Enabling Collaboration in Virtual Manufacturing Enterprises with Cloud Computing

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ABSTRACT

In our globalized world, in particular Small and Medium Enterprises of the manufacturing domain face serious challenges, such as constantly shorter product life cycles and strong competition with companies from low-cost countries. To remain competitive in this environment, efficient collaboration with partner enterprises is a necessity. Virtual Manufacturing Enterprises are a viable means to realize such collaboration, but usually require expert knowledge for developing and maintaining a suitable infrastructure for all partners. In this paper, we present a generic Information Technology (IT) architecture for realizing Virtual Manufacturing Enterprises. Further, we show how cloud computing can be employed and integrated to enable efficient data provisioning as basic building block for collaboration in Virtual Manufacturing Enterprises. With the proposed architecture and technologies, Small and Medium Enterprises are capable to easily form Virtual Manufacturing Enterprises, and hence, are enabled to quickly react to changing market requirements and increase their competiveness.

Keywords

Virtual manufacturing enterprise, architecture, cloud computing, cloud storage.

INTRODUCTION

Global competition has brought various changes to manufacturing companies, for example, shorter product life cycles, advanced process technologies, customers who demand low costs, quick response times, and a higher degree of customization at the same time. To remain competitive, companies have to cope with these challenges effectively (Dowlatshahi and Cao, 2006).

Agile Manufacturing (AM) (Yusuf, Sarhadi and Gunasekaran, 1999) is a popular concept to address the mentioned challenges and achieve competitive advantages required by SMEs. Yusuf et al. defined *agility* as "[…] the successful exploration of competitive bases (speed, flexibility, innovation proactivity, quality and profitability) through the integration of reconfigurable resources and best practices in a knowledge-rich environment to provide customer-driven products and services in a fast changing market environment" (Yusuf et al., 1999). In contrast to flexible manufacturing, which focuses on rapidly setting up a manufacturing system for producing different products, AM focuses on setting up whole organizations for production (Jain, 1995).

"Virtual Manufacturing Enterprise" (VME) is a core concept to achieve AM (Jain, 1995; Yusuf et al., 1999).[1] VMEs are created by two or more companies to address specific market opportunities (Park and Favrel, 1999). They enable organizations to work together in a collaborative manner and share processes across organizational boundaries (Ayyagari, Beck, and Demirguc-Kunt, 2007; Martinez, Fouletier, Park, and Favrel 2001; Schulte, Schuller, Steinmetz, and Abels 2012). Thus, the collaborating organizations benefit by sharing costs, skills, and core competencies to provide sophisticated products that individual companies are not able to develop and produce efficiently. Thereby, VMEs close the gap between big enterprises, which are powerful but slow in reaction, and small enterprises, which are rather weak but possess a strong ability to react on changes of market circumstances (Park and Favrel, 1999).

One of the core elements behind VMEs is Information and Communication Technology (ICT) (Faisst, 1997). Barba-Sánchez et al. identified several benefits for SMEs using ICT, e.g., higher productivity and effectiveness, possibilities to deploy new organizational, strategic, and managerial models, access new markets, and improved collaborations of locally dispersed partners. Because of the limited knowledge regarding ICT and the benefits arising by the use of it, provided solutions for SMEs need to be simple to use, reliable, and easy to integrate regarding the activities of SMEs (Barba-Sánchez, Pilar Martínez-Ruiz and Jiménez-Zarco, 2007).

Besides the organizational changes from traditional to agile and virtual enterprises, the underlying ICT structures have to change as well, because common systems do not provide the required flexibility. Corresponding IT structures should offer a high level of interoperability between organizations for a seamless integration of the business processes of the collaborating partners (Martinez et al., 2001). The ICT has to provide real-time communication to collect current information about manufacturing processes (Martinez et al., 2001). In VMEs, activities, procedures, and interfaces have to be defined precisely. To react quickly to changing circumstances, already established processes must be flexible and offer the possibility to exchange partners when needed (Martinez et al., 2001). Further, there must be mechanisms to monitor, control, and evaluate the business process performance as well as the ability to re-engineer business processes if required (Ayyagari, Beck, and Demirguc-Kunt, 2007).

Because SMEs will not be able to accomplish ICT investments in the same order like large companies, an ICT environment is needed, which is easy to implement with reasonable costs and thus reflects the usually lower budget for IT investments of SMEs. To achieve this, we propose a corresponding ICT architecture for efficient collaboration in VMEs. For the establishment of a common data base with easy access within a VME, we suggest to use cloud computing. Two of the main advantages of cloud computing to be exploited in the considered context are cost reduction and the billing in a pay-per-use manner (Buyya, Yeo and Venugopal, 2008; Vaquero, Rodero-Merino, Caceres and Lindner, 2008). Another main advantage to be exploited is the flexibility and variable amount of the provided resources. If more resources are required, they can be accessed on demand and released in case they are not needed anymore (Armbrust, Fox, Griffith, Joseph, Katz, Konwinski, Lee, Patterson, Rabkin, Stoica and Zaharia, 2010). Thus, the IT infrastructure can grow or shrink according to the business needs. Cloud computing also allows the access to IT services, for example software services, independent of the location of the user and eases the collaboration between companies (Hayes, 2008). Consequently, one focus of the work at hand is the description of a Cloud-based storage approach for efficient data storage in VMEs.

The paper proceeds as follows: In the next section, we present our approach for an ICT architecture for VMEs that supports SMEs in the manufacturing domain. Subsequently, we elaborate on possibilities of how to employ cloud computing as a central means for efficient data provisioning in a VME and its integration within our VME architecture. Afterwards, we present an overview on related work and finally provide conclusions and an outlook on future work.

VIRTUAL MANUFACTURING ENTERPRISE ARCHITECTURE

This section describes our proposed architecture model, which copes with different requirements of VMEs as described in (ADVENTURE Project Team, 2012). Before explaining the architecture components in more detail, we give an exemplary overview on how a VME establishment can be realized to clarify the interaction and the functionality of the components in practice.

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[1] In literature, VMEs are sometimes denoted as "Virtual Enterprises" (Martinez et al., 2001; Yusuf et al., 1999), "Virtual Manufacturing Enterprise" (Hardwick and Spooner, 1995), or "Virtual Factory" (Jain, 1995). Due to our focus on manufacturing, we use the term "Virtual Manufacturing Enterprise" (VME).

Exemplary Virtual Manufacturing Enterprise Workflow

The following example illustrates the handling of a customer order for production of a new machine from scratch in a VME environment. It highlights at which points the different components of our developed architecture come into play.

At the beginning of our exemplified and simplified workflow (cf. Figure 1), a customer orders a machine by entering all required specifications and sending the information to a manufacturer. This information is stored in a Cloud-based data store (the Cloud Storage component). All the following steps employing data provisioning and data storage make use of this Cloud Storage. After the order is entered completely, it is shown within the Dashboard component of the involved manufacturing company. At this point, a broker designs and enters a new process model to manufacture the requested machine with the help of an integrated Process Designer component, again storing the result in the Cloud Storage. Afterwards, the creation of a new process can start. First of all, partners for all described process steps and activities are needed. Corresponding partner data is accessible via a Data Provisioning and Discovery component. After having specified appropriate partners, a Forecasting & Simulation component evaluates the partners. On the one hand, the partner assessment can be based on stored historical information; on the other hand, it can base on actual data from partners' ERP systems. In the latter case, the required data exchange takes place by using Gateways to connect partners' legacy systems. Regarding the forecasting and simulation results, an Optimization component calculates an invocation plan with a mathematically optimal set of partners. Finally, the broker decides whether the proposed combination of partners should be used or not. After the final partner combination has been chosen, the process will be executed by the Process Execution component.

If there is no disruption encountered during the process execution, like a supplier not being able to deliver, the process keeps running continuously. However, a means to detect potential disruptions is the integration of Smart Objects. Such objects can, for example, monitor the state of machines and communicate status information to the VME via a Smart Object Integration component and corresponding Gateways. The Dashboard component provides a means to inform the broker about an encountered disruption. Decisions about the countermeasures have to be taken by the broker again.

Virtual Manufacturing Enterprise Architecture Components

In the following we describe our proposed architecture and its components, as introduced in the example above, in detail. As shown in Figure 2, the architecture consists of several individual components, grouped in four functional layers.

The overall system is capable of handling large amounts of data exchange between the individual components and provides scalability by distributing requests to different instances of a component, e.g., by establishing two instances of a process execution component. To achieve this, a direct 1:1 communication between components is not suitable, since it would end in a large set of point-to-point connections, and thus lead to poor maintainability and make change management complex due to the large amount of interconnections. Instead, a message routing infrastructure is proposed to connect components and exchange messages between them. Thus, there is no need that one component knows another component's location. Deploying the corresponding Message Routing component as a Cloud-based service, the required degree of performance, reliability, scalability, and stability can be achieved. Additionally, by running in the Cloud, on several independent servers, single points of failure can be avoided and therefore, a backup strategy in case of server outage is provided.

For enabling communication with heterogeneous external hardware and software systems, two dedicated components are used: Transformation Services and Gateway components. Gateways represent technical bridges to external third party systems like ERP systems, legacy systems, and Smart Objects. Therefore, each Gateway comprises standard features and features for specific external systems. For each customer and the used external system a separate customized component needs to developed and implemented. For translating data formats, Gateways can call a Transformation Service component.

The Cloud Storage component serves as central data storage of the VME. Specifically, we propose a flexible and extendable Cloud-based storage solution, allowing components to create different storage spaces for binary data, structured data, semi-structured data, and semantic data as described in more detail in the following section. However, the concept allows adding additional data storage types.

A Dashboard component provides user interfaces for accessing the functionality of the components and to monitor and manage the VME. Consequently, it provides the functionality to configure, monitor, and view all VME information and processes using existing application server technology and a web front end for user interaction.

The primary component for designing VMEs is the Process Designer component**.** It allows creating new processes either from scratch or based on ready-to-use templates. During this design phase, a broker, as a person who establishes a VME, creates the production steps of the whole VME including all relevant parameters for individual activities. To assess partners' ability to fulfill required process steps, a Forecasting & Simulation component can be used.

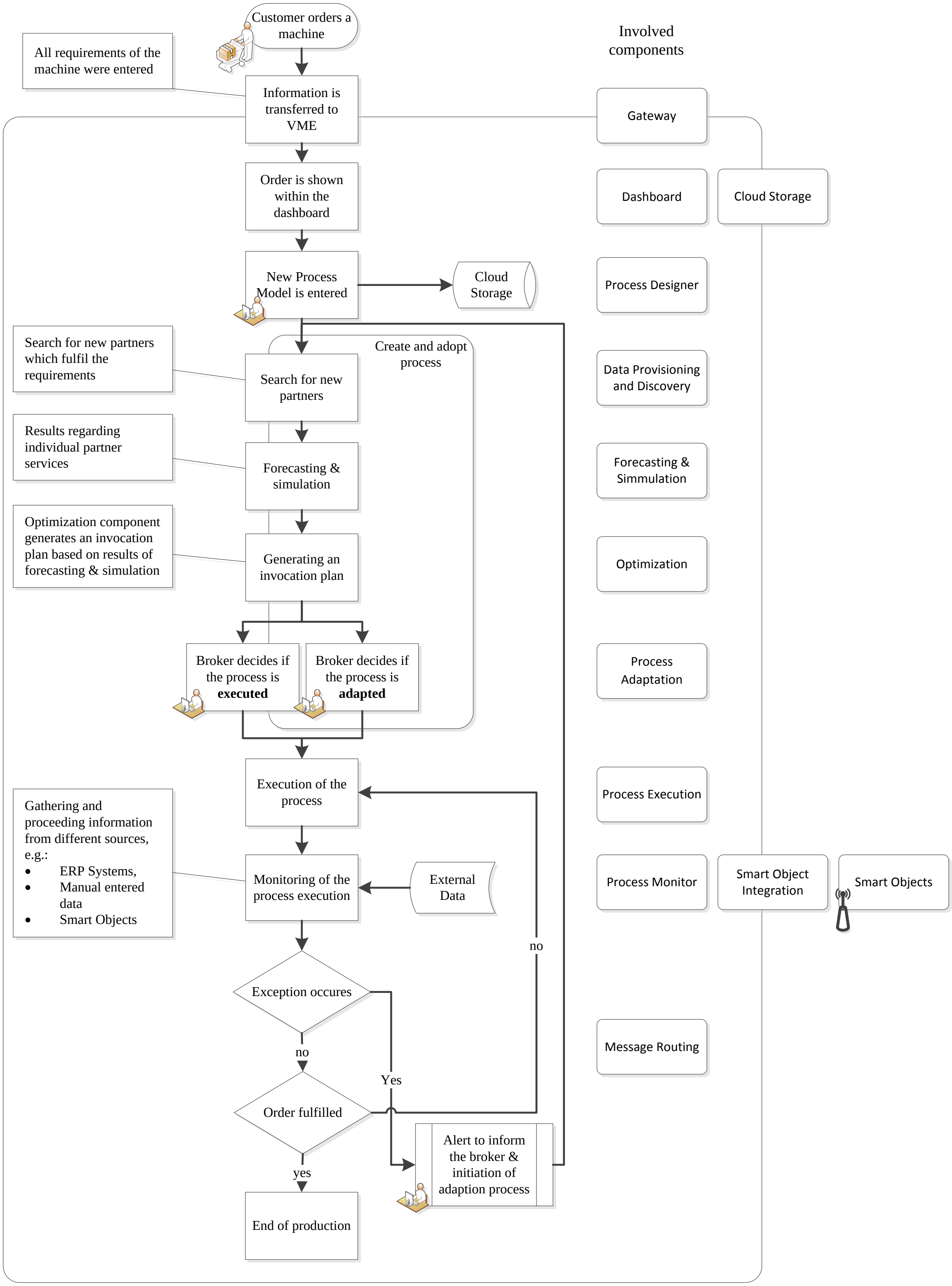

Figure 1: Exemplary Virtual Manufacturing Enterprise Workflow

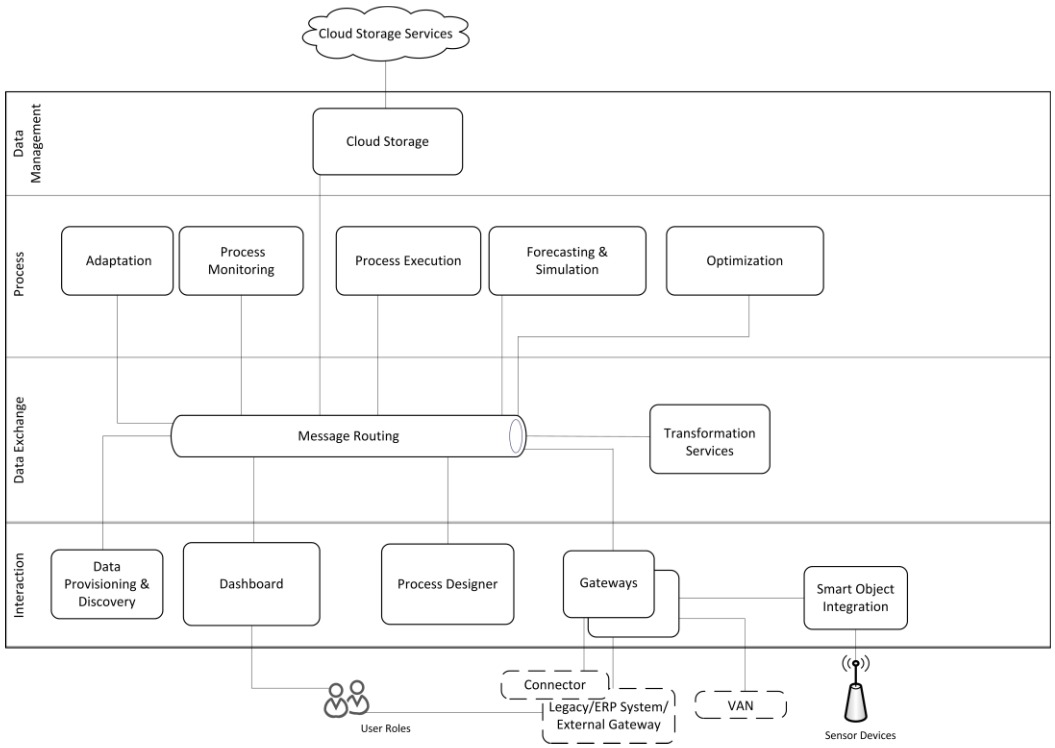

Figure 2: Virtual Manufacturing Enterprise Architecture (ADVENTURE Project Team, 2012)

For Forecasting & Simulation, gateways are used again to retrieve information from partner enterprises and their systems without starting real manufacturing steps. The goal of the Forecasting & Simulation component is to provide information about the possible duration and results of a complete manufacturing process or of single partner's activities within a manufacturing process. This information will support the broker in making decisions, e.g., whether a partner should be included in the process or not. It also allows her/him to estimate the robustness of a process based on forecasting values. The information can as well be used as input for the Optimization component.

The Optimization component will provide a recommendation of a set of best fitting partners by employing mathematical optimization models, based on a set of possible partners combined with non-functional properties like costs or delivery time.

When the design of a process is finished and VME partners are assigned to activities, the Process Execution component initiates the process execution. It provides real-time information for the involved partners and informs about exceptions. Again, these are displayed via the Dashboard component.

In order to monitor the execution of manufacturing processes and compare them with defined requirements and constraints, a Process Monitoring component is provided. This component uses information from internal components and external systems. The Process Execution component delivers information regarding all process execution related aspects. Furthermore, Smart Objects offer the ability to deliver real-time data from attached factories and the manufacturing processes by providing sensing, processing, and communication capabilities. To establish bi-directional communication channels between the internal components and Smart Objects, a Smart Object Integration component is used. It provides the functionality to gather and transmit relevant data to the internal systems and store them in the Cloud Storage. To deliver required information to the user in real time, the Process Monitoring Component pushes notifications to the dashboard.

As a result of unexpected events, changes to running processes could be necessary. In our architecture, the Process Adaptation component will deal with such changes. The reasons for changes could be multifold, for example, changing characteristics of partner services, like price or delivery time.

A central aspect for the functionality of all components is exploiting stored information. Corresponding tools and models for data representation, publication, and discovery are offered by the Data Provision & Discovery component. Its purpose is twofold. First, Data Provisioning plays an important role when partners are to join a VME. In this phase, partners enter descriptions of factories, their products, demands, offers, and properties, e.g., skills, location, standards, costs, delivery time, etc. Second, the Discovery component enables the finding of the information by other components or the broker.

For storing and providing corresponding data, our proposed architecture exploits cloud computing technology within its central Cloud Storage component, which will be described following section in detail.

DATA PROVISIONING IN VIRTUAL MANUFACTURING ENTERPRISES UTILIZING CLOUD STORAGE

The proposed architecture allows storage and access of data for all components, using cloud computing technologies via the Cloud Storage component. Data that is managed in the Cloud may originate from various data sources, e.g., from factories' ERP systems, Smart Objects, etc. Within this section, we explain how Cloud technologies can efficiently be utilized as central data store for VMEs.

Cloud computing provides the means for ubiquitous and convenient access to a shared pool of resources, such as network, applications, and storage. Such resources can be accessed on-demand with minimal effort (Mell and Grance, 2009). In the VME domain, using Cloud-based services is a natural choice, since partners are cooperating with each other in virtual spaces and without any central data centres. As such, the cloud computing concept can provide virtual services for VMEs.

The Cloud Storage component may be used to manage all types of factory information, such as a factory's profile or information about its classification. Managing all information in the Cloud allows partners to access it without having to worry about data replication, location of data, or scalability of storage. Especially with respect to SMEs, these characteristics reduce efforts and costs and help SMEs to focus on their core competencies.

User interviews and hands-on discussions have shown that within VMEs in the manufacturing domain, a storage component is required that can manage different information types including structured and binary information (ADVENTURE Project Team, 2012). Therefore, we propose a multi-storage-type approach, which allows different components to store information in different types by using one holistic API set. All storage types support basic CRUD (Create, Read, Update, Delete) functionality as well as an advanced query and storage language. All physical storage is distributed among several servers and different storage providers for ensuring scalability and reliability. Different data types usually have different needs. For example, to store large amounts of binary data, another technology should be chosen than for storing semantic or structured data. In consequence, different technologies for different data types are required.

In order to support this, we have defined the concept of "data buckets", which is inspired by the Amazon S3 Bucket approach[2]. Since the Cloud Storage component has to store data from several components, all data will be stored in different storage spaces, so called "data buckets". Consequently, in our approach, a bucket is an isolated specific storage space managing data for one or more components. One component may use several data buckets and may specify access levels for sharing buckets with other components. Each bucket has a "bucket type", which specifies the type of the storage space. Within our approach, we specify the following initial four bucket types:

- **Structured Data Bucket:** Used to store typical application data such as settings or component data. It provides a table-based structure on top of relational databases. Potential tools for realization include MySQL or PostgreSQL hosted on a Cloud-based infrastructure.
- **Semi-Structured Data Bucket:** Used to store data in a document-oriented way without a fixed data schema. It is usually referred to as "NoSQL" storage and can be realized by technologies, such as CouchDB[3] or MongoDB[4].
- **Binary Data Bucket:** Allows a document-centric storage for binary data. It may, .e.g., be used to store videos, PDFs, or other types of binary data. Queries are based on the document name or ID. For realization, potential technologies include Amazon S3 or (distributed) file systems such as GridFS[5].
- **Semantic Data Bucket:** Permits the storage of semantic information, e.g., for managing semantic factory descriptions. Queries are based on a semantic query language such as SPARQL. Possible tools for realization include Jena[6] or Sesame[7].

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[2] http://aws.amazon.com/de/s3/, last accessed: 2013-02-09.

[3] http://couchdb.apache.org/, last accessed: 2013-02-09.

[4] http://www.mongodb.org/, last accessed: 2013-02-09.

[5] http://www.mongodb.org/display/DOCS/GridFS, last accessed: 2013-02-09.

[6] http://jena.apache.org/, last accessed: 2013-02-09.

All data buckets are accessible using a holistic API, consisting of two parts: The first one is a set of core API methods, which is fully independent of the bucket type and provides core CRUD functionality for adding data sets, removing them, or accessing them by a fixed ID. The second part of the API is bucket type specific. This will allow components, e.g., to send semantic requests to a semantic bucket and to receive answers in the bucket specific format, e.g., a SPARQL result Set.

From a technical perspective, the Cloud Storage component consists of several subcomponents (cf. Figure 3). The proposed concept is technology agnostic, meaning that different technologies may be used to implement a bucket type. Thus, the technologies mentioned here should only be understood as technology examples.

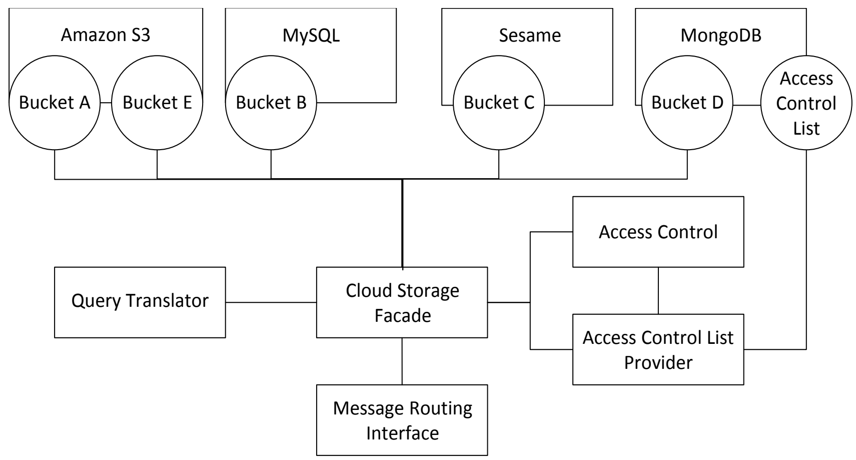

Figure 3: Cloud Storage Component Structure (ADVENTURE Project Team, 2012)

The required subcomponents of the Cloud Storage component are the following:

- **Message Routing Interface** provides the Message Routing API and the communication with the Message Routing component. An event handler is triggered, if a message is received and the Cloud Storage Facade starts to handle the message.
- **Cloud Storage Facade** provides the main logic of the Cloud Storage component. It manages buckets, interprets messages, and executes the commands sent in a message. Additionally, it checks, if data has to be transformed and if needed access rights are granted. To achieve this, it uses the Query Translator, the Access Control, and the Access Control List Provider.
- **Query Translator** converts request formats to database specific query languages and vice versa, if a transformation is needed.
- **Access Control** will be used by the Cloud Storage Facade and checks, if components are authorized to access a specific bucket. To get the component and user rights the Access Control uses the Access Control List Provider.
- **Access Control List Provider** provides access rights of components or users based on corresponding identifiers.
- **Access Control List** is stored in a semi-structured bucket, which implies that the Cloud Storage uses its own technologies to manage internal data which is hidden from other components for security reasons.
- **Buckets** are independent data storages that can be created and used by components of the VME. Depending on the type they are realized as own database instances, separate tables, or keys with specific prefix.

With this approach, we realize a storage that can be used for all accruing data, independent of its type, offering reliability and scalability without depending on specific service providers. With the concept of data buckets, the proposed storage component can easily be enhanced or adapted to future needs.

[7] http://www.openrdf.org/, last accessed: 2013-02-09.

Besides all the advantages of cloud computing, users have to face several issues, especially regarding data security and privacy (Lampe, Wenge, Müller, and Schaarschmidt, 2012; Subashini and Kavitha, 2011). In our first prototypical draft, the security of the Cloud Storage component can be realized with an Access Control List (ACL), including different roles represented by components, e.g., allowing the Optimization component to access the process designer buckets with read and write access, while allowing all other components just read-only access. Additionally, the ACL can be used to provide user-based authorized access to binary data (ADVENTURE Project Team, 2012).

RELATED WORK

In the past years, several publications address topics like AM and VMEs with different focus. Information technology has been identified as a general enabler for such organizational forms and as a means for SMEs to enhance their productivity and effectiveness (Faisst, 1997). It enables them to adopt new organizational, strategic and managerial models, and allows them to enter new markets (Barba-Sánchez et al., 2007).

The main challenge creating a VME is system control. Martinez et al. proposed a control structure for non-hierarchic and distributed control. The authors describe how complex processes should be decomposed and distributed to partners from an organizational point of view. Further, a multi-agent approach to link supply and demand for services in manufacturing is presented on a theoretical base (Martinez et al., 2001).

A key requirement to establish VMEs is the development of a proper information system infrastructure, which enables the interoperability of distributed and heterogeneous systems in collaborating organizations. Park and Favrel pointed out, that organizational and technical issues are closely connected. They presented a basic proposal of an infrastructure to enable interoperability (Park and Favrel, 1999).

Jain highlighted a Virtual Factory Framework as a key enabler for AM. The author proposed a framework including tools, methods, and procedures to support the development of VMEs. The foundation of such a framework is an IT-based common operating environment, which offers mechanisms for modeling and analysis of manufacturing processes. Core element is the rapid process re-engineering to shorten the time-to-market. Thereby, Jain focused on establishing a VME within a company (Jain, 1995).

Camarinha-Matos et al. analyzed VMEs and found that their quality highly depends on the underlying base of information. The authors propose a framework to support the creation of VMEs. In this regard, they identified three phases: planning, formation and launching. For each phase, the authors provide specific tools (Camarinha-Matos, Oliveira, Sesana, Galeano, Demsar, Baldo, and Jarimo, 2009).

Concerning cloud computing adaptation within the manufacturing domain, Xu distinguishes two types. The first one is direct adaptation of cloud computing. Thereby, companies can, e.g., benefit from lower costs. The second one is cloud manufacturing. In this case, manufacturing resources are distributed and virtualized. The authors propose an infrastructure, which consists of four layers to support the creation of factory networks for better collaboration (Xu, 2012).

All of these literature sources address areas like ICT in SMEs, decomposition of complex manufacturing processes and distribution of activities to partners, organizational issues of VMEs, organization crossing supply chains, etc., typically with a distinct focus on selected aspects of collaboration in a VME context. Since we propose a holistic ICT architecture for collaboration in VMEs, these rather focused works could beneficially be used as complementary basis for realization of our architecture. Additionally, we incorporate an explicit view on means for utilization of new technologies like Cloud computing, from which collaborating SMEs in the manufacturing domain can benefit considerably.

CONCLUSIONS AND FUTURE WORK

Small and Medium Enterprises (SMEs) in the manufacturing domain face several challenges, like shorter product life cycles, increasing demand for higher degrees of customization, and strong competition with companies from low-cost countries. One means to effectively deal with these challenges is collaboration with different partners. Such collaboration can efficiently be realized within Virtual Manufacturing Enterprises (VMEs).

Information and Communication Technology (ICT) plays a major role to overcome traditional organizational boundaries and form VMEs. Because current approaches in ICT do not fulfill the requirements of VMEs and do not reflect the needs of SMEs, new architectural models and implementations are required. In this paper, we presented such an architectural model to support SMEs to realize Agile Manufacturing by establishing VMEs. Core elements of such VMEs are the interoperability and the real-time communication between the collaborating partners. For this reason, several architecture components, like

Message Routing, Gateways and Transformation Services, address the exchange of information to establish a seamless interaction with all suppliers and customers.

The involved enterprises share processes across organizational boundaries by using a common set of components offered by our architecture. For design, execution, forecasting, simulation, and optimization of manufacturing processes, we incorporated corresponding components. To reflect the requirement of a high reactivity regarding changing market circumstances, an Adaption component provides the possibility to change currently running processes. Further, data provisioning is an integral part of VMEs. To enter information and find them within a VME, a Data Provisioning & Discovery component is proposed. This component enables the collaborating enterprises for example to enter information about provided products and services.

All information must be stored accessible by the VME components independent from its source. To realize this in a cost-efficient and flexible way, we propose a Cloud-based "bucket" approach. Especially for SMEs with a limited budget for ICT investments, cloud computing offers an easy entry point to use the proposed approaches. Our bucket approach offers different storage types and can easily be enhanced if necessary. Thus, we developed an ICT infrastructure which is scalable, highly adaptable to future needs, and caters for cost efficiency. Furthermore, we depicted how cloud computing can be beneficially employed within this infrastructure and used as major data store for SMEs collaborating in VMEs.

In our future work, we will provide prototypical implementations of the described components in cooperation with industry partners. This way, we want to validate the functionality of our proposed solutions on the basis of real data from the manufacturing domain. Furthermore, we will develop a metric which allows companies to efficiently select providers for the described Cloud services based on different functional and non-functional requirements. In further development steps, a more focused view on data security and privacy issues is also foreseen.

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