BUSINESS PROCESS MODELING AND SOA IN INDUSTRIAL O&M APPLICATION DEVELOPMENT

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Abstract: While striving to increase profits in global competition, companies are trying to improve efficiency and reduce costs by outsourcing and focusing on their core functions. For operation of industrial plants this often results in provision of services even for high-priority activities such as maintenance. Integration of external information systems and service providers to business processes and information workflows brings new challenges to application development in order to support introduction of maintenance services as efficiently as possible. This paper discusses the approach of applying business process modeling and service-oriented concepts to development of supporting software applications. Business process modeling is proposed for describing service interactions and information flows, and to function as a foundation for the application development. To satisfy required flexibility in changing business environments, the applications represented as services are composed into executable process workflow orchestrations using standard Internet technologies. To validate the approach a scenario consisting of a condition monitoring process and an environment footprint estimator is presented.

1 INTRODUCTION

Operating models in manufacturing and process industries have evolved in such a way that industrial companies have to concentrate on their primary production related functions in order to stay competitive and profitable in the global environment. This has led to provision of services for non-core activities in the quest to improve efficiency and reduce costs by outsourcing and relying on services from business partners.

Operation and maintenance (O&M) of industrial plants involves operative production and maintenance of devices and systems as a whole. Maintenance is an important factor in achieving high utilization and productivity, and its activities depend highly on operating processes and production schedules. For task co-ordination, asset management and sharing of mutually important data becomes even more important when services of external service providers are being used. This information is required in performing the service or produced as a result of it.

Unfortunately, a lot of this information exchange is still transferred manually between enterprises, i.e. from person to person or by email. Development of applications to support O&M tasks is complicated and the developed applications are challenging to maintain due to heterogeneity among technologies and practices. The work processes should be taken into account for information exchange requirements, and management of work processes and resources in service collaborations should also be considered.

Our previous work in the area of Web service technologies and O&M have shown inefficiencies in the development of O&M applications. In order to provide applications that better support operations in distributed service environments, the degree of automation in development has to increase. This paper presents an approach based on business process modeling (BPM) and utilization of service-oriented architecture (SOA) in development of applications to support O&M services. With process modeling a mutual understanding of services and information flows between participants can be achieved. These models are then essential in implementing the software applications that support activities in the distributed environment.

SOA is an important facilitator in loosely coupled information system integration and is well-suited for cross-enterprise integration. The

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autonomy and composability of services in SOA provide means for management of service processes and rapidly changing business environments.

To validate the approach, two different kind of executable business processes were implemented to illustrate integration of O&M activities and data gathering. The first process is an activity triggering *condition monitoring* process while the *environmental footprint estimator* is used for aggregating data to be used in decision support. The results and findings of the implementations are presented as well as examined for future research.

Section 2 presents background and related work in the area of O&M in industry, BPM and SOA advances. Section 3 presents the approach based on business process modeling of O&M activities in application development, and the service-oriented aspects of information systems implementing executable processes. The condition monitoring and environmental footprint estimator processes are presented in section 4, and the paper is concluded with future work in section 5.

2 BACKGROUND AND RELATED WORK

2.1 O&M in Industry

Current industrial manufacturing practices have evolved into efficient and rationalized operation processes. Utilization of expertise and supporting services from various service providers has increased as the emphasis of manufacturing is focused more on core competencies. This has resulted in extensive use of services, and in many cases, from a large number of service providers.

Maintenance is an important supporting activity that has been increasingly outsourced in manufacturing and process industry. Levery (1998) states that maintenance of productive assets is outsourced for specialist maintenance where the expertise is not available in-house or when repetitive routine work is performed. He continues that between these there are tasks, where maintenance requirements cannot be defined clearly or be related to certain assets of parts of the production process, that require knowledge of in-house maintenance and production process related information.

There are many different types of maintenance strategies used that all require a lot of planning of both preliminary schedules and tasks to be executed. Whether it is reactive maintenance, in case of a sudden failure, or a scheduled preventive maintenance operation, the tasks need to be allocated to an unambiguous location in the plant hierarchy. In addition to the plant model, also previous incidents and operations are of relevance when planning and executing the work.

As condition based maintenance is becoming general this brings another valuable source of information that is used in planning of maintenance operations. Condition monitoring systems can provide notifications and trigger events for starting required maintenance tasks either in advance or when a sudden failure occurs.

2.2 Towards Service Systems

Process device manufacturers have shown growing interest in providing after-sales services for their devices, e.g. maintenance throughout the lifecycle.

Auramo et al. (2004) have analyzed a process equipment supplier shifting its operation from selling equipment and services to offering long-term partnerships, and taking more responsibility of the operations of the customer. The authors argue that the supplier's role as a co-producer of value results in increased operational efficiency while simultaneously providing better service to the customer. Baines et al. (2007) reviewed the state-of-the-art in the integrated combination of products and services and concluded that provision of services requires understanding of how customers value the service and how products, technologies and operations support this value offering.

Managing the resulting service network requires administration similar to in-house processes. However, as work practices may differ, it is more challenging to integrate and, for instance, ensure sufficient communication and information exchange.

It is characteristic to a service network that the business environment may change, i.e. when service providers are replaced or a new participant enters the network. Introducing the new circumstances requires flexibility in adapting the processes accordingly. This requirement is especially challenging from an information systems integration point of view due to the various data exchanges required in the actual services performed.

2.3 Information Exchange

Straightforward access to maintenance data and related information systems is of significant value in planning, conducting and reporting maintenance activities. Information on running operations is constantly accumulated and stored in various systems. Maintenance related information is typically stored in enterprise resource planning (ERP) and manufacturing execution systems (MES). However, with more sophisticated control systems, i.e. DCS and PLC systems - and intelligent field devices with condition monitoring features, for instance - the diversity in integrations is increasing. In addition, there can be other information sources, e.g. provided by device vendors or authorities, that are of relevance in maintenance operations. Environmental aspects, for instance, are becoming more important for sustainable production and there are external data sources providing reference data that can be used in assessments.

In organizationally and geographically distributed business environments it should be of mutual interest to have access to up-to-date data in order to make the most of existing information and to be able to receive and provide the services as efficiently as possible. It is still quite common that information is not shared automatically between information systems as part of the operations, and data required for the tasks need to be gathered manually and reported after completion.

E-maintenance is a term used for software platforms and integration of physical processes with enterprise tools. In the PROTEUS initiative the aim was to create a software platform to support web based e-maintenance practices using Internet technologies and middleware (Szymanski et al., 2003; Bangemann et al., 2006). Business process integration to the platform has also been considered by Hausladen & Bechheim (2004). They state that for successful integration the workflow must be defined clearly and that the processes must be stable and not change on short term perspective in order to be implemented on the platform.

Viinikkala et al. (2005) have discussed the use of value added Web services to enhance O&M information management. In their approach, they propose a service framework using Web Service technology to address the challenges of information flow and integrated plant operations. The value added services are categorized based on complexity and the added value of O&M information.

Zeeb at al. (2008) have considered Web services for providing well-defined interfaces to support communication in maintenance procedures. In their approach on the LOMS platform, a maintenance procedure is modeled as a workflow and Web service based technologies with service templates used for creating services. However, BPEL was not used due to DPWS compliancy issues.

Hutchinson et al. (2007) state that there are, in general, significant challenges when trying to integrate services from different sources and migrating existing systems to service oriented computing. In the research, they identified typical architectural mismatches and suggest that a migration process addressing these challenges should include detailed business process analysis as well as architectural analysis.

3 DEVELOPMENT APPROACH BASED ON BPM AND SOA

The approach to be presented emphasizes the role of business process modeling of services when developing applications that support the service, e.g. in maintenance. A business process oriented approach supports operations driven development and process models are used to steer the implementation of respective software applications.

The other important aspect is service-orientation in the supporting IT infrastructure in order to facilitate exchange of data required in and produced as a result of services. Service-oriented architecture in information systems enables aligning applications with the business processes and not vice versa.

3.1 Plant Lifecycle Management

Plant lifecycle management stands for all the information related to a plant throughout its lifecycle from early design, construction, operation and maintenance to disposal and recycling. As a concept it integrates the logical plant to the physical and the technical model. In practice, this is integration of schemata and diagrams from e.g. the manufacturing process design, mechanical models for construction, e.g. CAD, and information systems such as ERP, MES and DCS.

The emergence of the so called digital factories enable extended utilization of information produced in all lifecycle phases. Ideally, all activities are defined and the outcome of all tasks is recorded in the plant wide model. The plant information model then becomes an almost equally important asset as the physical plant which it logically represents.

A logical plant information model is beneficial for plant operations, and especially for services performed by external service providers. The challenges of managing mutual information in distributed service networks can be met with open systems and standardization to make integration of applications easier. For example, allocating maintenance activities to assets, such as devices and equipment in a plant, can be specified if open and standardized access to the plant model can be provided for the service providers.

Despite standardization efforts, such as ISO 15926-1 (2004) and its other parts, there is still diversity in plant information model descriptions. Therefore, service integration platforms should not restrict models or data, and instead provide tools that are versatile for developing the needed applications.

3.2 Business Process Modeling of Services with BPMN

Managing activities in a distributed service network requires careful specification of responsibilities and interactions between participants. Traditionally modeling of business processes has been used as a tool to represent processes of an enterprise for analysis and process improvement. More recently, partly due to the process thinking paradigm, BPM has been used to present interweaved activities in complex business scenarios.

In contrast to many other approaches for application development in O&M and related services, lean management of processes and flexibility required in business environments of today should, according to our opinion, be emphasized. Applications that support O&M activities in services are required in order to enable efficient operation, and BPM can assist in specifying required interactions and information flows. Especially when operations are distributed and tasks of different service providers are interweaved, the benefits of process modeling are evident.

First of all, business process modeling is documentation and understanding of how operations are being carried out. When we understand how our processes work, identify who is involved and how activities flow we can improve our way of working. Often it is easy to improve efficiency by removing manual work with automated information systems.

Modeling of business processes using a notation providing mutual understanding enables specification of operations and tasks on a suitable level for the participants involved. BPM can be used to clarify the responsibilities and workflows in outsourced maintenance service scenarios. In addition to tasks, also information flows between participants and required resources can be described.

Business Process Modeling Notation (BPMN) is a standard notation for describing business process interactions and information flow (OMG, 2009). The graphical notation intends to be both intuitive and expressive for modeling of various types of processes. The diagrams consist of pools representing participants and inside them tasks represent activities. Tasks are connected by arrows indicating process flows and may include loops, sequences, conditions and alternative paths. Tasks connected between pools represent communication or events that in turn can affect the process.

3.3 Executable Processes - WS-BPEL

BPM diagrams present processes on an abstract level and are primarily intended for human interpretation. Efficiency of business processes can be improved by automation and implementation as executable processes integrating various information systems.

For operation and maintenance services it provides the following benefits:

- Automation of laborious processes and routine activities that can be defined clearly
- Processes can be executed periodically or started as a result of an event
- Activities can be automatically documented for future reference and analysis

Executable processes can be controlled by humans, include decision making based on conditions or utilize external services or composite processes that provide the required control and decision making. Although automation is preferred, human participation in some form may often be required to perform the correct operations.

In addition to programmatic system integration approaches, there are platforms and technologies for creating executable processes. For example, WS-BPEL (OASIS, 2007) as well as many commercial proprietary solutions provide means for managing workflow between systems with e.g. Web services. By orchestrating Web services, for example, it is possible to create programmatically executable business processes by composition of services.

WS-BPEL is a standardized, XML-based language for describing service orchestrations by linking Web service interactions and message flows. A WS-BPEL process can be composed inside another process and the process itself can be invoked as any other Web Service due to its standard WSDL interface description.

The executable processes can be implemented manually based on the abstract process descriptions. However, with the use of standard notations including sufficient data in the models, much of the work can be eased, and executable processes can even be automatically generated. Some transformations, for example mapping of certain BPMN structures to corresponding WS-BPEL elements, can be done automatically (see figure 1).

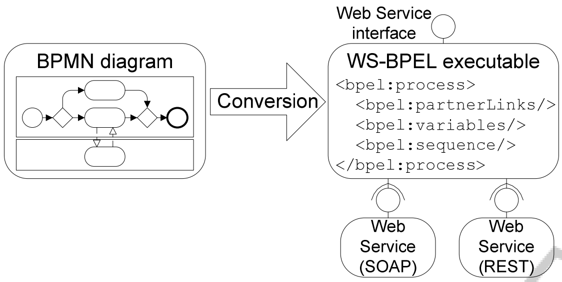

Figure 1: Abstract BPM diagrams are used as a basis for creating executable processes based on Web Service technology.

Advanced tools for specifying executable processes, e.g. in WS-BPEL, not only take implementing processes from a programming construct level to a more expressive level, but also bring reconfigurability to the process management. WS-BPEL processes can be used to invoke services, control execution flow and data management using a declarative approach. Reconfiguration is especially useful in O&M business processes when the business environment changes and processes need updating. For example, a maintenance service provider integrating a new service to plant operations might only need small modifications to an existing business process template, e.g. new data mappings and information routing.

Integration of systems requires well-defined interfaces and available services. Additionally, it is also important to have the data accessible in a machine-interpretable format preferably based on acknowledged standards. Ideally, the specification of automatic business processes mitigates to composing reusable service units and connecting information flows into executable processes.

3.4 SOA and XML Based Technologies to Facilitate Integration

In distributed environments, such as operation and maintenance of industrial plants, there are many partners involved with various information systems that would require integration in order to fully support the use of external services. When required information in maintenance tasks is transferred manually, it is often lost for future reference and analysis. If integration was flexible and systems were designed open, information exchange between participants could be significantly improved.

SOA characterizes assets as service components that for the O&M application development domain offer the following benefits:

- Application development in a business process driven manner
- Flexible applications suitable for dynamic business environments
- A foundation for integrating and managing data from various applications and sources, both horizontally and vertically
- Integration of operations and services of business partners and service providers

SOA provides many advantages of which especially abstraction, reusability and composability are of interest in O&M application development. Abstraction of the inner logic of a service promotes contract based development of interfaces, i.e. standardization, and obliges interactions to focus on information flows. Reuse of service components or service encapsulated legacy systems justify expensive development efforts and provides means to integrate systems also in the future.

System integrations are challenging due to heterogeneity in both technologies and data representations. Modern information systems such as many enterprise resource planning and maintenance information systems offer integration options using Web service and XML technologies. Where legacy systems are needed, migrations to SOA using wrappers can be used to expose data and functionality as services. However, requirements for implementing and integrating services are not limited to data access, but more importantly to its format and semantics. As different standards and practices are used, it is important for the application development method to support management of various contents with, for example, middleware or XML transformations such as XSL and XQuery.

When information systems involved in the process are available as services, they can be programmatically invoked, and a process flow between activities can be established. The supporting message processing and transformations required can also be included and controlled e.g. from WS-BPEL orchestrations. Human interaction can be implemented through input in existing tools or new interfaces for acknowledgment, acceptance or denial of actions in service processes.

3.5 Service Composition

Service based operation is composition by nature. From a plant operations perspective its main process is production. The main process consists of sub processes and is supported with activities that are related to the core functions. Similar to composing operational services, such as maintenance work, also the related processes in information systems can be composed to support the provided service.

Figure 2 illustrates the outline of business processes, service interfaces and applications. The top level in the figure models actual business processes, i.e. the interactions and tasks performed in daily operations on an abstract level of detail.

In order to create applications that either fully automate or support O&M processes, an approach based on SOA can be applied. The orchestration service layer represents an implemented, executable business process supporting and corresponding to the actual maintenance work processes. The orchestration is a composition controller that links services into workflows through a process service model. An orchestration can therefore also link other orchestrations into compositions.

The service interface layer can be divided, in addition to orchestration services, to business services and application services. Business services represent business logic and business models of maintenance service activities whereas application services provide reusable functions for processing data in various application environments. In addition to these, utility and adapter services are typically required to support the service compositions.

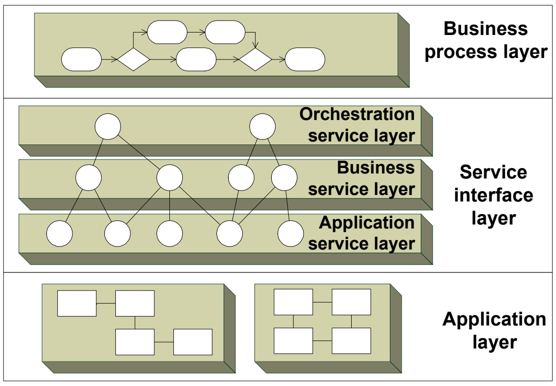

Figure 2: Vertical alignment of business processes, service compositions, services and applications. Erl (2006).

The composition of services based on business processes in a top-down manner enables development of applications that support actual business processes. When systems and applications are seen as services, process compositions can be created in a flexible manner satisfying the requirements of changing business demands in O&M services. The layered approach also enables service providers to implement their processes in their own way, and in turn utilize other service providers while still maintaining interoperability.

4 EXPERIMENTAL RESULTS

In this study, two business processes were created using the chosen technologies. The first example is a condition monitoring process that collects condition information from devices. The second process is an environmental footprint estimator for approximating the environmental load a device causes during its lifetime. The business processes can be used together; if the condition monitoring process indicates a need for a device replacement, different device candidates can be compared using the footprint estimator.

4.1 Development and Execution Environment

The software used to develop and run executable business processes in this study is Intalio BPMS. It provides tools for modeling business processes and their interaction with Web services in BPMN. Intalio BPMS can partially convert BPMN diagrams to WS-BPEL and execute the resulting processes. There is both a free and a commercial edition available.

Intalio BPMS has been used for managing clinical workflows (Nugrahanto & Morrison, 2008) and modeling of banking related business processes (Mpardis & Kotsilieris, 2010). Martin & Bagnoud (2009) used it in a case in which the interoperation of different business process platforms was tested. Jallow et al. (2010) introduced a requirements change management system for building industry.

In this study, BPMN is used to model the business processes. Based on these models service orchestrations are then created as executable WS-BPEL processes. WS-BEPL interacts with services using WSDL documents describing both SOAP and HTTP interfaces, including also REST resources.

4.2 Condition Monitoring

The condition monitoring business process retrieves the condition information from the devices of one manufacturer. There are three main problems. First, there has to be a means to find out which devices have been supplied by the manufacturer. Second, there has to be a way to find a device so that its condition information can be retrieved (the device network is dynamic so it can change any time).

Third, there has to be a means to integrate the devices to business processes.

The first problem is solved by using a plant information model. It can provide the serial numbers of the devices of a manufacturer. The second problem is solved by using a service to provide the endpoints of devices according to their serial numbers. The third problem, integration, is solved by using a technology called DPWS (Devices Profile for Web Services; Nixon et al., 2009).

The architecture of the condition monitoring service is presented in figure 3. Squares represent DPWS devices, circles are business processes and the rectangle represents the plant information model.

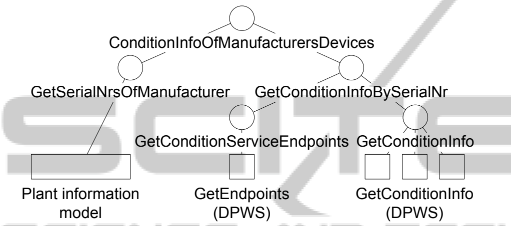

Figure 3: Composition of hierarchical processes in the condition monitoring example.

There are two types of DPWS services in the hierarchy. *GetEndpoints* takes device serial numbers as its input and finds the endpoints of the corresponding devices. *GetConditionInfo* provides the actual condition information for devices.

There is a total of five business processes. When *ConditionInfoOfManufacturersDevices* is called, it calls *GetSerialNrsOfManufacturer* that uses the plant information model to retrieve the serial numbers of the devices delivered by the chosen manufacturer. Then, *GetConditionInfoBySerialNr* is called. It calls *GetConditionServiceEndPoints* to retrieve device endpoints according to device serial numbers. Now that device endpoints are known, *GetConditionInfoBySerialNr* retrieves condition information from the devices by calling *GetConditionInfo*. Finally, the return value is returned to *ConditionInfoOfManufacturersDevices* which shall further return it to its caller.

Figure 4 demonstrates the use of BPMN and describes the flow of the *GetConditionInfo* business process. The business process retrieves the condition information of each device given in its input. Depending on the input of the business process, either the condition information of all the devices or only the condition information of devices with problems is assigned to the return value. To achieve this, conditional execution paths are used.

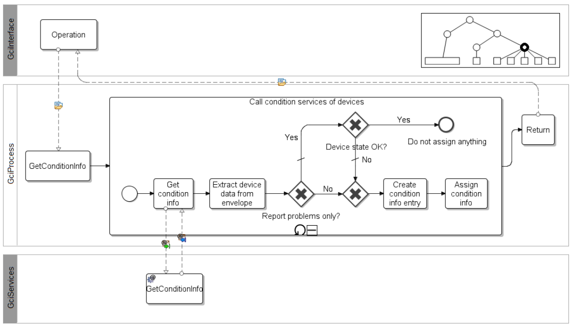

Figure 4: BPMN presentation of the GetConditionInfo sub process that requests and processes data from devices.

4.3 Environmental Footprint Estimator

The environmental footprint estimator estimates the emissions output of devices during their lifetime based on consumption of specific resources. For example, comparing consumption of electricity in alternative devices can give an estimate of emissions that can be taken into account in decision making. As there may be hundreds of emissions caused by a production process, the relevant resources consumed are chosen by the user when the business process is started. The emissions from only one resource are calculated at a time; if a device consumes more than one resource, the business process is run once for each resource. To enable the comparison of different devices, the business process can process several consumption amounts at a time.

A public European Union based environmental database (ELCD, 2010) is used to provide information about the emissions caused in resource production. If the duration of device life and its consumption of resources are known, it is possible to estimate the footprint of the equipment or device by using reference data from the database.

The architecture of the business process is presented in figure 5. It is a hierarchy that consists of business processes (circles) and environmental data resources (squares). The environmental data is provided in XML format, which facilitates integration to WS-BPEL business processes.

There are four XML document resources in the hierarchy. *Process data sets* provide the reference amounts of emissions caused by the production of one resource. To retrieve the units of emissions, three additional data sets must be retrieved for each emission: *flow, flow property* and *unit group*.

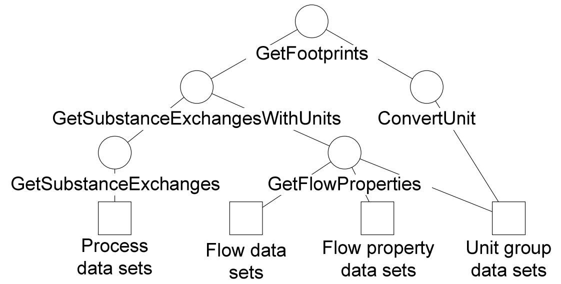

Figure 5: Composition of processes as services that are used in gathering environmental footprint estimation data.

There are five business processes in the hierarchy. *GetFootprints* calls *GetSubstance-ExchangesWithUnits* to retrieve the reference amounts and the reference units of the emissions of one production process. To perform that, *GetSubstanceExchangesWithUnits* uses two other business processes. *GetSubstanceExchanges* retrieves the reference amounts of emissions from a process data set, and *GetFlowProperties* retrieves the related reference unit by utilizing *flow data sets*, *flow property data sets* and *unit group data sets*. Once the reference emissions are known, there may be a need for unit conversions by *ConvertUnit*.

4.4 Future Refinement and Research

The examples illustrate how a plant information model, including engineering data from design, can be utilized in maintenance services. Because the condition monitoring process is fully automatic, it can be executed periodically and trigger events of assessing the maintenance need or replacement of a device. The environmental footprint estimator process, on the other hand, is invoked manually and can be used to gather data to support decision making e.g. in choosing new equipment.

In order to improve the examples the condition monitoring process could, either automatically or by human operator acceptance, invoke processes such as device inspections or ordering of maintenance services. The devices being monitored might also have different maintenance service providers requiring either separate processes or additional logic in looking up the service provider.

The condition monitoring example could also be upgraded to use a standard message exchange format. A good candidate for this would be the Open Systems Architecture for Condition-Based Maintenance (OSA-CBM; MIMOSA, 2006) that is intended for transferring information in a condition-based maintenance system.

Regarding processes in general, and especially automation and event-driven execution, the WS-Notification standard family (Graham et al., 2004) is interesting. WS-Notification provides a topic-based publish/subscribe pattern for registration to events of interest that could be used to implement event-driven process execution. Beneficial to service compositions in real business environments and characteristic to the pattern is dynamic registration to the data source and separate messages to registered subscribers.

In the long run, the emergence of Semantic Web technologies opens up new possibilities especially in classification of information and applying reasoning to further automate processing and workflow. Also as further standardization in the O&M domain is needed the importance of semantics is increasing.

5 CONCLUSIONS

In efforts to make industrial plant operations more efficient, maintenance among other operations has been outsourced. Integration of mutually valuable information could improve service collaboration by giving the service provider more insight in providing the service and the customer in receiving it.

Especially in distributed service networks, information on maintenance operations and maintenance history is shared inefficiently partly due to laborious integrations that would be required. In our opinion, application development should take business processes and information exchange requirements better into consideration when designing new applications and integrating information systems. An operation driven O&M application development approach suitable for services can be achieved with business process modeling and implementation based on SOA. The approach presented is a top-down development approach that enables business demands and service operations to steer the application development. For technologies and migration of existing information systems, a standards based service-oriented approach is suggested for providing service interfaces for data exchange and service composition.

The experiments indicate that business process modeling with BPMN and integration of O&M application services using WS-BPEL provides means for composing services efficiently while maintaining the required flexibility and reconfigurability of services. The approach probably also saves time compared to traditional programming approaches, and promotes standardization of data, application interfaces and operation practices.

An interesting future research topic from a services point of view is management of service collaborations where more details and participants are involved. This, as well as previously presented challenges, call for standardization to aid in integration of services and information systems. Also advances in the use of intelligent agents, utilization of technologies of the Semantic Web, and the increased capabilities of plant floor devices provide interesting research topics in the future.

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