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Collaborative smart process monitoring within virtual factory environment: an implementation issue

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The focus of this paper is to elaborate collaborative business process monitoring within virtual factory (VF) environment in a smarter way. This process monitoring is tracked through visualisation over a user interface such as 'dashboard'. This research briefly provides all aspects of implementing process monitoring through the dashboard user interface and explains technical aspects of monitoring. The dashboard features state-of-the art business intelligence and provides data visualisation, user interfaces and means to support VF partners to execute collaborative processes. With advanced visualisations that produce quality graphics it offers a variety of information visualisations that brings the process data to life with clarity. This data visualisation provides critical operational matrices (e.g. KPIs) required to manage virtual factories. Key reporting outputs such as KPIs and day-to-day operational data can be used to monitor and empower partners' processes that help to drive collaborative decisions e VF broker or partners' also retain full flexibility to create, deploy and maintain their own dashboards using an easy to understand wizard-driven widget and an extensive array of data visualisation components such as gauges, charts, maps, etc. Various technical aspects of this dashboard user interface portal are elaborated within the scope of this research such as installation instructions, technical requirements for the users and developers, execution and usage aspects, limitations and future works. In addition to the dashboard user interface portal this research also investigates the VF life cycle and provides architectural framework for VF. The research work highlighted in this paper is conceptualised, developed, and validated within the scope of the European Commission NMP priority of the Seventh RTD Framework Programme for the ADVENTURE (ADaptive Virtual ENterprise ManufacTURing Environment) project.

Keywords: business collaboration; virtual factory; business process monitoring; process visualisation; small and medium enterprise (SME)

1. Introduction

There is a growing interest among companies to perform business in a collaborative environment. The concept of business collaboration or networking is not new but it attracts growing interest to the business communities due to its associated benefits and the ongoing globalisation within the manufacturing domain. This collaboration usually begins after identifying a possible business opportunity. This business opportunity is elaborated within the possible partners, who are selected based on specific criteria such as their capacity, skills, costs or locations. Often there exists a pool of companies with similar expertise and products known as business community (Carneiro et al. 2010), virtual organisation breeding environment (Camarinha-Matos and Afsarmanesh 2005), industrial cluster (Flores and Molina 2000), etc., from which potential partners are selected to form such business network, known as virtual organisation, virtual enterprise, VF (Jain et al. 2001), etc.

A Virtual Factory (VF) is a temporary or permanent alliance of partners selected from a business community and facilitated by the partner who designs /creates /adapts a process and proposes business opportunities. The concept of VF as presented in this research combines the power of individual factories into a single VF to achieve complex manufacturing processes.

The developed technological and software components facilitate the creation and operation of collaborative processes in a business environment through a distributed, integrated, computer-based system. It offers dynamic business portfolio like partner finding, process creation, process forecasting and optimisation, information exchange as well as real-time monitoring. Along with such offers, VF needs to offer proven tools or technologies that provide end-to-end integrated information and communication technology (ICT) which will help to facilitate information exchange between factories (Molina, Velandia, and Galeano 2007). This possibility moves beyond the boundaries of the individual enterprises involved in the business network (Carneiro et al. 2010).

In any successful business cooperation there needs to address monitoring and governance of the collaborative

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processes (Shamsuzzoha, Helo, and Khadem 2013). This process monitoring enables to increase the degree of flexibility within the VF partners and helps them to react quickly to changes and to participate in larger cross companies manufacturing processes (Romero and Molina 2009, 2010). Generally, VF partners monitor their business processes based on their tiers in the network. For instance, a partner company is allowed to monitor only its collaborative processes while, its supplier has no or limited access to its overall process monitoring. A VF broker, who initiates the formation of VF, has full access right to monitor the entire collaborative business processes.

The objective of this research is therefore to focus on process visualisation that is applicable to monitoring and managing VF business environment. This research briefly presents all aspects of implementing a dashboard user interface that is to be used by the VF partners to process monitoring.

The rest of the paper is organised as follows: Section 2 highlights the theoretical framework, where generic researches on business process monitoring and technologies used for it is described, while Section 3 briefly explores the VF life cycle. In Section 4, VF conceptual architectural framework is elaborated. The possibility of process monitoring through dashboard user interface portal is explained in Section 5, whereas, an overview of technical and functional contexts of dashboard portal is stated in Section 6. ADVENTURE dashboard portal to be used as user interface portal to VF process monitoring is outlined in Section 7. Implementation of process monitoring in real case company is illustrated in Section 8, while, overall conclusions, limitations and future research directions are mentioned in Section 9.

2. Theoretical framework

Due to recent development of ICT influences the concept of forming collaborative networks that allow manufacturing organisations to move from highly data-driven environments to more cooperative information or knowledge driven environments (Jeong and Nof 2009; Camarinha-Matos et al. 2009). This environment develops innovative manufacturing processes and products that are capable of responding rapidly to changing/uncertain demands, demands for custom-tailored products and fierce international competition in the new global economy. Typical shared expertise, resources and skills through business collaboration impose companies (SMEs) high productivity levels for labour and manufacturing facilities, a high level of agility and the use of new business models to enhance the production capabilities beyond companies' borders (Moore 1996; Fujii, Kaihara, and Morita 2000; Montreuil, Frayret, and D'Amours 2000; Shamsuzzoha et al. 2013).

2.1. Business process monitoring among collaborative SMEs for achieving enhanced competitive advantages

In today's business environment there is growing interest by companies, especially SMEs to moving towards networked businesses with the objective to achieving competitive business advantages and mutual benefits with extended market share. With this changed business environment, network partners expect an efficient process monitoring for each product or service related activities in a real-time environment. Although, there has been some progress in business process monitoring to date, nevertheless existing monitoring processes are not innovative and cost efficient (Jeston and Nelis 2008). Keeping such constraints in mind, this proposed research concentrates mainly on design and developing a framework that guides network partners to overcome current barriers that exist in collaborative business process monitoring and offering an effective monitoring process through the application of available technologies or tools.

The concept of business process monitoring can be viewed from the contribution it makes to add value to the potential customer and the alignment and realisation of the strategic business objectives. Process improvement as achieved through process monitoring will start by obtaining better understanding of the customers and their demand on the business. There is a lack of automated support in process monitoring which is mostly an isolated set of activities separated from the actual process execution. It is critical for virtual network partners to monitor and manage accompanied processes. There are several sensor-based technologies that existed to monitor individual products or processes (Krasteva et al. 2011), but only limited research has been done to monitor processes within VF business environment. Most of the research work in collaborative business process monitoring has been done mainly to identify resources abnormalities in the partner's premises (such as machine breakdown, labour unrest, etc.,) and not necessarily to status information on the processes as a whole such as process delay, process failure, process adaptation, etc., (Hallikas et al. 2004).

2.2. Technologies for collaborative business process monitoring

Today, flexibility and business agility are important factors for modern organisations in order to compete in personalised and customer-driven markets. The need of proactive decisions impose a growing interest on business process monitoring and in particular on real time monitoring, where cyber physical systems play an important role, bringing shop-floor data to the managing layer quickly. In this scenario Process Monitoring (PM) techniques have an important role on converting raw data into meaningful information.

PM is a systematic collection and allows the analysis of information in real time in order to identify and measure changes. Monitoring means track the process execution against time, resources and performance targets. Business Processes are often managed and orchestrated by enterprise systems called Workflow Management Systems (WfMS) to achieve continuous improvement focused on designing, executing, and monitoring business processes. WfMS promises better control and higher quality, lower costs, and an intrinsic capability to rapidly adapt the process flow. WfMS integrates with and can be built on service-oriented architecture (Van der Aalst 2004). However, is it not trivial when to apply a WfMS or another toll for the management of business processes. It depends on the process nature and the level of knowledge and human decision needed (Faria and Nóvoa 2015)

The WfMS can raise events when certain conditions occur and call services to perform automated tasks. Complex Event Processing (CEP) is a field that started to be explored in the early 1990s, and later in the IT industry. CEP handles large volumes of continuously streaming data, producing aggregates, trends, exceptions, and patterns. The event mediator handles the events produced by WfMS, and propagates them to potential consumers (Luckham 2008).

Complex Event Processors are able to integrate several heterogeneous sources and the outcome of processing consists of events that are sent through usually more homogenous channels in structured data formats. Note that the event processors are decoupled from both the producers of the events and the respective consumers of the events they produce (Luckham 2002). The processors perform the following operations on incoming events resulting in the events:

- Add context meaning to events;
- Aggregate events;
- Detect patterns;
- Compare correlated events;
- Identify a sequence of values or value changes;
- Promote or propagate the result of the preceding operations;

Business Activity Monitoring (BAM) transforms information from CEP into meaningful visual dashboards to support decision makers. It can be described as a component for the aggregation, analysis, and presentation information about activities inside organisation. Using BAM, decision makers gain the ability to build interactive, real-time dashboards and alerts to monitor their business processes. BAM can also process rules, testing values or aggregations against targets or other conditions. The rules engine allows BAM to do event processing somewhat similar to CEP, with smaller volumes of events. When the rules conditions are satisfied, several types of actions can be triggered by the BAM engine. Among these actions are alerts, e-mail, and invocation of Services. Thus, BAM complements CEP with the visual presentation and the ability to take actions. There is some overlap with CEP, because both products analyse events in real time, aggregating and detecting patterns. While CEP is geared towards more intense event streams with generally simple and meaningless, almost payload-less signals and events (Kolár 2009).

Rules can be specified to identify exceptional situations that may require instant action. When a rule is activated, a visual alert can be displayed in the dashboard and the configured actions can be executed. The rules can be quite advanced, thus allowing BAM to do a fair bit of filtering, aggregation, and pattern matching against its data objects and the events that update them. A rule engine, as part of a BAM application, is a piece of software, which having some knowledge is able to perform conclusions.

A rule-based programme is made up of discrete rules, each of which applies to some subset of the problems:

- It is simpler, because you can concentrate on the rules for one situation at a time
- It can be more flexible in the face of fragmentary or poorly conditioned inputs
- Used for problems involving control, diagnosis, prediction, classification, pattern recognition

Rules engine usually applied to the problem is beyond any obvious algorithmic solution or it is not fully understood, when the logic changes often or the domain experts are readily available, but are nontechnical.

3. Virtual factory life cycle

The concept of VF business model is developed as part of work accomplished within the ADVENTURE project under the funding from European Commission (Ref. 285220) (ADVENTURE 2011). This model basically provides the necessary guidelines to form a plug-and-play VF to be used for achieving the identified business opportunity. The developed business model consists of four phases in its complete life cycle. The four phases are namely Join, Plug, Play and Dissolve. The phases of the VF lifecycle along with their corresponding subprocesses are displayed in Figure 1. From Figure 1 it is seen that the VF life cycle starts from Join phase and ends at Dissolve phase. Details of the phases are described in the following paragraphs.

From the Join phase of the VF life cycle it is noticed that participating partners within the VF business environment first of all need to understand the identified business opportunities after analysing the existing market trends clearly in

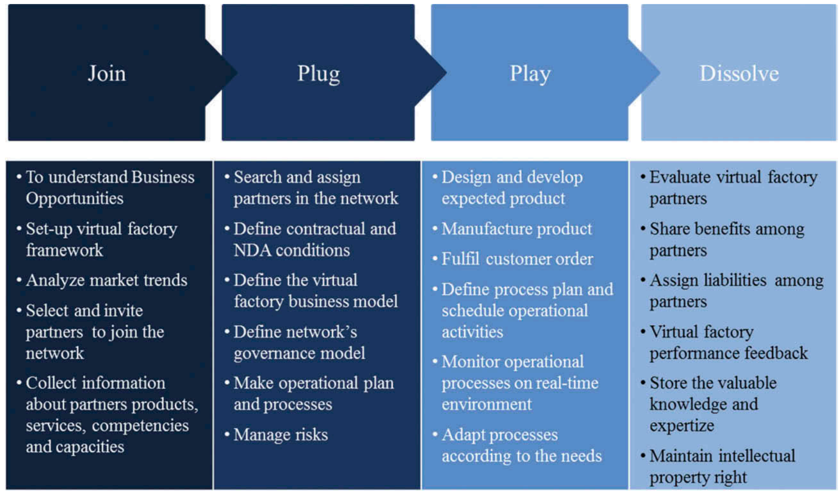

Figure 1. Phases of the virtual factory life cycle.

order to enthusiastically and actively join the VF network. At this phase, the VF broker establishes VF framework to guide VF activities and collects necessary information of the participating partners with respect to their products portfolios, services, competencies and capacities. Core partners are invited and selected at this phase too to join the network.

In the Plug phase of the VF life cycle potential partners are searched and assigned with specific tasks or processes. Specific contractual agreement is defined within the network partners and a non-disclosure agreement (NDA) conditions are agreed and signed to protect partners' intellectual property rights. At this phase required business model and governance models are defined to execute the VF. Various operational processes are defined and planned in this phase. Specific risk management plan is also prepared in the Plug phase in order to eliminate or minimise potential risks.

During the Play phase of the VF life cycle, the VF broker begins necessary steps to design and develop the expected product. At this phase, essential design and drawing of the expected product is done in a collaborative manner within the partners that consequently fulfil customer order. Various process plans are defined and operational activities are scheduled at this phase. In order to manage all the VF processes, essential process monitoring is evoked to update processes in real time. At this phase, there is an option to adapt any business processes in case of process abnormalities or failures.

The last phase of VF life cycle is Dissolve. This phase is instantiated when the identified business opportunity is over. At this phase, overall performances of the VF partners are evaluated based on agreed criterions. The expected benefits and liabilities are shared between the partners along with maintaining intellectual property rights. The expert knowledge and valuable information as gained during executing the VF are stored for future use before dissolving the VF.

4. Virtual factory conceptual architectural framework

The VF aims at the integration of multiple organisations into one virtual platform for exploiting a market opportunity. Upton and McAfee (1996) define virtual factories as 'collaborative, internetworked environments in which several partners electronically share information and IS tools around a product (CAD/CAM, simulation-based design) process, or project'. The VF can be implemented to ensure that manufacturing processes and sub-system designs will meet the preidentified requirements. It is used as the source of enterprise knowledge sharing (know-how), adoption of common best practices and open source/web-based applications are enablers to achieve both the concept of integrated enterprise and the implementation of collaborative networked enterprises for manufacturing industry (Ferreira et al., 2012; Carneiro et al., 2014).

In order to execute a VF it is essential to develop an architectural framework. This VF architectural framework can be defined as the complete list of components and their interfaces required forming and executing a VF successfully. The proposed framework as developed within the ADVENTURE project is displayed in Figure 2. From Figure 2, it is noticed that this framework consists of three layers: User Interface Layer, Process Management Layer, and Data Management Layer. The associated components of each of the individual layers are also displayed in Figure 2. From Figure 2, it is noticed that the 'User Interface Layer' is considered as the top level which is interfaced directly with middle layer named as 'Process Management Layer'. The bottom level consists of the 'Data Management Layer' as seen in Figure 2.

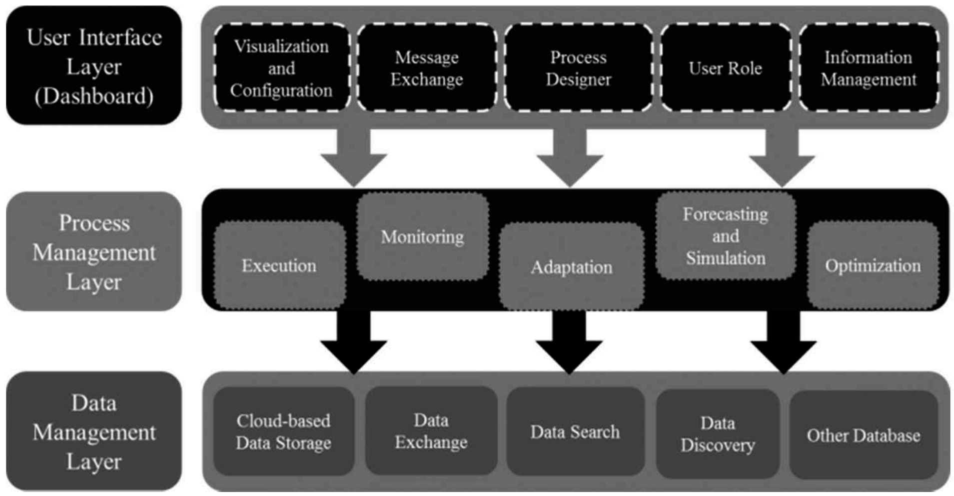

Figure 2. A conceptual architectural framework for virtual factory environment.

The top level (User Interface Layer) is also considered as the 'dashboard' layer, where VF partners are directly interfaced with various collaborative processes. This 'dashboard' layer consists of several user interface components such as visualisation and configuration, message exchange, process designer, user role, and information management. Each of the components has individual functionalities. For instance, the visualisation and configuration component ensures the visibility of the operational activities and configures the visualisation according to the users' needs; the message exchange component offers real time message transfer to the users; the process designer component is responsible for designing the required processes needed to run the complete VF; the user role component defines the users' access to the dashboard through login functionality; and the information management component supports storing and retrieving the required information associated with collaborative activities.

The Process Management Layer of the VF architectural framework is responsible for process related activities and consists of components such as execution, monitoring, adaptation, forecasting and simulation, and optimisation. All the components are defined according to their functionalities. For instance, the execution component accounts for running the designed process of the VF, whereas the monitoring component ensures the process management and finds out any abnormalities during process execution; the adaptation component fulfils the operational gap in case of process failure; the forecasting and simulation component invokes the essential forecasting and simulation of the VF processes that support the future needs and optimisation; the optimisation component facilitates choosing the best option during process management. All the components within the process management layer interact with each other in order to ensure optimum output.

The final layer of the VF framework, 'Data Management Layer' can be defined as the activities related to data processing within the VF. As the other two layers, this layer also consists of several related components such as cloud-based data storage, data exchange, data search, data discovery, and other database. These components are associated with their respective functionalities. For example, the cloud-based data storage component stores the related process data in the cloud from where any data can be easily retrieved according to need; the data exchange component assures frequent and fast exchange of relevant data among the process components; the data search component helps to find any data as needed; the data discovery component provides the required facility to discover any data from the existing data storage system; other database component ensure access to required databases which are not readily available within the VF system.

5. Process monitoring through dashboard user interface

The communication channel between VF partners' is maintained through web-based platform known as dashboard. This platform is operated by the application of Internet technology that provides necessary support to exchange information between VF partners. Different VF components or layers are connected with the web portal through portlets that allows them to interface with each other for establishing required communication channel. This channel is used as the base for VF processes monitoring and management during the execution phase of the VF. Each portlet of the portal contains restrictive information depending on the predefined user role. So in the same web portal the displayed portlets will be different for users with different roles. The technical functionalities of process monitoring can be detailed in the following paragraphs.

5.1. Process monitoring component context

The process monitoring approach has to consider monitoring and control functionalities for the process execution, provide meaningful data in order to allow an up-to-date, real-time diagnosis of the process execution status. The process monitoring should be able to process high amount of data and it has to be as user-friendly as possible. To do so, several technologies have been evaluated and applied. Within the approach of the ADVENTURE project, data is received via Extensible Messaging and Presence Protocol (XMPP) events subscribed at the CPEE. Events and associated data are then stored at the cloud storage – a flexible and scalable data storage system, being distributed among different physical servers. A real-time monitoring component shows the process flow status. A business intelligence engine allows key performance indicators definition, calculation and analysis. Finally, a rules engine is used to create rules and trigger notifications to a holistic dashboard.

The process monitoring component within VF environment is used to present the actual status information, data log and performance data related to various virtual factory processes. The details subcomponents of process monitoring component and their interdependencies with each other are presented in Figure 3.

From Figure 3, it is noticed that process monitoring component consists of the following subcomponents:

- Events receiver
- Real-time monitoring
- Process analytics
- Process log
- Monitoring rules engine
- Monitoring engine

Details of each of the subcomponents can be explained as follows:

Events receiver: Responsible for receiving events with raw data published by the CPEE; stores raw data in the in the cloud storage. XMPP protocol is applied.

Real-time monitoring: This subcomponent shows the actual status of process instances. It uses the same user interface as Process Designer in order to have the same look and feel, allowing identification and tracking of the process instances.

Process analytics: This subcomponent provides an independent service that just queries finished process instances and show them to the user. It collects the key

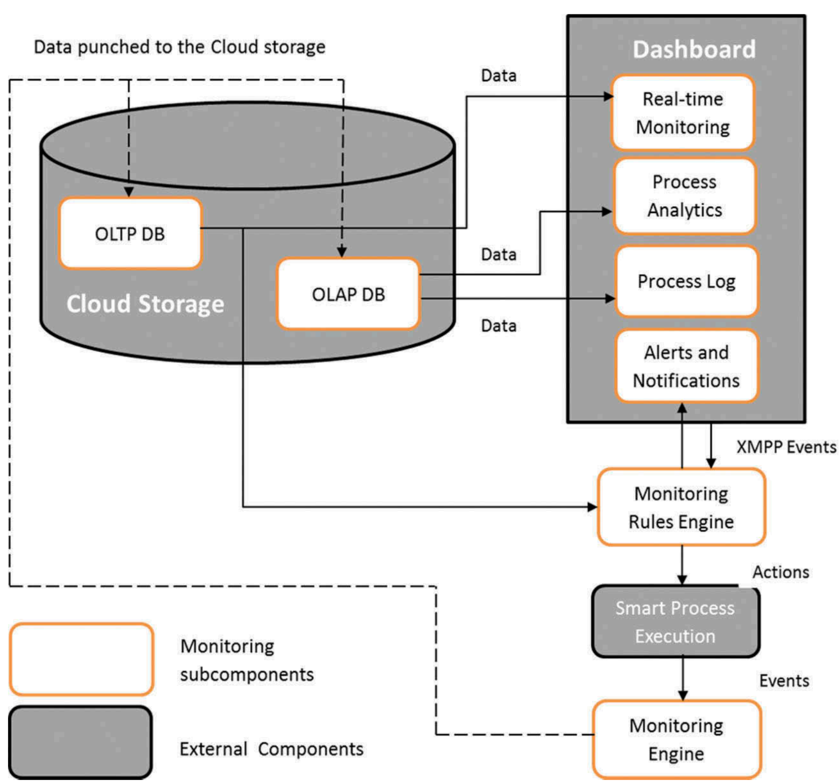

Figure 3. Process monitoring subcomponents.

performance indicators associated with the manufacturing processes.

Process log: It includes a search engine and shows historical data of process instances. It allows users to search for finished process instances and display its data in a graphical interface.

Monitoring rules engine: This subcomponent is mainly responsible to allow the definition of rules and corresponding actions. It throws alerts to the dashboard, as well as performs action upon the Smart Process Engine. The rules are evaluated based on throwing events and notifications. Rules engine allows the definition of rules and associated actions, evaluates rules based on events and key performance indicators (KPIs) values throws events and notifications to the dashboard.

Monitoring engine: It allows the visualisation of key performance indicators related to the manufacturing processes and aggregates and analyses data. It provides a graphical display with the objective to track KPIs.

Performance management engine: It allows the configuration of KPIs related to the manufacturing processes, aggregates and analyses data, and provides a graphical display in the dashboard in order to track KPIs. The monitoring services are implemented REST Web services; provides meaningful data to the other components such as the dashboard.

Based on the data provided by the monitoring component services, a set of widgets can be included in a dashboard in order to create a holistic monitoring environment.

It is observed from Figure 3 that the monitoring engine receives data via XMPP events from the Smart Process Execution and stored the relevant event information in the cloud storage component, so that all data will be available for predictive maintenance analysis. The events data are stored within the cloud within two separate databases such as onLine transaction processing (OLTP) database and onLine analytical processing (OLAP) database according to events types after following the XMPP protocol. The real-time monitoring subcomponent displays a live view of the event data as stored within the OLTP database using the process editor interface. This data visualisation helps virtual factory brokers to improve the performance of the manufacturing processes.

The process analytics subcomponent displays the key performance indicators related to the manufacturing process over the dashboard user interface, which were stored in the OLAP database within the cloud storage. The Process Log also receives finished process instances from the OLAP database and visualises in a graphical interface over the dashboard as displayed in Figure 2. The monitoring rules engine evaluates rules based on the events stored within the OLAP database in the cloud storage and triggers events and notifications. Finally, the Alerts and Notifications subcomponent provides the definition of the rules based on process execution delays which are evaluated by the monitoring rules engine and throws alerts to the dashboard.

6. Dashboard portal: an overview of technical and functional contexts

The application of dashboard user interface as designed and developed under ADVENTURE project is used intensively to process monitoring and management. This user interface layer interacts with the VF partners to know the status update of each of the running processes within the VF. To access this user interface layer, the user needs to register his/her name and detailed in favour of his/her company within the VF. After registering in dashboard portal, the user will get a user name and password to be used to access the portal. The user roles and access rights can also be defined by the VF broker in order to control the information flow and confidentiality among the VF partners, potential new companies, suppliers, customer

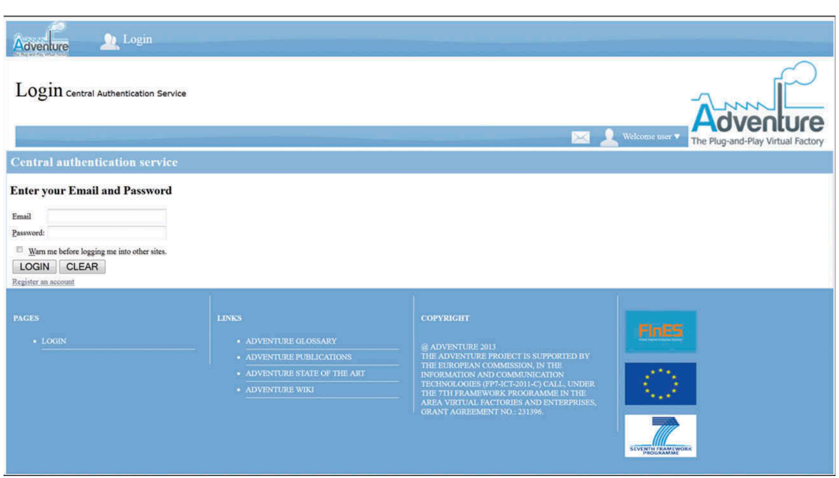

Figure 4. User login page within dashboard portal.

and the broker. For example, the VF broker might access all the necessary information to execute the VF processes successfully, whereas VF partner might have limited access to the process information within dashboard portal and so on. Figure 4 displays the login page of the dashboard portal.

After successful registration and login the user can access the dashboard portal and visualise his/her updated process information. The dashboard portal displays the overall view of different widgets that have their own functionalities as necessary to process update. In order to get detailed information from each of the widget, a user might need to navigate different levels within a widget.

The dashboard portal is populated with 13 widgets that are mainly archived to use them according to users' needs. The widgets are:

(i) Getting started with virtual factory
(ii) Combined C02 (my processes)
(iii) My smart objects
(iv) Process instances
(v) Process may be checked for optimisation
(vi) Resources
(vii) Processes that I own
(viii) Next tasks to be finished by you
(ix) Your work load
(x) Virtual production plan
(xi) My most popular services
(xii) Alerts
(xiii) Chat – message board

Each of the widget has its own functionalities according to users' needs. For instance, Figure 5 displays a snapshot of 'Process Instances' widget within the dashboard portal. This widget contains the necessary process information such as process flow chart using BPMN (business process model and notation), all the processes used in a specific virtual factory environment (simulation, optimisation, forecasting, etc.), etc.

The widget named with 'Processes that I own' provides a list view of the processes that a partner is responsible and currently working for. It displays various processes names and their corresponding progress levels in terms of percentages in relation to the planned progress in time. In addition to the progress levels in percentage, it also visualises the progress in terms of colour codes such as red, green and yellow. For instance, red colour in a process indicates that its progress is less than 50%, yellow indicates that its progress is from 50% to 75%, while green indicates above 75% as displayed in Figure 6.

Another widget named with 'Message Boards' offers an online discussion site, where virtual factory members can hold

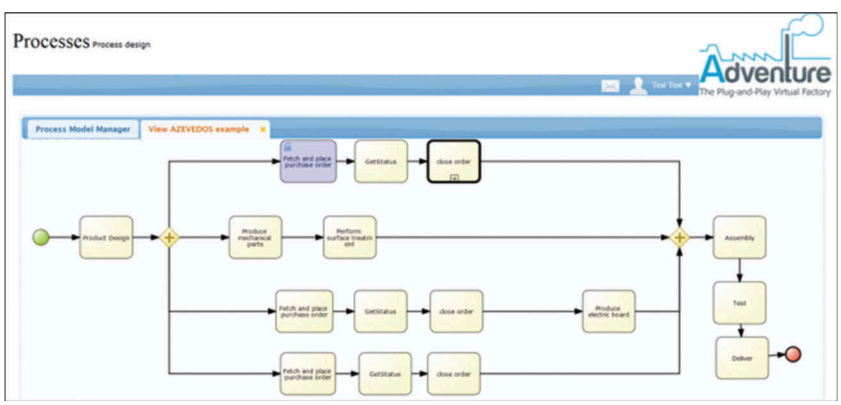

Figure 5. Processes widget snapshot within the dashboard user interface portal

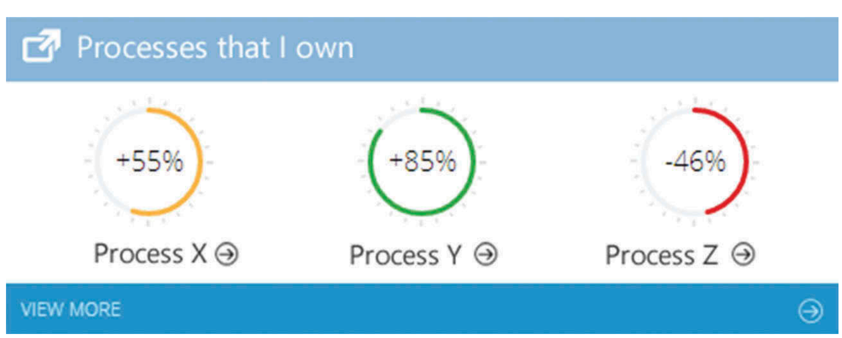

Figure 6. Snapshot of processes that I own widget

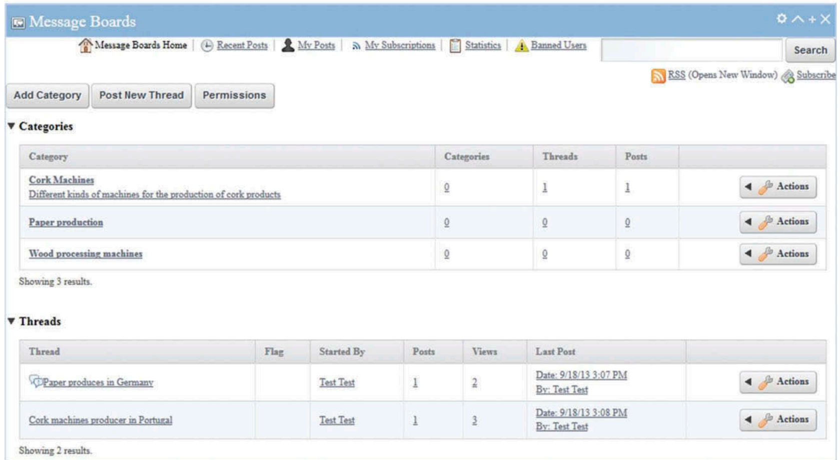

Figure 7. Snapshot of message board widget.

conversations in the form of posted messages. This differs from chat in that messages are at least temporarily archived. In the message board, a single conversation is called a 'thread' or topic. The message board is hierarchical or tree-like in structure: The top end is 'Categories'. It can be divided into categories for the relevant discussions. Under the categories are subforums and these subforums can further have more subforums. Each subforum may have several topics. The topics come under the lowest level of subforums and these are the places under which users can start their discussions or posts. Within a topic, each new discussion started is called a thread and can be replied to by many users. In VF, users have to be registered and then subsequently logged in, in order to post messages. Figure 7 displays a snapshot of the VF sample message boards.

7. ADVENTURE dashboard platform: user interface portal to process monitoring

As mentioned earlier that the dashboard portal is used to monitor VF processes in a most effective and efficient way. This portal collects necessary process information from various sources such as smart objects, sensors, etc., and visualises the data or information in the format of charts, tables, graphs, texts, etc. This data visualisation offers real-time information update of the VF processes and resources which directly influence to overall decision-making processes within the VF partners. A snapshot of the dashboard interface as developed within the scope of ADVENTURE project (ADVENTURE 2011) is displayed in Figure 8.

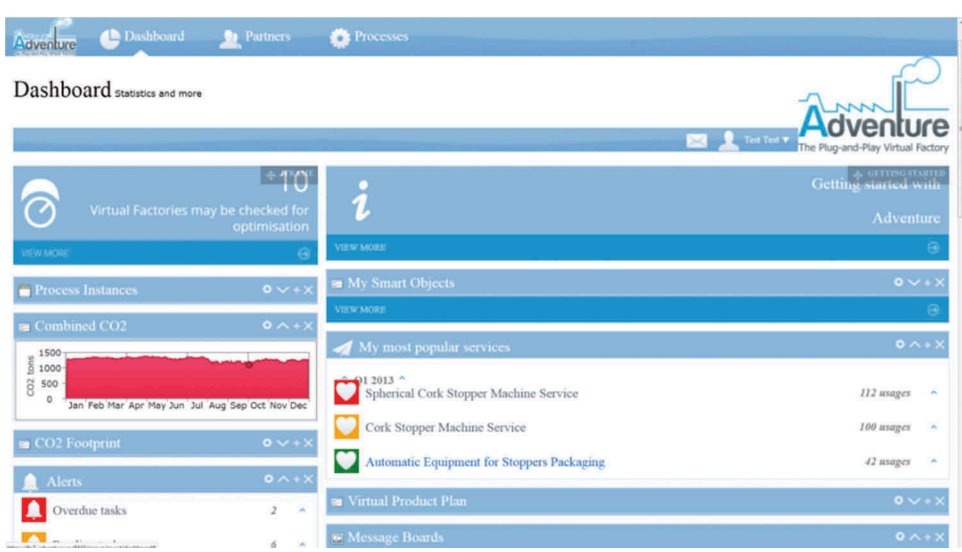

Figure 8. A snap shot of the ADVENTURE dashboard homepage.

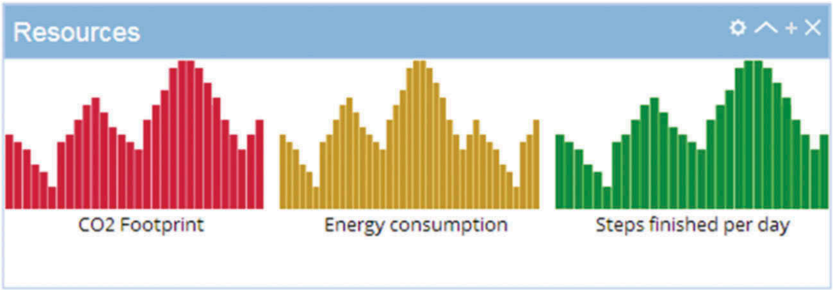

Figure 9. Snapshot of resources widget.

7.1. Status of process resources

From Figure 9, it is seen that the dashboard interface contains several portlets or widgets, such as, process instances list, my smart objects, resources, etc. These widgets are responsible for visualising individual data or information according to the widget type. For instance, 'Resource' widgets as displayed in Figure 9 visualises the corresponding resource status such as CO_2 footprint, energy consumption and steps finished per day. Often this widget also displays other relevant resource information such as resource ready, breakdown, downtime, shortage, etc.

7.2. Alerts message

The idea of the alerts widget is to alarm the VF member related to different VF processes. Figure 10 displays a snapshot of sample alerts widget of the VF dashboard. These alerts are used to get status update of different processes that are executing during the VF runtime environment. The alerts can be in the form of message such as overdue tasks, pending tasks, task failure, tasks over budgets, etc. From these status updates, VF broker and/or partners are able to monitor their corresponding processes and to take necessary measures to manage the processes that are eventually contributes to minimise risks or abnormalities.

The alarms are triggered by the process monitoring rules engine and can be customised by the user according to his/her specific needs. The majority of alarms will be based on the data provided at the design time, comparing it with the actual data. For example, alerts can be:

- Task overdue
- Pending tasks for a long time
- Task/process out of budget
- Supplier out (cannot deliver anymore)
- New high priority message
- Alerts from smart sensors
- High temperature
- High disturbance
- Transportation time too long
- Location not correct
- Transport stopped for 48 h

Figure 10. Snap shot of alerts widget.

7.3. Process monitoring through smart objects

This widget mainly provides the visibility and status information of each of the smart objects within the VF processes. Along with the status information, it also visualises the location of the VF partner's smart objects and presents its status through displaying different colours (e.g. red for urgent, yellow for alert, green for normal). The snapshot of my smart object widget is displayed in Figure 11.

7.4. Status of next tasks to be finished by the corresponding broker/partner

The widget within VF dashboard represents a list of tasks that are next due or were just finished in processes that the user's company is participating in. It allows the VF brokers/partners to track their completed tasks and also the due tasks need to be finished within certain time frame. This widget is displayed in Figure 12.

These are some examples of the VF dashboard widgets and their corresponding functionalities. Each of the widget provides necessary status update of any VF processes and ensures to avoid process delay or process related risks.

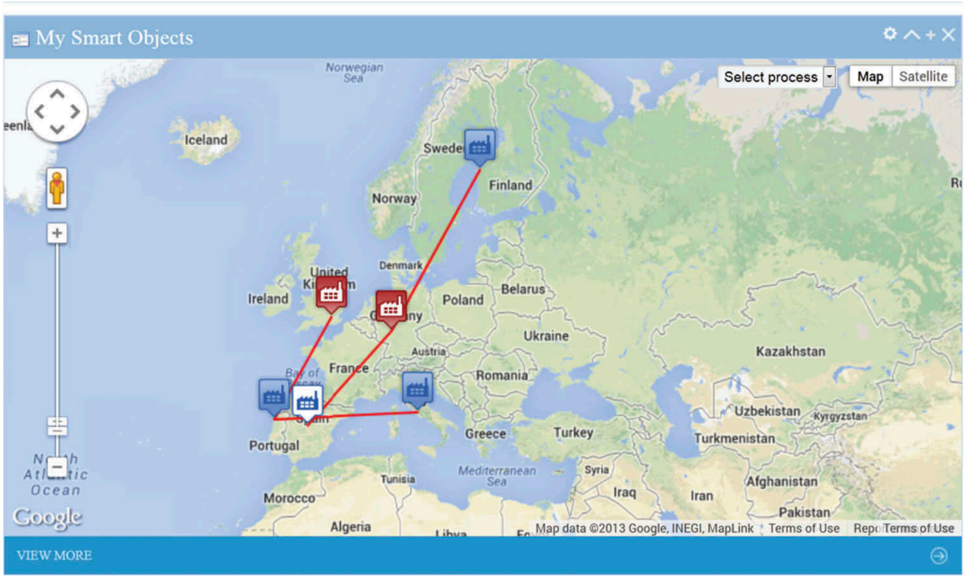

Figure 11. Snapshot of my smart object widget.

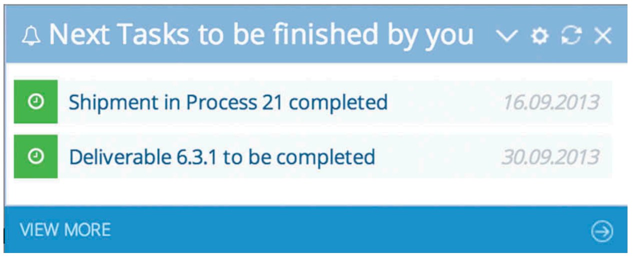

Figure 12. Screenshot of next tasks to be finished by you widget.

8. Implementation of process monitoring within case company

The implementation case regards a leading manufacturer in the cork transformation industry. The company develops, produces, sells and provides post-sales assistance to a wide range of production machinery. Products are complex (multi-part and multi-technology) convergent products that are comprised of hundreds of different components and different technologies. Casting, bending, milling, CNC, image processing, GUI, automation systems, electric and pneumatic components are some examples of technologies and components used.

The company only outsources activities that are not covered by in-house competences such as bending, casting, parts' surface treatment and, on very few occasions, product engineering. Main reasons for outsourcing are the lack of competences (mainly technological) in some operations and the increase of general factory productivity by reducing delivery time to customers.

In a one-of-a-kind production environment or in an engineer-to-order business model, a new business opportunity means a new project and to execute such an order involves specific combinations of different activities, like understanding the customer's requirements, conducting a rough product design, feasibility studies, engineering, rough production planning, production, commissioning and after-sales support.

In order to understand the applicability of the framework to this kind of environment, the business needs and requirements have been analysed using the reference model introduced in Section 3. This analysis led to the process model represented in Figure 13.

Both engineering and manufacturing tasks can be performed internally or outsourced. The outsourcing is decided by the industrial manager for each particular customer order. The manager takes into account the current and future available production capacity.

The design of the virtual factory takes as input a process template providing a rough model that is likely to be changed several times all along the lifecycle using the Process designer tool: The model is progressively refined and specialised as far as engineering proceeds with product design. The process model may also change during the execution time (adaption) in order to react to events such as order delays or quality test failures.

The handling of each customer order includes a specific arrangement of intra- and inter-enterprise tasks whose sequence is described by the developed process model. The lifecycle of each supplier order involves a set of negotiation, contracting, design or manufacturing tasks, expediting and inbound tasks as well as test and

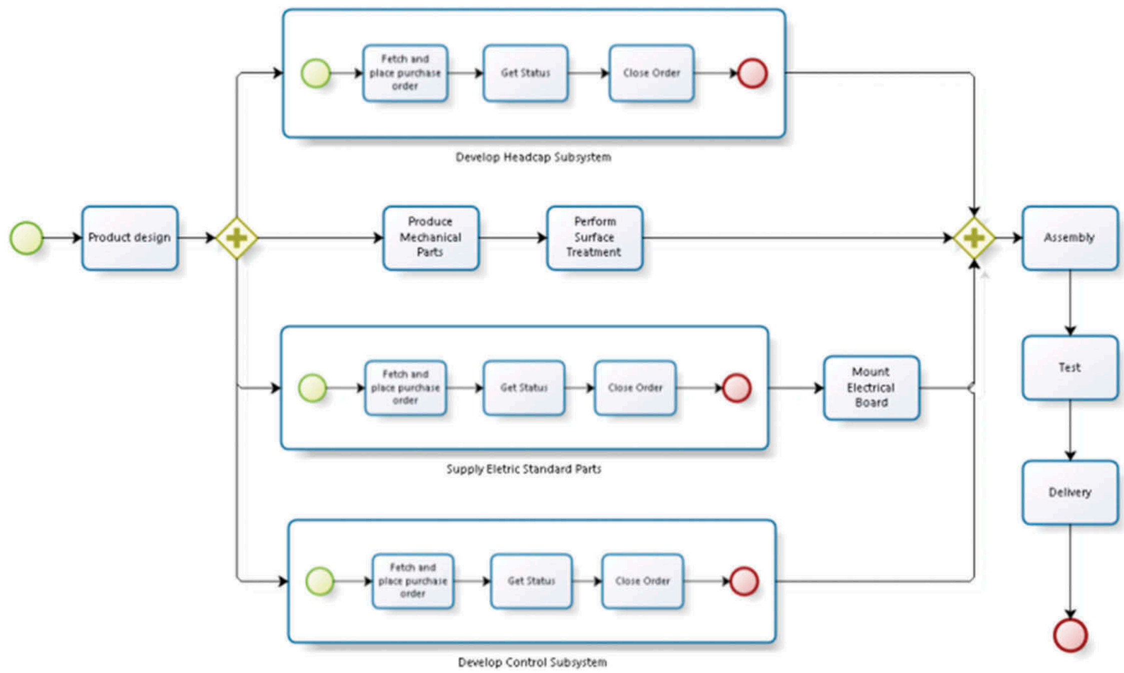

Figure 13. The process model.

verification tasks. Figure 14 Shows the main systems involved in the execution of the extended manufacturing process

Using the process designer and the integration with the Profiles Manager data provisioning and discovery, the process manager is able to search for suitable partners, filtering them by non-functional requirements (CO2 emissions, lead time, cost, location, etc...) and assign them to each external order. Once the process is defined, the simulation and optimisation components can be employed in order to achieve the best result for this concrete process.

The next step is the execution of the process, that's where the Smart Process Engine comes in, controlling the workflow and invoking services on the internal legacy systems as well as on the legacy systems of the partners also involved in the collaboration network. Figure 15 Provides a snapshot of the process dashboard with monitoring functionalities.

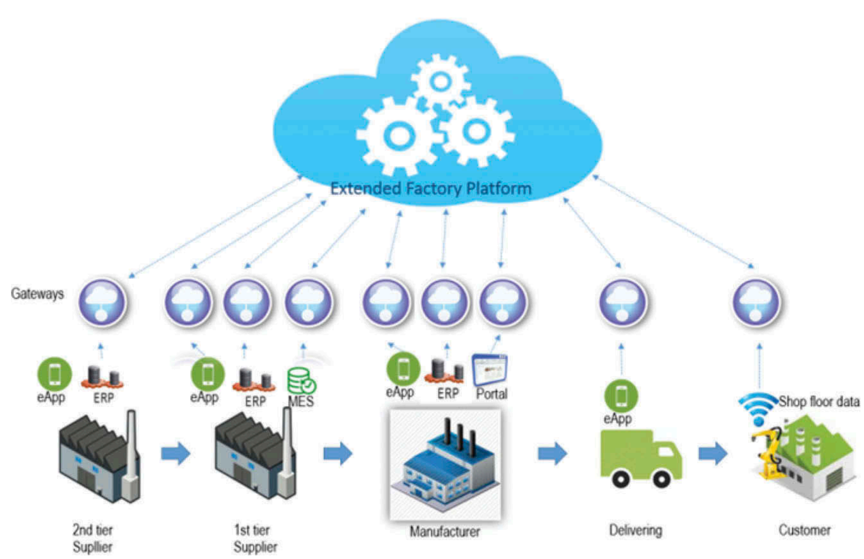

Figure 14. Main systems involved in the extended manufacturing process.

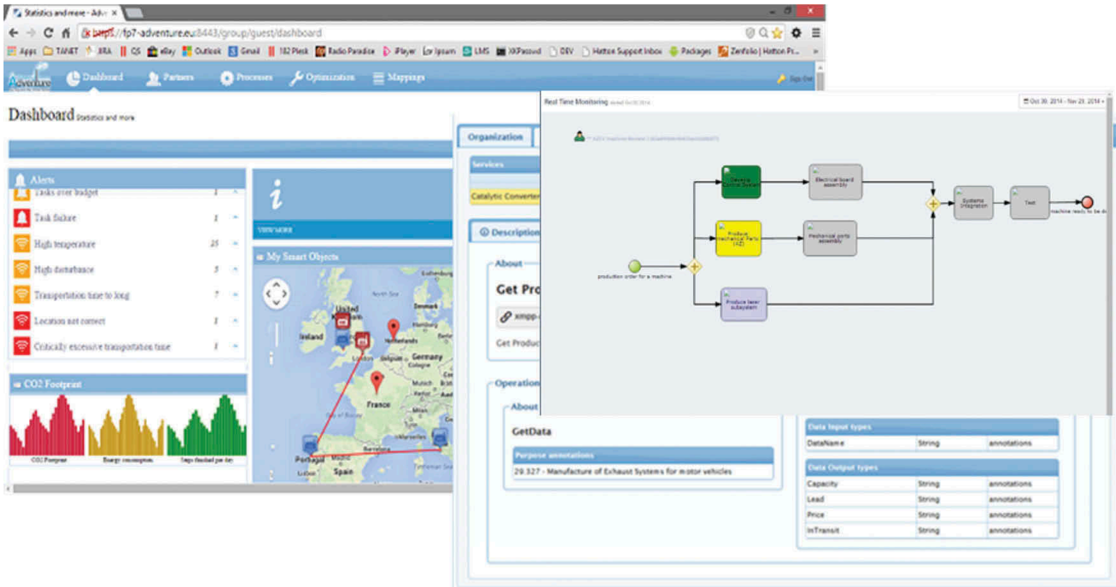

Figure 15. Dashboard screenshot.

The functionalities of the process monitoring component were tested within a case company. The company considers this requirement fully fulfilled by the functionalities of the process designer and dashboard widgets. It was possible to track the status of the entire process through the attached smart objects with it that send real time process status. The dashboard widgets gave a holistic view of the process status as displayed in Figure 15.

From Figure 15, it is noticed that sub-processes of the main process are displayed in various colours that defines their status. For instance, sub-process with yellow colour indicates that there are some disturbances in this sub-process, while green coloured sub-process indicates that it is running fine and so on.

9. Conclusions, limitations and future research

The objective to form and execute a virtual factory is to integrate a group of manufacturing companies to achieve pre-identified business opportunity. Usually, in this type of business collaboration, manufacturing companies with similar product portfolios and expertise are cooperate with each other for sharing valuable resources and skills for mutual benefits. This collaboration cannot be successful until and unless it's associated business processes are monitored and managed properly. Such process monitoring is enhanced in the presence of visualisation options such as display of data or information in the form of graphs, tables, texts, etc. An effort is initiated within this research study to monitor VF business processes through dashboard user interface. This user interaction layer provides necessary technical supports to visualise the monitored data/information within VF processes.

The process monitoring component as presented in this research highlights briefly its associated subcomponents and their functionalities, which contribute to trigger an effective and efficient process monitoring. This component provides process visualisation that is applicable to managing VF business environment. It focuses on meaningful monitored data and control functionalities that allow an up-to-date, real-time information repository. All the data or information is accessed as user friendly as possible and displayed over the dashboard portal.

The dashboard portal features state-of-the-art business intelligence and provides data visualisation, user interfaces and menus to support VF partners to execute collaborative processes. It presents the high level process widgets as used to monitor and manage the virtual factory processes. Each of the widgets functions based on the user requirements and contains specific information repository according to its predefined functionality. All the widgets which are the integrated part of the dashboard portal execute required functionalities and visualised the expected process information over the dashboard. This process information can also be displayed with its levels of urgency such as high, medium and low. This urgency levels help VF processes owners to respond as quickly as possible which ultimately supports to avoid or minimise the possible risks. In addition to, this portal provides an easy way to visualise the status information of the VF processes in real-time business environment.

Process visualisation over the dashboard portal provides critical operational metrics (e.g. key performance indicators) required to manage virtual factories. Advanced visualisations with quality graphics offer information updates that bring the process data to life with clarity. The interactive dashboard portal supports the flexibility to mould the data around unique business objectives in real time through an intuitive graphical interface.

This research also highlights the basic steps of VF life cycle and briefly illustrates the conceptual architectural framework of the VF. Demonstration of such life cycle provides necessity methodological guideline to form and execute VF successfully, whereas the architecture framework supports to the technical know-how of the VF components and their interfaces with each other.

This research has several limitations. First, the stated VF dashboard portal is under developmental stage and will be completed in future research approach. The current dashboard portal is tested upon by using fake data, which will be validated in future with the real data from various business case networks in order to generalise this approach to be used for VF process monitoring. Second, visibility and information contents of each of the widgets will be improved in future version of the portal. Missing widgets and their associated data will be added in future. To support developers to create their own component widgets an instruction manual with descriptions and example, how to work with the dashboard portal has to be written. Furthermore, the dashboard portal has to be tested in-depth to find and fix all possible bugs.

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Disclosure statement

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