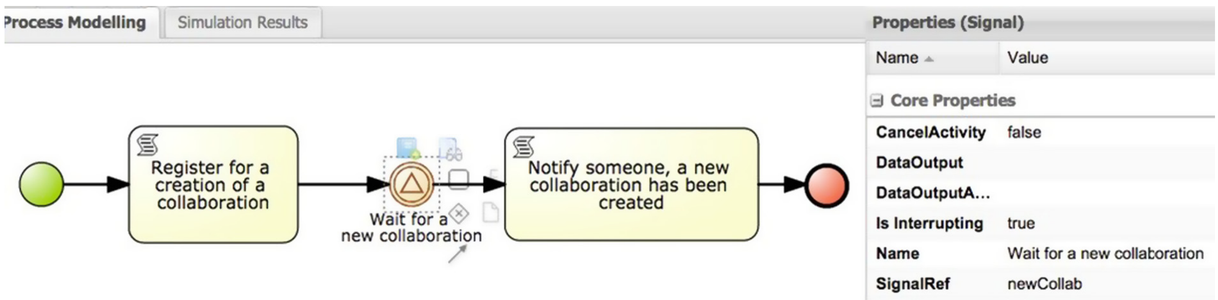

Fig. 9. A process model fragment: triggering tasks by an event.

collaboration. In the latter case, heterogeneous information resources are provided to collaborating organizations in a uniform and interoperable way.

4.3. Pilot testing and evaluation

The prototype of the VENIS system was completed in May 2015. After that, the system was installed on the premises of three project user partners, where it was configured and deployed for application case testing and evaluation. These application cases were based on typical business activities performed by the VENIS participant enterprises, with the aim of identifying potential future markets for commercial exploitation of the VENIS system and its related services.

The first application case, supervised by the Engineering Ingegneria Informatica S.p.A., Italy, concerns the development process of a new product. In particular, the application context refers to the management of an integrated CAD-CAE design process in the aerospace domain. The collaboration includes the prime Contractor (an LE) with its legacy system (Liferay Portal, www.liferay.com), a Partner enterprise (LE and SME) responsible for product development management, and a Supplier (an SME) that provides the design and optimization tasks. The network of VSI instances was configured for connections via adapters to Liferay Portal, to a proprietary process modeler based on Signavio (www.signavio.com) and used by the Partner, to local file systems and SMTP e-mail servers of each collaborating participant. In order to enhance the usability, the VSI Data Dashboard portlets were customized and integrated into the Liferay portal of the prime Contractor. By means of VSI semantic search and attribute matching, the most suitable supplier was identified from a set of available candidate profiles.

Then the contract between the parties was prepared with the help of the VSI repository and dashboard interface, while the related e-mail communication were mediated by the VENIS platform as well. The process model for the product development activities was prepared by the enterprise Partner in its Signavio-based modeler using standard BPMN 2.0 notation. This was exported to the VSI Process Dashboard, and enhanced based on VSI-specific events and data artefacts stored in the VSI repository. The collaboration, moderated by the VENIS platform, lasted four weeks and resulted in the CAD design of a product in line with the contract. The users who were involved appreciated the integration of the VENIS system with the required legacy applications, as well as the efficient communication and exchange of documents, which was provided by the VSI network.

The second application case, which addressed the supply chain process between SMEs and LEs, was conducted by Link Technologies, Greece. The VSI network infrastructure was installed for testing a scenario for the Request for Quotation (RFQ) process between the Public Bus Transport provider of Thessaloniki (LE) and a local service Supplier (SME). The Public Bus Transport service provider has a staff of over 3500 employees operating a fleet of 700 vehicles. They have various requirements on a daily basis so the fleet can provide a premium service to the community. In order to do this, they require specialist services and equipment to keep the fleet running. They run a customized ERP system that was developed specifically for LE, which incorporates their payroll and ordering system. The service provider SME supplies IT and telematics software and hardware to the LE as well as staff when required so as to fulfil the needs of their control room staffing requirements. The VENIS test case was prepared to support the LE and SME collaboration for the process of getting quotes and orders. The RFQ documents, generated from the LEs ERP system, are automatically uploaded to the VSI repository. The pre-defined VSI process model controls the flow of tasks, starting with an invitation to prospective companies (SMEs) to give quotes on the required parts stated within the RFQ. The RFQ is shared with the invited SME so that it can update the RFQ with the details required and then send it back to the LE via VENIS with proper notification. This application case focused on manipulating versions of various file formats (Excel files for the RFQs, PDF and Word documents for technical specifications or requirements) that were produced and consumed by the inner legacy applications of the collaborating organizations.

Finally, the third application case addresses supply chain aspects related to software development and maintenance. The related VSI network depicted in Fig. 10 has been installed on the premises of InterSoft, a.s., Slovakia, and supported by the Technical University of Kosice and the Institute of Informatics at the Slovak Academy of Sciences.

The application case models inter-enterprise communication between companies involved in a common software development project. The Customer (LE) requests an extension of its existing point-of-sales system via e-mail and asks the Provider (LE and SME) for the software solution. The Provider searches in the VSI repository for profiles of suitable supplier candidates and, using the semantic search facility of VENIS, it selects the Supplier (SME). The Supplier is invited into an established collaboration and its VSI instance is connected to the network. The contract and project details are negotiated by e-mail communication, which is moderated by the underlying VENIS system. As a result, the e-mail messages and attachments are automatically indexed and stored in the VCR repositories for all of the networked VSI instances, which enables semantic searching over sent and received messages and attached artefacts for all the involved parties. Based on the contract that is agreed upon, the Provider prepares a business process model in its VSI Process Dashboard. The Seapine TestTrack (www.seapine.com/testtrack) environment is established on the Providers side to manage the software development cycle. And then, manipulation with TestTrack generates events that are connected with the signal elements of the process model. For example, Fig. 11 presents such a connection for uploading a new version of a software component specification

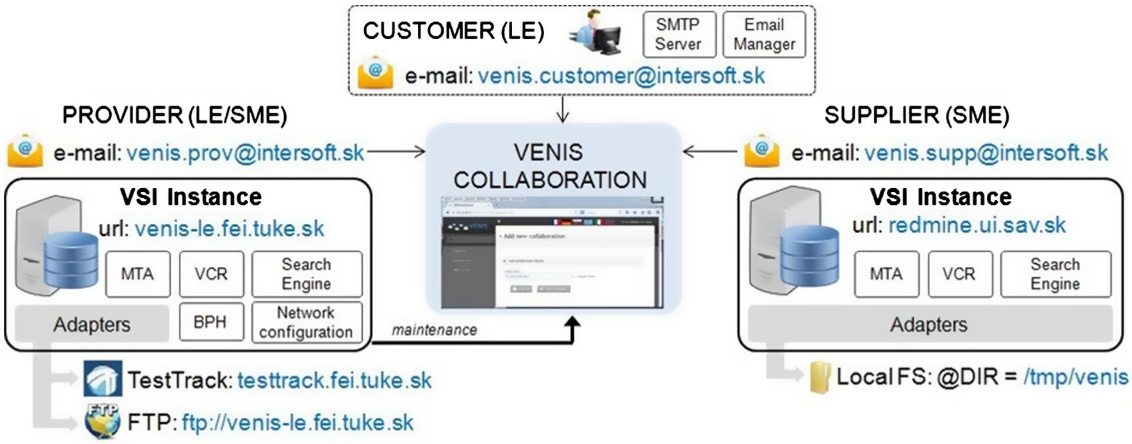

Fig. 10. Installation schema for the software development application case.

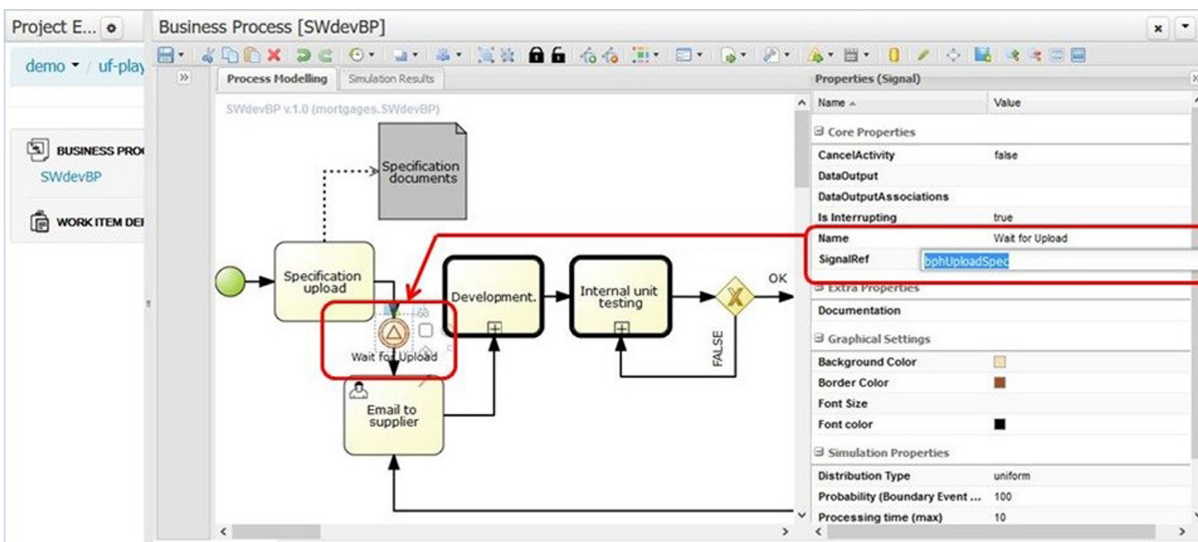

Fig. 11. The TestTrack event "Upload Specification" triggering process model tasks.

into TestTrack, which triggers the Development and Internal unit testing sub-processes.

The VENIS platform enables a flexible VSI network extension. For example, the Supplier can sub-contract other supplier partners for partial tasks and extend the collaboration by connecting more VSI instances to the network. The Customer does not need to have the VSI instance installed; its involvement in the collaboration is handled solely by registering its e-mail addresses and SMTP servers in the MTA of the root VSI instance. This way, the Customer can supervise product construction and delivery while the software development work is continuously maintained by means of the VSI network.

In the three application cases, we demonstrated that the VENIS system is capable of facilitating communication within LE and SME business collaborations of various types. It supports email exchange, storage and sharing of documents and other information artefacts produced within connected legacy applications, as well as overall project maintenance.

Broader investigation of the pilot outcomes occurred for the testing of the application cases. We designed and implemented an evaluation procedure within the VENIS Project that was intended to specify indicators for system improvements, in accordance with the USE Questionnaire (Lund, 2001) and the IT Infrastructure Library's methods (ITIL, 2014). The survey evaluation form was prepared to measure parameters such as performance, scalability, usability, and usefulness in terms of the benefits, user satisfaction, ease of learning and use, security, reliability, and the overall business applicability of the VENIS system. The online evaluation questionnaire covered all phases of the VENIS software installation. The phases included configuration, deployment, and daily operation for the main operator roles. (1) The *technical system administrator* is responsible for the installation, configuration, deployment, and daily operational technical maintenance of the VSI network. (2) The *collaboration owner and administrator* uses the Data Dashboard web interface to perform the actions needed for setup and maintenance of the collaborations and their participants, the handling of the VCR repository, and the business process models. (3) The new *collaboration member* participates in an established VENIS collaboration. This user role has controlled read-and-write access to the shared space of artefacts by means of token links, *t*, and is notified about the required tasks specified in the business process models or by the owner's commands.

Questions in the evaluation survey for the operator roles cover the quantitative dimensions of collaboration (the number of collaborations created, users invited, email notifications, and artefacts received via token links, as well as the complexity of the business process models) and the qualitative dimensions of usability (the degree of intuitiveness and ease of use, security level, the reduction of time and resources consumed, and so on). The qualitative parameters were investigated related to the support features and actions performed by each of the operator roles. For example, technical administrators had to evaluate the installation, configuration, deployment, and operational maintenance procedures; collaboration owners also had to answer questions on the collaboration set up, user friendliness and functionality of Data Dashboard interface; and the collaboration members had to evaluate communication and data exchange performance, navigation and user interface quality, as well as perceptions about the security, usefulness and overall satisfaction with respect to the VENIS system.

The evaluation of all three pilot cases started in June 2015 and lasted five weeks. Ten to fifteen evaluators participated in the survey for each of application cases and operator roles. A complete report of the evaluation procedure and the analysis of obtained results was published as a project deliverable in Seleng et al. (2015). For example, the business applicability of VENIS was estimated with five indicators evaluated on a 1–5 scale. (See Fig. 12.)

Average values for the collaboration Owner (left) and the collaboration Member (right) are presented for different application cases: (1) the development of new CAD design product (blue); (2) outsourced software development (green); and (3) supply chain collaboration for public bus transport (red).

The results of the surveys point to the users' positive experience with the VSI User Interface for the navigation and maintenance of collaborations. The Data Dashboard was fairly intuitive, easy to use and simple to maintain for the users. There also was positive sentiment expressed toward security and usefulness, however, more operational support was viewed as necessary, for example, through the provision of helpdesk facilities. In general, the results indicated that, on the user level, the feedback was positive and showed the VENIS system had a positive impact on business as a whole. The respondents noted that they had an easier and better experience when using the VENIS system, as opposed to when the VSI network was not yet installed. The time and effort needed for establishing and maintaining collaborations were reduced by about 30%. From the perspective of the members of the collaboration, there was satisfaction overall with the communication and information exchange too. Users evaluated that there was a need for minimal or no change in the SME's working environment, which is achieved by e-mail based communication and interoperable connections between existing data sources and legacy applications.

5. Related issues

5.1. Interoperability

One of the main technical requirements for networked enterprises is the overall *web services interoperability*. This is defined by Oracle (2015) as the ability of heterogeneous business applications to smoothly work together. In order to employ an infrastructure supporting interoperability between networked organizations, business partners are required to formally specify their workflow structures and model the flow of processes, tasks, actions and messages between various applications. This workflow modelling process is now supported mostly by the BPMN 2.0 standard of the Object Management Group (OMG, www.bpmn.org).

To support the loose coupling of software components deployed on different sites across the operations of networked enterprises, ESB was introduced as an SOA-based architecture model. It routes messages in service exchanges, resolves connections between communicating nodes and controls their deployment.

The BPMN standard and ESB technology focus on the syntactic specification of workflow structures and services. Extensions of the core ESB technology to support the integration of services based on meaning has been challenged by Karastoyanova et al. (2007) though. The Semantic Service Bus that facilitates the lifecycle of semantic web services is presented by Roa-Valverde and Aldana-Montes (2008). In more recent work, Diop et al. (2012) have proposed the ideas of an Automatic Service Bus (ASB) that takes into account not only functional requirements, but also non-functional quality of service (QoS) aspects. They include such things as availability and response time, among others, in a dynamic, autonomous way.

5.2. Supply chain management

According to Mentzer et al. (2007), a *supply chain* is defined as a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances and information from a source to a customer. *Supply chain management* is defined as the design, planning, execution, control and monitoring of supply chain activities with the objective of creating net value, building a competitive infrastructure, leveraging worldwide logistics, synchronizing supply with demand, and measuring performance globally (SCM APICS, 2015).

Supply chain management has become standardized by the *supply chain operations reference* (SCOR) *model* (Stewart, 1997). It provides a cross-industry framework describing standard process definitions, terminology and metrics. By defining a common lan-

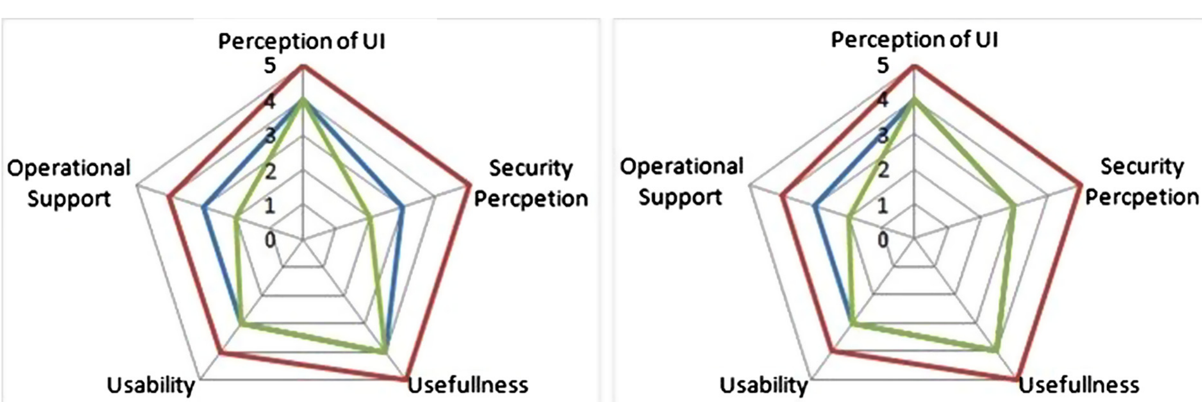

Fig. 12. Evaluation results for the business applicability indicators.

guage, SCOR has become useful for describing value chains across multiple organizations.

Interoperability issues in supply chain management systems also have been studied by many authors. For example, the semantic inconsistencies of the SCOR model have been resolved by SCOR-Full ontology developed by Zdravkovic et al. (2011). Also, Lu et al. (2010) have proposed a supply chain ontology-based architecture for networked enterprise interoperability. It concerns not only product life cycle, but also product sales, marketing, customer activities, and organizational structure.

5.3. Semantic business processes

The theory of semantic models provides a unified view of intraorganizational processes, and was developed by Hepp et al. (2005). Within the EU-funded research project, SUPER, enhancements to existing business process modelling solutions have been developed to achieve more flexible and manageable business processes. An overview of the complete ontology stack developed by the SUPER Project is provided by Pedrinaci et al. (2008). A case study, accompanied by the architectural design of the system applies semantic business process modelling in a domain of supply chain management, is presented by Ferrandiz-Colmeiro et al. (2010).

5.4. Advances of SPIKE and VENIS toward solutions

The main accomplishment of the SPIKE Project in comparison with other similar approaches is its application focus, which was determined in consultation with three different industry partners. The broad scope of application had a deep influence on the technologies used during the prototype's development. The concept of a Semantic Service Bus was adopted by employing the SA-WSDL semantic layer on the top of the well-known industry standards for web services. Dynamic service binding and semantic service orchestration are important extensions of previous WSMO-based solutions to support the interoperable connections for various applications that are on the side of collaboration partners. The Liferay portal technology ensures integration on the user interface-level, which together with the developed modules of security and events flow management, supports features such as single sign-on and federated identities. In addition to these technological advances, the SPIKE Project developed a set of methods guidelines providing a list of best practices and know-how for potential adopters of technology, so they can overcome the initial phases of setting up short-term alliances.

The solution that the VENIS Project produced builds on concepts such as ESB, the controlled flow of events, interoperability supported by semantic web services, and semantically-enhanced process models for supply chain workflows. The shift is in the replacement of the relatively static WSMO-based knowledge structures with the light-weight semantic approach of semi-automatic knowledge extraction, which increases the flexibility and adaptability of the solution. Further, VENIS is specifically focused on LE and SME collaboration. From this perspective, it provides native support for e-mail communication, token-based security, a set of adapters for the most common data repositories, information systems and legal applications.

As of 2016, there are several types of collaborative platforms available on the market. For example, there are cloud-based platforms for sharing services and resources: iCloud, Dropbox, OneDrive, and others. There also are solutions supporting the exchange of files: LinShare, AdroitLogic, SparkleShare, and so on. There also are process management frameworks, such as ProcessMaker, Intalio, jSonic, and Activiti, among others. Most of these platforms can be configured according to the needs of a single organization. As well, their common characteristic is that they are monolithic: they do not easily support the interoperability between solutions from different vendors. In fact, the decision about which of the commercial solutions mostly means that an organization will be forced to commit to specific software for infrastructure or operating systems. This often is a major problem for establishing a *trans*-enterprise collaboration platform. In addition, none of the commercial systems offers open source capabilities.

Many commercial products have been presented to the market and claim to support enterprise interoperability, but none fully matches both the key requirements from LEs and SMEs. They must be flexible enough to be adopted by LEs on top of their legacy infrastructures. At the same time, they also have to be easy to deploy, simple to use, have an open source implementation, and be cheap enough to be adopted by SMEs. VENIS overcomes these difficulties due to its modular service-oriented approach, which enables an interoperable combination of heterogeneous services from different providers and legacy applications, by means of open and standardized web service interfaces.

The virtual repository stores and retrieves multi-partners' activities and documents. This approach guarantees that all partners are able to access the correct and the latest information, decreasing the necessary communication effort. The main innovation of the VENIS virtual repository is its distributed nature and token-based authentication. Existing legacy systems are integrated, and exploit a formal interface with the virtual repository, while standard inter-SMEs communications can be used and enriched to convey authentication grants among partners.

The data services extend the existing distributed search framework with the authentication model of VENIS and dynamic peer-to-peer interactions. Access to the content of shared documents is mediated by virtual repository services allowing data services to abstract from a specific legacy system used to manage enterprise information. The light-weight semantic is employed to achieve semi-automatic discovery of relevant documents and business objects generated by legacy systems. Authentication tokens play a key role in data services interoperations. Each token is received in an e-mail message, and represents a unique authorization granting access to a partner VCR. Data services use this information to build, at run-time, a collaboration network between the authorized business partners. The dynamic collaboration network is a key requirement for an interorganizational search and authentication engine, since relations may change rapidly in the networked enterprise environment.

The process services integrate the business process engine with the collaboration systems used by enterprises. This integration enables the firing of business activities and the invocation of proper procedures when the events occur, such as the distribution of a new document version released by a partner, the receipt or dispatch of e-mail messages, as well as events generated related to changes in the collaboration network. Thanks to the jBPM framework, VENIS allows enterprises to take full control of their collaborative activities and evaluate their performance by means of built-in process mining tools.

6. Practical implications

6.1. Impact on enterprises competitiveness

In a changing world, the strategy of a country is to become a smart, sustainable and inclusive economy. These three priorities should help to deliver high levels of employment, productivity and social cohesion.

SMEs and their collaboration with large enterprises are very important. As shown in European Commission (2010b), SMEs make up some two-thirds of industry employment and a large share of EU industry's growth and jobs potential is to be found in its lively and dynamic SMEs. Promoting the creation, growth and internationalization of SMEs thus has to be at the core of the new EU integrated industrial policy.

To meet their business objectives, enterprises need to collaborate with other enterprises. SMEs that need to specialize in niche activities to increase their added value have to combine forces with others to compete effectively in the market. Today, enterprise competitiveness is determined to a large extent by their ability to seamlessly interoperate with others. The SPIKE and VENIS projects view interoperability as *utility-like capabilities* for enterprises, as we showed related to their pilot applications.

Today, specialized SMEs and LEs are seeking solutions that enable them to cooperate and establish networks through which they can offer complementary services to stay competitive in international markets. The only way for SMEs to innovate is to leverage their collaboration with other LEs. This is necessary, especially for firms that are not high-tech and struggle to innovate on their own. In this context, ICTs are key enablers for creating strong and continuous collaborations between SMEs and LEs. So industry is increasingly in need of open and interoperable solutions t across all multiple sectors (European Commission, 2010a), and enterprise interoperability is an emerging need for joint projects and business that facing new market challenges.

Consistent with this, the SPIKE and VENIS Projects developed a new level of interoperability between large and small enterprises, based on the virtual enterprise paradigm. The results increased the competitiveness of the enterprises. Clusters and networks improved industrial competitiveness and innovation by bringing together resources and expertise, and promoting cooperation among businesses, public authorities and universities.

Sustainable growth can be achieved by supporting enterprises in their adoption of *a global value network model* and use of new technology solutions to reduce costs, optimize resource use, and make production processes more efficient. Based on the pilot applications, we evaluated how the results of the projects supported the competitiveness of the enterprises by fostering knowledge and competency sharing, and by promoting innovation through the injection of novel IT knowledge into the legacy systems used for collaboration among the LEs and SMEs. We assessed: (1) support for enterprise competitiveness, based on how knowledge and competencies are joined, and improved interoperability and collaboration among SMEs; (2) increased business opportunities and reduced product costs; (3) innovations that resulted based on the injection of novel IT knowledge – especially via the CWE, SOA and WST technologies – beyond the legacy systems of the LEs and SMEs; and (4) how the way toward fuller industry interoperability was paved, and the direct impacts occurred application areas such as communication and transport, among others.

6.2. On the impact of the future Internet

The Internet will drive positive changes in the future. Innovative forms of online cooperation will result in more efficient governments, businesses and not-for-profit institutions. Internet technologies, systems and services can create real value and generate new business opportunities, through increased online cooperation. The means are already there, and will only become more numerous and functional.

Following the European Commission (2010c), we view the Internet as a strategic opportunity that will support the next generation of Enterprise Software Applications. For example, according to Future Internet (2014b), in the sphere of the enterprise, the migration of business toward innovative virtual enterprises is continuing, and also transforming the roles of customers and employees, providing opportunities to exploit networked knowledge through open innovation and collaboration.

Our results are consistent with opportunities related to the Internet in the future. The solutions we have offered address the virtual enterprise concept by providing interoperability through merge the data and processes of different-sized companies into a single *virtual organization*. They also suggest the promise of a dynamic and open environment, supporting interoperability between SMEs and LEs, by supporting the design and development of a collaboration approach that is able to bridge the gap between the needs of companies of different sizes. We developed an innovative platform, tailored for LE and SME interoperability to provide a set of services focused on their collaboration through technological support.

Through the platform, the interoperability functions are delivered as services, and expected to be modular, cheap, fast, reliable, and without major additional integration effort needed. Interoperability becomes a routine, and not a problem. The platform acts as a transparent and invisible infrastructure for the business operation. The services are simpler to use, adaptable to dynamic needs, affordable for organizations with small budgets, and have the required technical attributes of accessibility, reliability and interoperability.

The future of the Internet involves networked innovation, data and interactions, and other forms of augmentation, and provides a foundation for transforming industries and addressing important social challenges. Consistent with views expressed in the report on the Future Internet (2014a), we implemented and evaluated a set of services based on: (1) an ability to unify the scattered information of the enterprises; (2) distributed data sharing, offering a smart mechanism for the exchange of the distributed data; and (3) business process handling, offering an interactive assistant for joint projects and business, where the information is automatically collected, merged and served to enterprises users.

A practical implication of our solution is the creation of a *trans-enterprise collaboration environment* by the combination of different services, relationships and dependencies. This becomes as easy as the creation of a spreadsheet, based on the combination of different services (as the cells) and the various dependencies (as the functions).

6.3. Impacts on companies based on new models of interaction

The new technologies, connected with the Internet of the future, enable this new collaborative vision, and contribute effectively to building up a novel level of interoperability between the LEs and the huge number of SMEs. Both LEs and SMEs suffer from the lack of a collaboration environment that able to enhance their interoperability at the knowledge and process levels. They can use this to achieve: (1) synergy in technological research, by covering gaps and creating complementary capabilities; (2) the joint development of products, by merging new or already existing solutions; (3) joint manufacturing and the operation of the related supply chains; and (4) common businesses, with phased marketing efforts and new customer identification over time.

With reference to these assumptions, stakeholders can take advantage of our results, and collaborate with their partners in the management of business processes. This applies to large multinationals and also small enterprises with their suppliers and partners, as well as single users. This will be possible through the services offered by the project, and our effort to find innovative solutions to create new types of interoperability with minimal impact on the organizations' information systems. The services that we introduced and the platform we demonstrated can be applied within different models of company interactions that produce different forms of competitive advantage. VENIS encourages enterprises to be more community-oriented in their innovation, organization, production and business partnerships, and it lays the groundwork for the *network as the enterprise* (European Commission, 2011). So the establishment of new forms of collaboration, the creation of new business networks and the rise of the knowledge interoperability appear to be developmental keys for the future.

We would like to suggest a further category of *actors*. They can be *indirect stakeholders*, who contribute indirectly to the project results, or *direct stakeholders*. In this new category, companies may gain profits from interacting with others organizations without entering the network itself. They can make an outside contribution that is complementary to the main objectives of both projects. They can create and benefit from new forms of network interoperability, because their aim is to identify new market segments in which to invest. Consider the interest of large IT companies such as Google, which may from interacting with organizations in different business networks through interfaces between the products and systems services offered. An example that comes to mind is the use of Google Docs for document-sharing services offered by the platform. There may be an opportunity for the indirect stakeholders to increase their earnings, and also to lend a hand with making improvements to the services offered by our solution.

7. Conclusions

The software solutions discussed in this article were developed within the European research projects, SPIKE and VENIS. The experience that we took away from the research indicates that the combination of semantic web services, business process models, and service bus mechanisms offers a suitable technology platform for the IT infrastructure of business alliances. Regarding the underlying semantic models, the light-weight approach with semi-automatic ad hoc construction of a knowledge base, free schema annotations and user tagging (Laclavik et al., 2012) proved to be more advantageous than static semantic models, with respect to the flexibility and adaptability of business collaborations. ESB technology was applied in both of the solutions that were implemented, and was essential for the interoperable handling of services, events, and the data resources provided and consumed by the business alliance participants. The approach employed in VENIS was based on RESTful web services. It provided functionality comparable with the SA-WSDL and WSMO platforms used in SPIKE. However, the REST and SOAP-based web service interfaces are better supported now: they enable adaptation and inclusion of a broader set of external data repositories, information systems and legacy applications. A similar situation has developed is in the field of business process modelling. BPMN 2.0 frameworks such as jBPM are more progressive than these built on the BPEL and BPMO standards of the past.

The implemented prototypes of both the SPIKE and VENIS systems have been tested on a series of pilot applications and deployed in industry environments involving aerospatial CAD and CAE design, documentation services, IT systems development, and public transportation services. The evaluation results presented in this article demonstrate the acceptance by users of the technology that was provided. The SPIKE evaluators appreciated the support for the inner collaboration phases, while the setup and re-configuration of collaborations were perceived as somewhat less successful. In VENIS, the intuitiveness of the user interface was rated as being highly positive, along with security, usefulness, and general usability. There still is room for further improvements though: in operational support, which includes assistance during system reconfiguration, regular maintenance and adaptation of collaborations to new requirements.

From the business perspective, an important outcome of our evaluation of the VENIS system is that the prototype we tested helped to reduce the time and effort needed for managing the business collaborations by about 30%. It indicates good business applicability and how systems supporting networked enterprises in various domains of services and industry can create value. Further research i should focus on enhancements to reliability, scalability, and performance. These can be investigated by applying software systems for business collaboration networks in large-scale industry environments.

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