Virtual Enterprise Process Management: An Application to Industrial Maintenance

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Abstract. The paper firstly reviews the relevant concepts on virtual enterprise operations as well as industrial maintenance processes. Then a virtual enterprise enabling platform is presented. The architecture of the platform and its main modules are briefly introduced. Within this platform, a smart object extension is highlighted. This smart object is used to collect data from remote equipment and pass it to the Virtual Enterprise Management Platform (VEMP) through a gateway. The data collected by the smart object will be aggregated and monitored, using the business intelligence tools of the platform, enabling the implementation of maintenance strategies, rising fault conditions that will trigger a repair business process. In the final part of the paper, it is discussed a business case for a SME with worldwide operations.

Keywords: Virtual Enterprise, Business Process Monitoring, Industrial Maintenance, Virtual Enterprise Management Platform.

1 Introduction

The literature and technical references on virtual enterprises often focus on the supply chain processes. This paper presents a different view once it discusses the use of virtual enterprise enabling technologies in the context of industrial maintenance processes. Due to the nature of their key business activities, maintenance processes require local operations that are performed close to the technical apparatus. As SME’s often lack the resources needed to offer a suitable quality of service level to remote clients, they need to find partners all over the world that will be engaged in business processes accordingly to their specific needs. When a robust worldwide operation network need to be set-up, the use of virtual enterprise platforms can be a rather valuable enabling technology for formation, management, adaptation and monitoring of the dynamic collaborative processes [13]. There are various forms of business collaboration such as business community, industrial cluster, collaborative network organization (CNO) [1], virtual organization (VO), [3] and virtual enterprise (VE)

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[4].In such business environment, there is always the need to continuously monitor and manage the underlying business processes, as discussed in this paper.

This paper is organized in 5 sections and presents the results of a research that was carried out in four main steps. First of all, we reviewed the existing literature in areas such as Industrial Maintenance and virtual enterprise for collaborative business. Secondly, we specified a hardware integration tool to apply to the field equipment, which is then integrated with a Virtual Enterprise Management Platform (VEMP). Thirdly, a requirement elicitation process is carried out, which includes semi-structured interviews to two different business enterprises, namely; a machinery manufacturing SME located in the north of Portugal (Engineer-to-Order business model) and an electronic and automation SME located in the United Kingdom (Engineer-to-Order business model). The results of these three steps conclude the requirements elicitation process through collecting the expected requirements list. Fourthly, a set of discussions were carried out with the platform development team to understand the hardware integration and technical requirements.

Section 2 of the paper reviews the literature about predictive maintenance, virtual enterprises, and business activity monitoring and process analytics concepts in order to build a theoretical background and to support the business process monitoring. Section 3 contains the main contribution presenting the results of this research with the requirements, functionalities and design of a VEMP applied to the maintenance processes management. Section 4 presents a case study where the concepts presented were tested and validated. Finally, section 5 presents some concluding remarks and perspectives for further work.

2 Literature Review

2.1 Business Collaboration through Virtual Enterprise

The uniqueness of virtual cooperation between companies in the form of VO or VE is that this type of collaboration is orchestrated through the direct use of Internet or Web-based technologies and tools. Such technologies and tools ensure real-time communication between the partner companies, while they are physically located in different regions or countries.

The beauty of business collaboration through VE is that it represented a temporary alliance of organizations that come together to share skills or core competencies and resources, in order to answer to a specific business opportunity" [1]. The formation of such business collaboration begins after selecting potential partners based on predefined criterions and invites them to join the virtual enterprise. Before joining the network partners also need to agree and sign the contractual terms and conditions to execute the VE effectively and efficiently [4], [13]. After formation of the VE, next available steps are to execute (monitoring, simulation, optimizing, forecasting) and dissolute (share out, liabilities assignment, partners evaluation) the VE.

In the VE business environment, all the required business processes are designed after consultation with the participating partners. Usually, the broker company who initiates the collaboration invites partners to design the processes needed to execute the VE operational activities. The VE process can be defined as the group of activities carried out by individual partner or group of two or more partners with the objective to fulfil certain requirement(s) that successively creates value to the end customer[7][2]. The creation and operation of manufacturing processes within the VE are done in a modular way.

The aim of VE is to provide tools and processes that will help to facilitate information exchange between partner enterprises and move beyond the boundaries of the individual enterprises involved. Within the VE collaborative manufacturing processes are optimized by enabling the integration of partner selection, forecasting, monitoring, and collaboration during runtime. The essential monitoring and governance of the collaborative processes are supported by smart technologies such as Internet of Things, smart objects, wireless sensors, etc.,[6]. Existing tools and services of the VE partners also can be integrated during the development of the VE platform [5].

2.2 Industrial Maintenance Management

Today's complex and sophisticated equipment needs to enhance up-to-date maintenance management systems. These maintenance systems are recognized as the high costs including inspection, repair, and equipment downtime with advanced manufacturing organizations [9]. High maintenance cost highlights the expectation to clearly define the maintenance objectives and to enhance modern maintenance management methods and to implement intelligent computer-based maintenance systems. In industrial domain two major maintenance management approaches are available namely; failure-driven and time-based maintenance [10]. There are also other maintenance systems such as conditioned-based maintenance (CBM), statistical-based maintenance (SBM), etc., are used to reduce the uncertainty of maintenance according to the needs indicated by any industrial equipment condition [11]

Predictive Maintenance (PM) is used as a maintenance methodology to monitor and detect incipient problems and to prevent catastrophic failure. The PM can be defined as comprehensive maintenance management program that optimizes the availability of process machinery and greatly reduces the cost of maintenance. It is a philosophy or attitude to regular monitoring of the actual mechanical condition, operating efficiency, other indicators of the operating condition of equipment and manufacturing processes and to improve productivity, product quality, and overall effectiveness of manufacturing and production plants [12]. PM is basically a condition-driven maintenance program, where instead of relying on industrial or in-plant average life statistics the maintenance activities are planned on schedule. It utilizes non-destructive testing technologies such as infrared, sensors (like smart objects), acoustic, sound level measurements, vibration analysis and other specific online tests.

PM solution opens up innovative new possibilities for companies. It does not depend on industry statistics but relies on real signals demonstrated by a single and specific piece of equipment. Any data or signal from specific sensors monitoring machine condition is automatically reviewed to pick up any patterns that indicate a possible fault. It offers the onset of stoppage to be recognized early and corrective measures to be planned. In addition to early fault detection PM also can be used to avoid unplanned downtimes and both staff and resources can be employed more effectively [8].

One area that many times is overlooked is how to, in an efficient way, transfer the predictive maintenance data to a computerized maintenance management system (CMMS) system so that the equipment condition data is sent to the right equipment object in the CMMS system in order to trigger maintenance planning, execution and reporting. Unless this is achieved, the predictive maintenance solution is of limited value, at least if the predictive maintenance solution is implemented on a medium to large size plant with tens of thousands pieces of equipment.

3 Virtual Enterprise Management Platform

The goal of a Virtual Enterprise Management Platform (VEMP) is to simplify the establishment, management, adaptation and monitoring of dynamic manufacturing processes in Virtual Factories. This includes the finding of partners, the design, forecasting and simulation of Smart Processes, and their execution and real-time monitoring.

To establish processes between different companies, data about the partners wishing to collaborate in a virtual factory is needed. Therefore, each Virtual Factory member needs to be able to add data about his company, products, services and processes. To achieve this in a user-friendly way, VEMP has to provide an editor in the scope a Data Provisioning and Discovery component to enter, view, update or delete this data. For reasons of availability, accessibility, access-control and the possibility to have redundant backups if needed, this data should be stored in the cloud. The Cloud Storage component should support several types of data storage, including NoSQL semi-structured data storage, used internally by the VEMP, as well as semantic data necessary for semantic company descriptions and also data storage for binary files. Binary files may be used for storing documents such as specifications or even multimedia files.

To design the VEMP, the platform has to provide a Process Designer. To improve and facilitate the usability of all user interfaces should accessible via a single application interface with a single look and feel and a quick learning curve. All the user interfaces should therefore be embedded in the Dashboard, including the process designer.

The Process Workflow Execution component, executes process models and the Real-time Process Monitoring shows the actual status of the process execution and can additionally query machines interfaces for their current state, collecting information for preventive and predictive analysis.

The Machine sensor interfaces as displayed in Figure 1 will be integrated via the Gateway, with acts as a Client for the Smart object services, the gateway will then communicate with the platform via the Message Routing. External systems like legacy systems etc. should also be able to communicate with the VEMP's Message Routing component making use of the Gateway component, which effectively fulfils the role of a bridge, connecting the external system with the platform. The Gateway as well as the Message Routing may invoke Transformation Services that can be used to translate between external (legacy) technology which will use different messaging protocols, interfaces and message formats. The Gateways therefore will be the only components that might need to be expanded or recreated when a new member wants to connect uncovered legacy systems to the message routing. The message transformation may be used as a base by the gateways to transform a variety of data formats, hence allowing a wide support of systems.

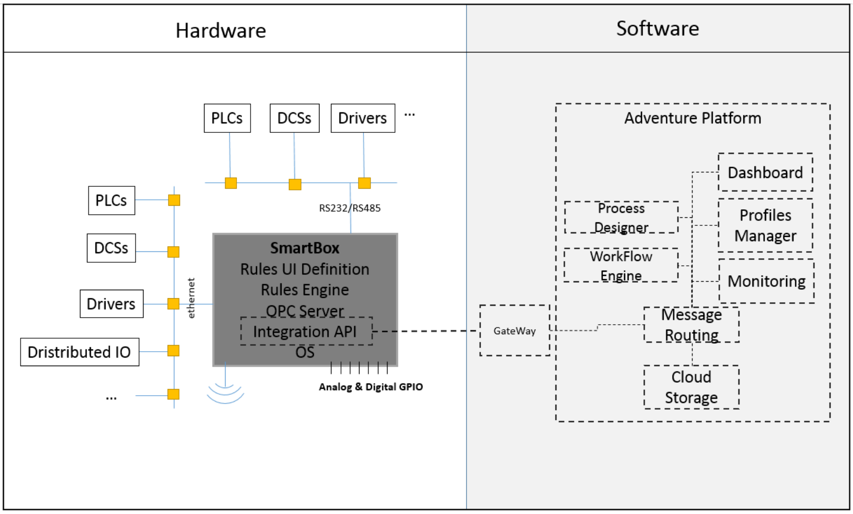

Fig. 1. Smart object integration with the VE Management Platform

A new process model is created in the process designer either as an empty model or based on a ready-to-use template from templates repository. As the broker starts to design (edit) the process, the model enters its 'in design' phase. This is the core phase for the process designer and the designer can perform several types of tasks in it: manage process metadata with the goal to enable automation and make the process discoverable; design process models, e.g. add/configure/remove process activities or other process model elements, using the notation and semantics supported by the process model design tool; use the simulation module to trigger simulation of the process and verify its qualities before executing it and potentially return to redesign for better results; use the optimization module to trigger optimization of the process for optimal business goal results and potentially return to redesign for better results; save for further work or share the designed process model; load, if the process model has been saved earlier or has been shared by another user.

The workflow process execution component will be at the heart of the platform, as it will orchestrate all interaction in a virtual factory. Its purpose is to execute processes, modelled in the process designer. This component will deal with processes, process instances and the communication with gateways and logging.

The monitoring component in the platform is the component that provides the real time monitoring of ongoing process, historical data relating to finished processes and instances and business analytics relating to process and activities types. The Process Monitoring component provides real time, log and performance data relating the virtual factory processes. The Monitoring Engine captures the events produced by the smart process engine and stores the relevant event data in the cloud. The real-time monitoring component provides a live view of the ongoing processes using the process editor interface, so that virtual factories brokers may decide to undertake flow adjustments and efficient decisions in order to improve the performance of the manufacturing processes.

An integration smart object was designed and developed to interface with the virtual enterprise's equipment to be monitored and managed. As displayed in Figure 1, the smart object enables the integration with the overall virtual enterprise platform via gateway implemented services. The black box itself works as a smart object with sensors, collecting raw data from programmable logic controllers, Industrial PCs, DCSs and spread sensors from different vendors using different communication protocols and physical layers.

A gateway will comprise of standard components and custom components with functionality developed or created for connecting to a specific external system type and/or instance. A gateways mission is to communicate with a specific system, meaning that a significant part of a gateway implementation is tailored for specific technology or communication/interface protocol.

4 Business Case

In this section, we explain the use of the VEMP and the smart objects integration for managing distributed maintenance processes. The request for service (call) could be done as follows: The customer (machine owner) opens a new call via the VEMP dashboard or mobile app. Moreover, with the inclusion of the smart object, it is possible to send maintenance alerts directly from the equipment to the manufacturer technical team as well as to the customer, helping those to shift from a corrective to a preventive maintenance and thus decreasing the risk of failure and downtime.

Using the VEMP dashboard, stakeholders have access to the list of machines installed, their status, location, manuals, technical assistance plans, procedures and drawings. Thus, it becomes simple to select equipment and ask for assistance, introducing the problem description. Manufacturer is then notified in real time and knows exactly which is the equipment that needs service, having access to all the machine data, history, manuals, drawings and service records instantaneously, even if the service manager is out of office. It's a huge advantage in terms of time to market.

Moreover, if the equipment is connected to the internet (wired or wireless) and the problem is about software, it is possible to solve it remotely and have real time feedback from the equipment. This is quite useful for costumers far from the manufacturer plant. For customers far from equipment supplier plant, it's common to subcontract 3rd party firms (partners) to assist their customers. One of the advantages of this new approach is that the manufacturer becomes able to remotely monitor the process by using equipment's control software integration and the mobile applications where the partner updates the service status and the details of the technical intervention. Customer will be able to: make a new service call, track their service calls, and access technical documentation. Service Manager will be able to see all customer calls, evaluate and control customer calls, create service orders, schedule service orders, assign technicians to service orders, access related documentation, manage human resources, and manage maintenance warehouse stock. The technician will be able to see service orders assigned to him, access equipment technical documentation, report the status of his work, and submit the order at the end of the intervention. Sales Manager is able to see the overall view of the calls and service orders performance indicators such as: mean repair time per equipment, customer or technician, uptime as well as mean time between repairs per equipment.

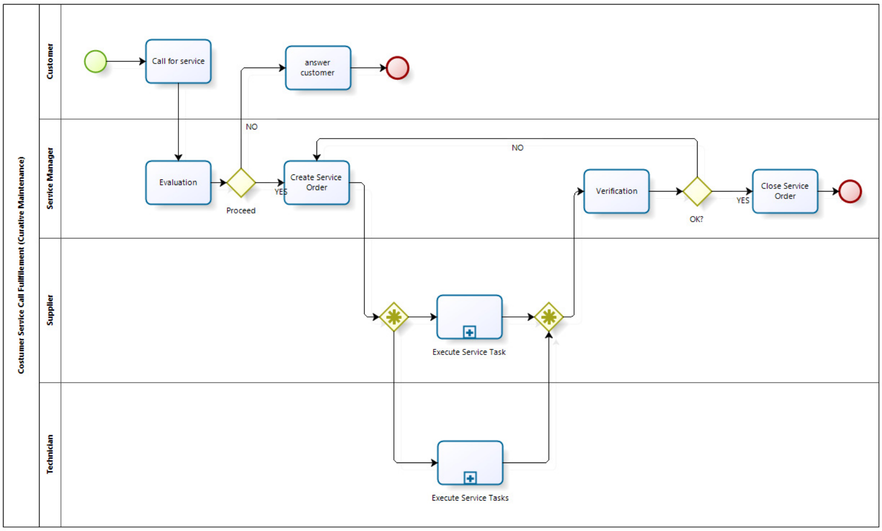

Fig. 2. Maintenance process BPMN Diagram

5 Conclusion

In the advancement of technological knowhow, companies are forming business collaboration or network between each other within shorter pace of time. The up-to-date and available technology such as Internet makes the collaboration easier with added mutual benefits between the partners. In such rapid business environment, collaborative partners need for real-time information update of their processes and resources. This information update ensures partner companies to take corrective actions against abnormal situations if there any. The real-time information update also contributes to predictive repair and maintenance of the equipment or resource's used in any business network. Business process monitoring in collaborative environment avoids potential risks and ensures sustainable growth.

The main focus of this research is to highlight a complete loosely coupled virtual enterprise management tool applied to the virtual enterprise maintenance processes. This tool is composed of with nine modules: (i) The integration Smart object, (ii) Gateway with OPC Client, (iii) Process Execution Engine, (iv) Message Routing, (v) Process Designer, (vi) Process Monitoring, (vii) Data Provisioning and Discovery, (viii) Cloud Storage and (ix) Dashboard. This study mainly highlights two components such as Process Monitoring and Smart Object Integration that are directly interfaced with VE business process monitoring and management. All other components are the supporting ones and are responsible to execute the virtual enterprise management platform successfully. The integration 'smart object' as highlighted in this research collects resources or equipment data and visualizes over the dashboard through gateway services. The collected data from an individual equipment or resource by the integration smart object acts as the source of predictive maintenance of the specific equipment. The overall real-time status information of the specific equipment can also be used as the condition-based maintenance program. This conditioned-based monitoring data can be used as the forecast information of the specific equipment and supports actively towards the scheduled maintenance. This approach consequently contributes to the cost cutting of the equipment in terms of getting well-ahead information before the equipment failure and ensures its uninterrupted operability.

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