Virtual supply chain for networked business : perspective of collaborative bill-of-materials, scheduling and process monitoring for developing innovative product

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Abstract

This article presents a methodology applicable to the formation of collaborative bill-of-materials (C-BOM), coordinating production scheduling and monitoring operational processes. The concept of collaborative product development process is described in detail through an example network, where the participating organizations form a temporary virtual organization (VO) and contribute throughout the entire product development processes. In this paper, the basic need for exchanging product information among the partners is carried out through IT-based software tools, where the partners are enabled to visualize and monitor the operational processes in a real-time environment. This research study concludes with the overall research outcomes and future research directions.

Keywords: collaborative manufacturing, collaborative engineering, logistics management, virtual enterprise, web-based manufacturing, virtual manufacturing

1. Introduction

Business collaboration can be started as early the identification of a business opportunity. Networking among manufacturing firms is becoming ever more attractive (Camarinha-Matos et al. 2008). To compete in the global business environment, manufacturing firms, especially small and medium enterprises (SMEs) need to be collaborative. This collaboration offers extended benefits to firms, which may not be achieved by staying alone. Nowadays, customers are demanding more with customized products and a faster delivery time. Today's business scenarios such as more product variety, shorter product life cycle, and unpredictable demand levels, are exerting extra pressure on manufacturing firms globally. To cope with such situations, geographically distributed firms are needed to work cooperatively in a virtual business environment (Carneiro et al. 2010: Shamsuzzoha et al. 2013).

In a networked business environment, the partner companies collaborate with each other from the early conceptual phase of the product, where necessary design and engineering are undertaken. The key phase of the product development process is the conceptual design phase, where most of the efforts such as defining product architecture, identifying product specifications, creating BOM (bill-of-materials) and operational scheduling are done with a view to managing the lead time and cost. In product lifecycle management (PLM), seventy percent of the total development costs are incurred during this critical conceptual design and engineering phase. The impact of design decision is therefore crucial to improving the overall product lifecycle process. In collaborative design, the partner organizations support the

product's entire lifecycle such as faster time to market, lower development costs, adoption of dynamic market segments and more satisfied customers.

During any kind of collaboration among SMEs, it is very important for respective partners to manage the information across the product development life cycle, which helps them in making better decisions. The real-time information management system supports better focusing on customer-valued core competencies through integrating designers and customers in a true customization environment (Kankaanpaa et al. 2010). This information exchange system provides visibility and cooperation within the partners' value chain (Brusey and McFarlane 2009). It also supports monitoring of the collaborative production processes and finding possible bottlenecks. Along with product engineering, a collaborative business environment also facilitates the formulation of collaborative bill-of-materials (C-BOM), planning for operational scheduling and necessary production routings. In addition, this environment supports resource sharing among geographically distributed partners and ensures true customization on a virtual basis (Rob et al. 2014).

In collaborative product design and engineering, the developed C-BOM, is shared among the network partners to allocate the responsibilities in developing each of the components as required to develop the finished product. During the design and development of a product within a collaborative environment, its entire design efforts should be interwoven among the partner organizations in order to maintain the product's consistency. To maintain such consistency, it is essential to develop collaborative scheduling and production planning to develop the final product. To track the progress of scheduling and planning, the broker company needs to monitor, coordinate and control the collaborative processes (Wu et al. 2007).

From the above discussion, three research questions are identified in this research. They are as follows:

1. How to form a collaborative business environment to develop innovative product for mutual benefits?
2. How does collaborative bill-of-material (C-BOM) and scheduling support the development of innovative product within a collaborative business environment?
3. How to monitor and manage collaborative business processes in fulfilling business goals?

The rest of the paper is organized as follows: Section 2 presents a review of the existing literature on business collaboration in respect to product design and development, while Section 3 presents the research methodology. Section 4 highlights the collaborative definition of BOM along with a case example. The management aspects of business collaboration are depicted in terms of collaborative scheduling and managing abnormal situations in Section 5. A case business network is also presented. The overall managerial implications of the research are illustrated in Section 6. This paper concludes with future research directions in Section 7.

2. Literature review

2.1 Business collaboration – globalized perspectives

The trend towards strong business competition motivates manufacturing organizations to form dynamic collaboration among themselves. Within such collaborative environments, there needs to be seamless integration among business processes with the objective of adapting to continuous changes in business conditions, and staying competitive in the global market (Liu et al., 2009). Different forms of collaboration existed within companies such as collaboration between OEMs (Shi and Gregory 2003, Lin 2004), between suppliers (Croom 2001), and between OEMs and suppliers (Noori and Lee 2000, Schilli 2006). The increasing trend of business collaboration has important implications for the strategic performance of organizations and also for the promotion of open innovation (Mazzola et al. 2015).

Such business collaboration support the facing of challenges in the management of global knowledge networks, distributed project teams, and collaboration across business boundaries

by using information and communication technologies (Rodriguez and Al-Ashaab 2005). It also emphasizes the need to reduce growing complexity of inter- and intra-organizational connections and identities and promotes reflection about organizations in a globalized business context (Soderberg and Holde 2002). With the advent of business globalization and commoditization, manufacturing organizations tend to be more dependent on managing business processes in order to keep their business processes in control (Liu et al. 2009). A business network that consists of geographically dispersed enterprises forms a virtual consortium with the interest of facilitating the efficient performance of resources and task allocations.

Collaborative business demands a platform, which allows potential partner organizations to establish the real-time synchronization of information exchange that is required in developing collaborative product. Global and regional competition has intensified within manufacturing firms due to the development of communication and information technology (Lee et al. 2003, Peyton and Hu 2007, Rittgen 2010). This competitive environment creates the possibility of communicating and working concurrently with all the partners within the business network (Magdaleno et al. 2009; Ebrahim et al. 2011). This is especially encouraging for manufacturing firms that rely heavily on outsourcing or contract manufacturing (Wognum et al. 2002, Palakshappa and Gordon 2007).

Different types or formats of tools have been developed in order to facilitate business collaboration within business organizations. Vojdani (2003) proposes a business integration platform or middleware that enables organizations to improve the integration of information systems, integration with partners, automation of business processes and workflow, and real-time process visibility. O'Reilly (2005) has introduced Web 2.0 as a tool for networks as a platform. Roman et al. (2006) review various business models for Web 2.0 communities. Romero and Molina (2009) propose an Integral Business Process Management (I-BPM) framework to promote collaboration within organizations. Rabelo et al. (2014) highlight a governance reference model to execute intra- and inter-organizational business processes in a coordinated and secured way, which is mostly supported through computer networks. Arsenyan et al. (2015) propose a game theory approach to integrate trust, coordination, co-learning, and the co-innovation dimensions of collaborative product development.

2.2 Collaborative product development – application of information and communication technology (ICT)

The product development process in a collaborative environment assists organizations to move towards a value chain approach, where the strategy helps to uncover new product and market opportunities (Shamsuzzoha et al. 2009, 2017, Chen et al. 2009). This approach creates synergy among the collaborative partners and sharing of the resources to contribute to selling larger projects together. This collaboration can be temporary, based on an identified business opportunity, or longer term, depending on the trust and commitment among the partners. In collaboration, SMEs can overcome the challenges of customers' demands for high quality, and low cost products with added functionalities (Ebrahim et al. 2009, 2010). It has always been a very difficult task to develop an innovative product, where different complex systems are designed in a collaborative way (Aziz et al., 2005; Mazzola et al., 2008).

Such business collaboration integrates differentiated offerings, quick response manufacturing and better commitment by sharing risks and profits. The development of possible innovative product with competitive price is also a benefit for the collaborative network (Miles and Snow 1986, Thorelli 1986, Snow et al. 2011). The collaborative product development process needs to exchange real-time design information among partners and customers in order to form a mutually influential value chain system (Lu et al. 2013; Camarinha-Matos 2014; Durugbo 2015). This value chain system is usually implemented all the way in the product development system from idea generation, preliminary evaluation,

concept design, product development, product testing, trial run and product launch (Cooper 1994). The objectives of collaborative product design and development are to optimize the product function, develop collaborative BOM, minimize production or assembly costs and provide an economic way of monitoring and managing the operational schedules.

Before starting collaborative product design, partners need to identify the customer requirements and product specifications on which the design partners determine the basic product framework and design parameters (Wang et al. 2002; Huang et al. 2003; Ritter et al. 2004; Camarinha-Matos 2008, 2009). To be successful in developing innovative product within collaborative business, it is critical to implement ICT tools extensively. This supports the maintaining of a real-time communication system between the business partners (Li and Qiu 2006). Litter et al. (1995) suggest that collaboration requires frequent communication among all involved partners, where an ICT tool has a significant role. Bruce et al. (1995) suggest that the involvement of collaborative partners through an ICT framework supports the reducing of product development complexities and ultimately increase market competitiveness. Table 1 displays a research synthesis on collaborative product design and development.

Table 1: Research synthesis on collaborative product design and development

Authors	*Application domains*	*Key findings*
Lin (2004)	Research survey	The author examines the relationship between manufacturing strategy of the original equipment manufacturers, suppliers and network innovation agility in design and development of product.
Aziz et al. (2005)	Case study	This research proposes a collaborative product development and knowledge management platform based on ontologies, rules and workflows.
Li and Qiu (2006)	Literature review	The authors present a number of research works and commercial systems to provide solutions for collaborative and distributed product development.
Mazzola et al. (2008)	Case study	This study provides a methodological solution to develop inter-firm collaboration in new product development by searching for a trade-off between market and relational approaches between partners.
Shamsuzzoha et al. (2009)	Case study	The authors outline an integrated configuration framework along with different tools and methodologies to support firms in developing collaborative customized products in both upstream and downstream activities.
Kankanpää et al. (2010)	Research study	This research work presents a methodology concept to support SMEs in building non-hierarchical business networks to develop collaborative innovative product.
Hou and Yang (2011)	Case example	The authors propose an integration methodology of product data model and knowledge management to establish a structure for the collaborative design of project, design, process, proceedure and product.
Poetz and Schreier (2012)	Research survey	This research focuses on the crowdsourcing concept which constitutes a promising method to gather user ideas that can support manufacturing firms in generating new product development ideas.

Comuzzi et al. (2013)	An optimization model	This study proposes an approach to flexibly design and enact cross-organizational business process monitoring based on product-based workflow design. This monitoring process is optimized by an ant-colony optimization heuristic.
Zeng et al. (2014)	Business case	The authors highlight a method based on Petri nets to coordinate intra and cross-departmental patterns including a message interaction pattern, resource allocation pattern, task coordination pattern, service outsourcing pattern and process activation pattern.
Mazzola et al. (2015)	Theoretical framework	The authors explore the role of the interaction of centrality and structural hole positions on the likelihood of developing new products and moderating role of an open innovation flow.
Wu et al. (2015)	Theoretical framework based on literature	This research highlights a service-oriented collaborative product development model in which service consumers are enabled to configure, select and utilize customized product realization through cloud-based design manufacturing.

2.3 Collaborative business process monitoring and management for mutual benefits

In a collaborative environment, the required business processes are run across multiple partner organizations, and therefore tracking or monitoring the business processes becomes particularly important in order to perceive the progress of the collaborative activities. However, the tracking process is generally complicated in order to maintain the correlation of collaborating process instances (Liu et al. 2009). The objective of process monitoring within a collaborative environment is to uncover the inherent complexities and to explore their impact on performance based on a paradigm of collaborative advantage. In order to gain competitive advantage, partner companies are needed to reorganize their business processes by implementing automated or semi-automated process execution based on workflow and process engines (Kung et al. 2005). Often there is a need to combine process modeling, process execution, and process measurement in order to gain efficient process monitoring within the collaborative environment.

The management of business processes that span the organizational boundaries has been a focus of interest from individual and collaborative organizations. There are usually two channels of business process monitoring and management. One way is to drive by conceptual aspects of business process integration, modelling issues and formal foundations, whereas the other way is mostly based on developing technologies in the web services arena (Sadiq et al. 2006). Typically, process integration occurs through the exchange of events between process instances and/or message exchange. It is considered a hard problem to manage a business process that requires collaboration between multiple sub-processes within or across organizations (Gouy et al. 2010). Coordinating the entire processes correctly and efficiently demands the integration of partner organizations' IT infrastructures (Zeng et al. 2014).

In collaborative business, partners need to track and trace the product development activities beginning from the conceptual phase to the product retirement phase. In order to fulfill such business requirements, the collaborative partners establish common communication platform from which they can easily visualize the operational activities within the network. Any abnormalities during the operational processes are controlled and managed through the support of an effective communication and information-sharing tool among the partners. This information-sharing tool facilitates the managing of the potential risks, which might evolve

during the distributed/decentralized operations and promotes a well-connected buyer-manufacturer relationship. The communication tool or platform ensures the real-time information tracking necessary for building up long term business collaboration (Benford et al. 2001, Hou and Yang 2011, Brown and Recker 2011). It is, therefore, an important issue to establish an efficient information and communication infrastructure before considering any kinds of collaboration, whether it be short term or longer term (Comuzzi et al. 2013, Wu et al. 2015, Lee and Lee 2015).

2.4 Identified research gaps related to collaborative business process monitoring

From the literature review, it was noticed that extensive work has been performed regarding the formation of business collaboration within manufacturing companies (Romero and Molina 2009). However, little research has been carried out on illustrating collaborative product development, where easy to access tools and techniques are used to design and develop collaborative product. This research gap is identified and an easy to access web-based tool developed in this research, which can be used with facility to develop an innovative product. This web portal demonstrates the steps of collaborative product development such as concept design, development of C-BOM, partner search, process schedule and monitoring. It is believed that such a combination can contribute to promoting business collaboration with extended benefits such as increased productivity, reduced lead-time and higher customer satisfaction.

It was also noticed from the literature survey that very limited work has been performed on business process monitoring within a collaborative business environment. Potential research on this new dimension might add value to the success of collaborative business. To achieve a win-win business benefit from collaborative business, the partners are required to monitor their business processes in real-time. Keeping such a research limitation in mind, this study introduces a web-enabled business process monitoring within the networked business environment. It is hoped that the presented process monitoring methodology and tool will be able to offer a unique opportunity for collaborative partner organizations to execute real-time business process monitoring and take the necessary remedial measures for any process abnormalities.

3. Research methodology

The methodology of this research was based on an extensive literature survey, which was followed by the development of a web-based portal to enable the formation of business collaboration. Research conducted by different authors on business networking was reviewed and the key findings from each work were identified and presented in a research synthesis. Based on the research survey potential research gaps were identified.

The research outcomes were implemented in a case business network that followed the concept of business partnership with other companies for mutual benefits. This case business network was demonstrated with the objective of validating the research outcomes with the help of the developed web portal. The study included a strategic analysis and an analysis of its collaboration processes to develop innovative product with higher customer satisfaction. The case business network was based in Europe and its target product was to design and develop innovative shoes.

In order to conduct this study, both qualitative and quantitative approaches were considered in the field of collaborative business. In the qualitative part of the study, necessary data from the case business network were collected with the objective of analysing its product development strategies and develop an innovative product at the end. In the qualitative part of the research, a list of the necessary components of the case business network's product were identified with the objective of developing collaborative bill-of-materials (C-BOM), process scheduling and monitoring of the business processes.

In addition, a web-based tool was developed within the scope of the research project named 'Net-Challenge', a 7th framework EU project. The developed web-based tool was used and validated through the collected data from the case business network. This tool was demonstrated in terms of its suitability or applicability to develop the C-BOM, operational process scheduling and process monitoring in the case business network. The software architecture of the designed tool used to develop and engineer the collaborative product can be seen in Figure 1.

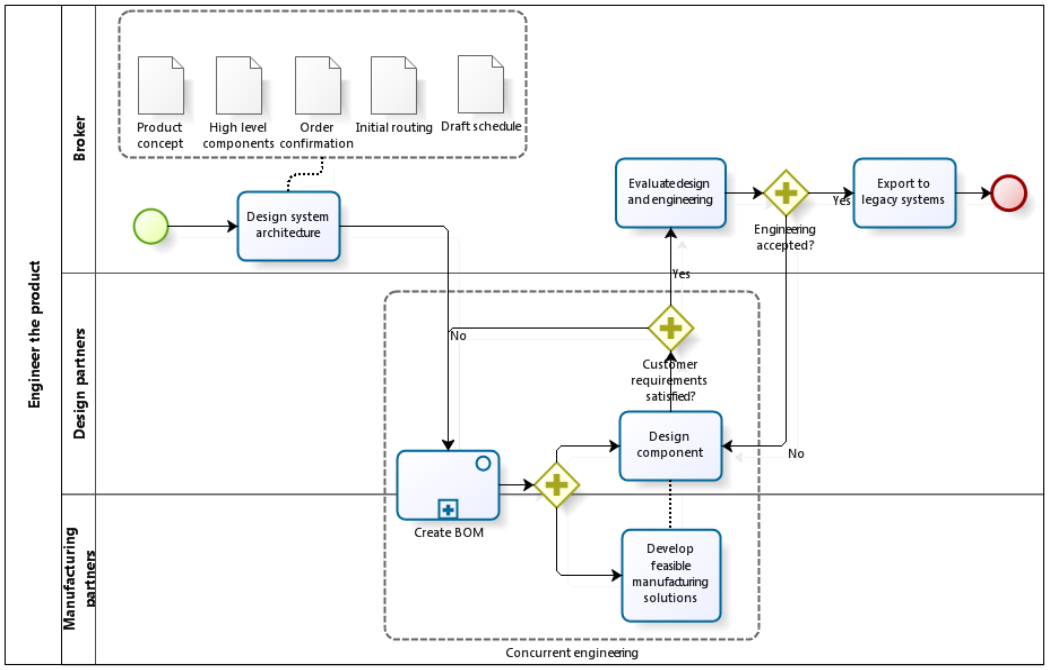

Figure 1. Display of the software architecture of the developed tool used to design and develop the collaborative product.

From Figure 1, it is seen that the software architecture used to design and engineer the product has three levels, namely broker, design partners and manufacturing partners. The virtual organization broker who initiated the business collaboration starts by designing a system architecture. This architecture is designed immediately after receiving proposed product details such as product concept, high-level components, order confirmation, initial routing and draft schedule. The next step of the product design process is to create the BOM (bills-of-materials), which is done by both the design partners and manufacturing partners iteratively within the business network. After creating the BOM, necessary decisions are taken by the design partners to design the required component, whilst the manufacturing partners simultaneously develop feasible manufacturing solutions.

In order to design any component by the design partner, a continuous information exchange is maintained with the manufacturing partner to develop the necessary manufacturing solutions. During the designing of any component of the proposed product, it is checked whether it satisfies the customer requirement or not. If the designed component fails to satisfy any customer's requirement, it goes back to the BOM creation phase; otherwise it moves to the broker organization for required evaluation of its design and engineering. All the three phases, namely BOM creation, component design and manufacturing solutions, are worked concurrently in order to avoid any mismatch. If the required design and engineering of the component is satisfied, it is then exported to the legacy systems; otherwise it goes back to the design partner for any necessary updating. The design of a component is ended after satisfying the legacy system, as seen in Figure 1.

From Figure 1, it is also noticed that the proposed software architecture optimally interacts among the three use cases of broker, design partner and manufacturing partner. This common interfacing creates an optimal design solution within the business network. The number of use cases might vary from one business network to another one depending on the level of required interaction and collaboration need. In this study, three partners from different countries in Europe were selected as the broker, design partner and manufacturing partner respectively and the validation of the software architecture was performed accordingly within the scope of this research.

4. Collaboration within the business domain – essential benefits

Collaboration between organizations, whether they are distributed globally or locally are a fact of reality in business today. In the global economy, sustainable and fruitful collaboration offers organizations a significant competitive advantage. The collaboration is an effort by two or more organizations to achieve business benefits that they cannot achieve individually. It has been widely discussed in a variety of disciplines. Usually, a collaboration or business network can be short term or long term depending on the needs. It promotes the development of innovative products, where each aspect of the developmental phases such as product design, preparation of BOM, scheduling and operations planning are shared among partner organizations.

4.1 Collaborative bill-of-materials (C-BOM) – perspective from business networking

During the conceptual phase of collaborative product design and engineering, the designers from partner organizations need to develop the draft bill-of-materials (BOM), which is populated as time proceeds. In the conceptual phase of the product design, the design information is shared among the business partners for necessary feedback from their corresponding design teams. At this stage, the initial design specifications are enriched with the updated information as received from the partner organizations. The next step in collaborative product development process is to create a detailed design, where the conceptual design is extended and detailed BOM is developed simultaneously with the design teams within the partner organizations.

The fundamental concept of the collaborative BOM (C-BOM) comes from the business network, where the partner organizations directly participate in the conceptual stage of the product design up to the final delivery of the product. In this product development chain, the partners create the C-BOM dynamically after performing any necessary iterations among them. All the product information/specifications are made available and visible to the corresponding partners in order to contribute to the development of the detailed BOM, known as C-BOM in the network environment. This C-BOM covers the detailed level of the component hierarchy along with essential information related to operational routing and scheduling, resources planning, and monitoring the production status. It is therefore considered an important milestone in the networked business to develop an up-to-date BOM which is essential for the proper planning and managing of the overall product development process.

The detailed level of the C-BOM is confirmed after securitizing the multiple BOMs created and iterated within the partner organizations. This develops an identical view of the target product and process definition among the cross-functional design teams within the network partners. It also helps to promote true collaborative engineering in the early stages of product design and optimizes the work between the design and manufacturing team. In today's globalization era, planning for product development is an important activity for manufacturing companies. To ensure a seamless production process in a decentralized business environment, the collaborative partners need to promote the concept of web-enhanced dynamic C-BOM. In this environment, the developed C-BOM enables smooth handling of the specified product development process regardless of the geographical locations of the partners. During the developmental stage, the C-BOM considers the customer order, supplier order as well as

manufacturing order to formulate the necessary integration within the production planning process.

4.2 Production scheduling – perspective from collaborative business

Production scheduling is an important factor in developing any product. Major product development costs are associated with production scheduling. In the case of production delay, the developmental cost of a product increases significantly. This scheduling is even more important in the case of a collaborative business environment, where partner organizations are needed to communicate, collaborate, and cooperate with each other effectively and efficiently. The implementation of information technology can provide faster communication within such a collaborative environment.

In addition, information technology supports information exchange across organizational boundaries, which helps the decision-making process within the business collaboration. In the case of collaborative scheduling, such a decision-making process enables the partners to maintain a real-time process update within the business network. In order to maintain distributed scheduling within the partner organizations it is therefore necessary to establish an information technology-based platform (Chan et al. 1999). The objectives of collaborative scheduling are to minimize the total costs due to delay in the production process and delay due to distribution of the workloads within the partner organizations.

4.3 Business process monitoring – perspective from collaborative business

To be competitive, manufacturing firms engage together to form a business network, where various business processes are executed simultaneously. In order to improve collaborative business processes continuously, an online-based process monitoring system is required. This monitoring system consists of a combination of process modeling, process execution, and process monitoring and control. Based on the collaboration requirements, the process monitoring system integrates with different process engines and performance management software, with the objective of supporting process monitoring, process measurement and business activity monitoring.

Along with status update, monitoring and management of the business processes, this monitoring system finds abnormal situations or process bottlenecks, which might evolve within the business network. The aim of the process monitoring system is to support real-time analysis of the collaborative business processes with a view to improving the speed and effectiveness of the collaborative business operations. It is therefore essential to develop an analytical tool to provide a timely and integrated view of the monitoring and evolution of the business processes or activities within a business network.

5. Business collaboration: a case business network

In this section, a case business network is presented, in which the partner organizations are working in a collaborative business environment. The example of this case business network is taken from the European Union project named ‘Net-Challenge’, a 7th framework EU project. The idea to present this case business network is to explain the use and importance of information sharing in developing collaborative innovative product. It also facilitates the achieving of business benefits in terms of cooperation and coordination between the network partners.

The broker company of this case business network is situated in Italy and its products are different types of shoes. In this specific case, the production scenario of a men’s shoe is developed collaboratively. In this case, three important aspects of the business collaboration are highlighted, namely collaborative BOM, and the scheduling and monitoring of business processes . All three collaboration aspects are presented in the following sub-sections.

5.1 Example of collaborative BOM within a networked business domain

In the business network, the definition of collaborative product enables the partners to specify a high level of product structure. This product structure is considered the basis for searching for appropriate partner organizations, which are suitable for a specific operation within the collaborative case business network. The basic product concept and partner search within the case business network is presented in Figure 2. From Figure 2, it is seen that the case business network's product, 'Shoe for men' is developed by implementing the concept of C-BOM.

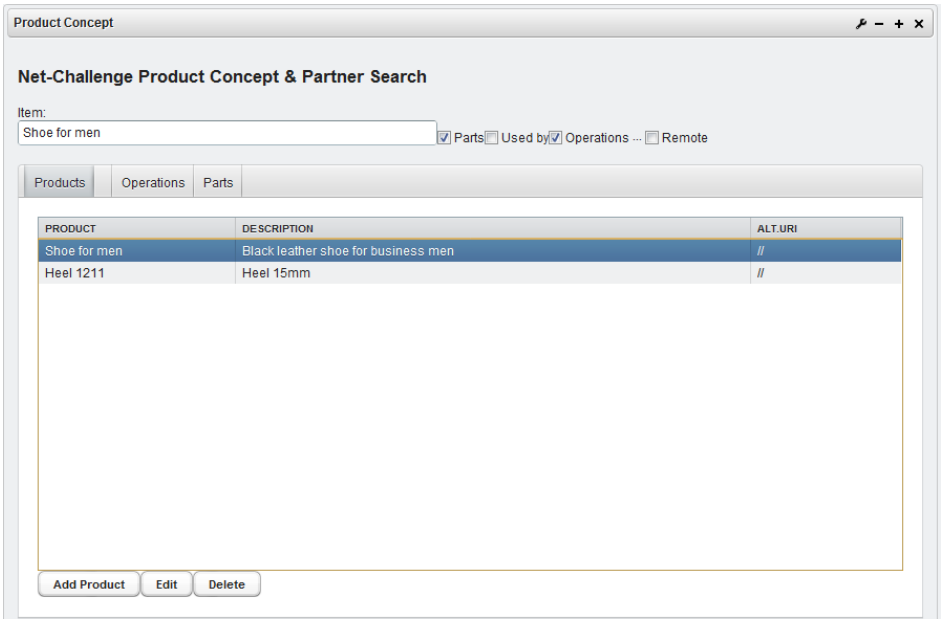

Figure 2. Display of the case business network's product concept and partner search window.

A high-level description of the collaborative product (shoe for men) is populated in Figure 3, from where the product name, product description, selection option for the product, and URL address of the product type can be identified. All these features are available under the 'New Product' category of Product Concept window. Within this window, additional categories such as 'Products' (containing available products), 'Parts' (containing available parts) are available too.

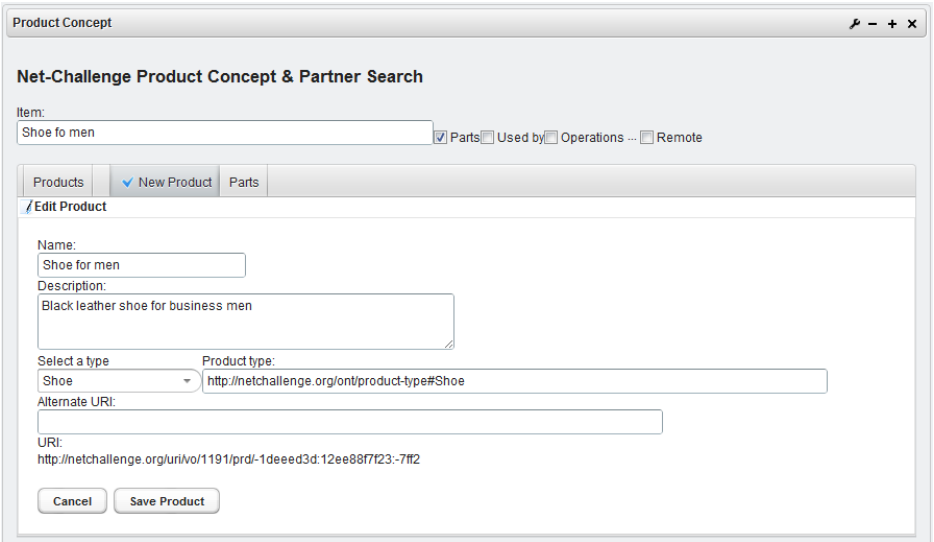

Figure 3. An example of case network's product description along with URL address window.

Different parts of the collaborative product need to be identified in order to create the C-BOM and to allocate the responsibility for each part among the case business network's partner organizations (here mentioned as supplier). Figure 4 presents the parts list along with partner's name as required to develop the final product. In Figure 4, other information related to the production process such as sequence number, part for specific variety, product name, part ID, supplier name, quantity and cost can be seen. This product concept window can also be used for the purpose of editing each of the items product or part, add part, delete part, select sub-product, as also displayed in Figure 4.

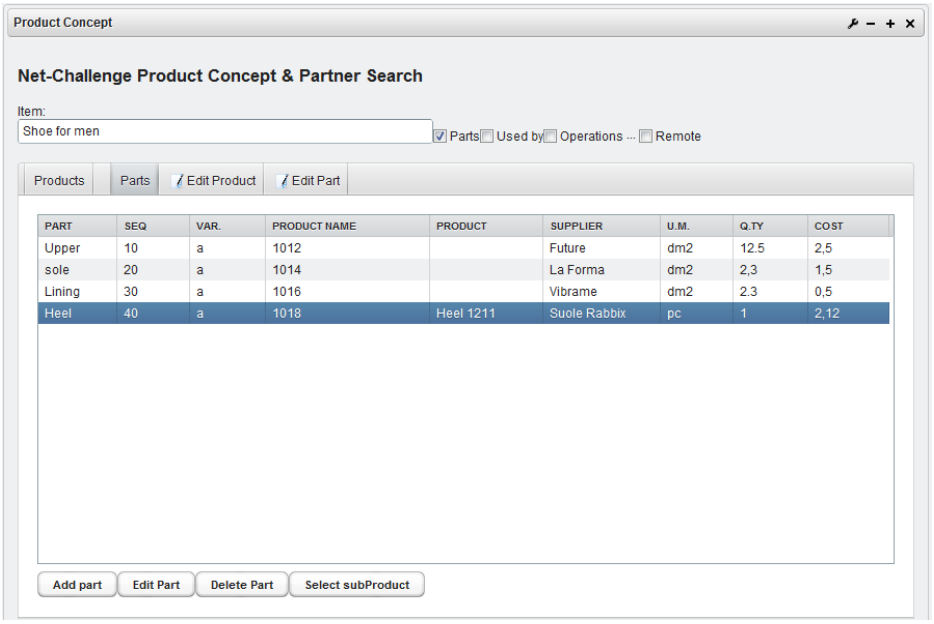

Figure 4. Detailed parts list with necessary information about the case business network's product window.

The parts list as displayed in Figure 4 can be edited according to the product's requirements. Figure 5 visualizes the detailed information related to edit part. The necessary information associated with editing a part such as role, known roles, sequence, variant, type, supplier name with URL address, product code and description, can be seen in Figure5. All this valuable information is important in maintaining and managing a C-BOM within the case business network.

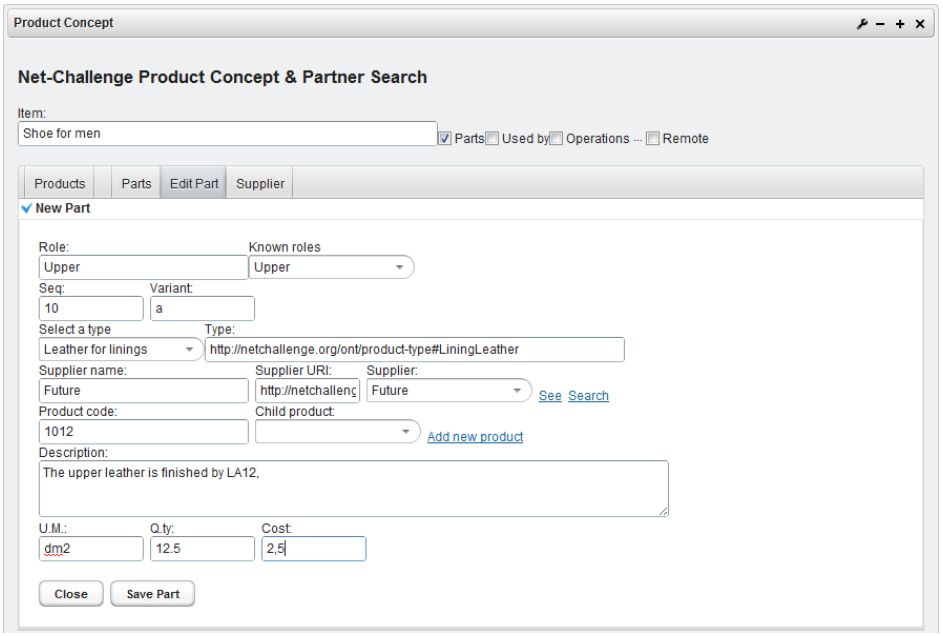

Figure 5. Display of available information for editing a part within the case business network.

5.2 Example of collaborative scheduling in a collaborative business domain

In collaborative business, the operational processes within the partner organizations are usually scheduled and controlled by different communication media such as telephone, e-mail, SMS, social networking, etc. This often creates an information jam and it needs time to obtain a response to any urgent query. In networked business, it is critical to have real-time information updates on the production schedule, process status and inventory management, in order to obtain optimum benefits. Keeping this in mind, partner organizations need to look for prospective solutions to procuring real-time process updates on their operational activities. These activities can be visualized in the Gantt chart, where collaborative process schedules are displayed, as shown in Figure 6. This operational schedule helps the partners to monitor and manage their business processes and take necessary actions in case of abnormality or delay.

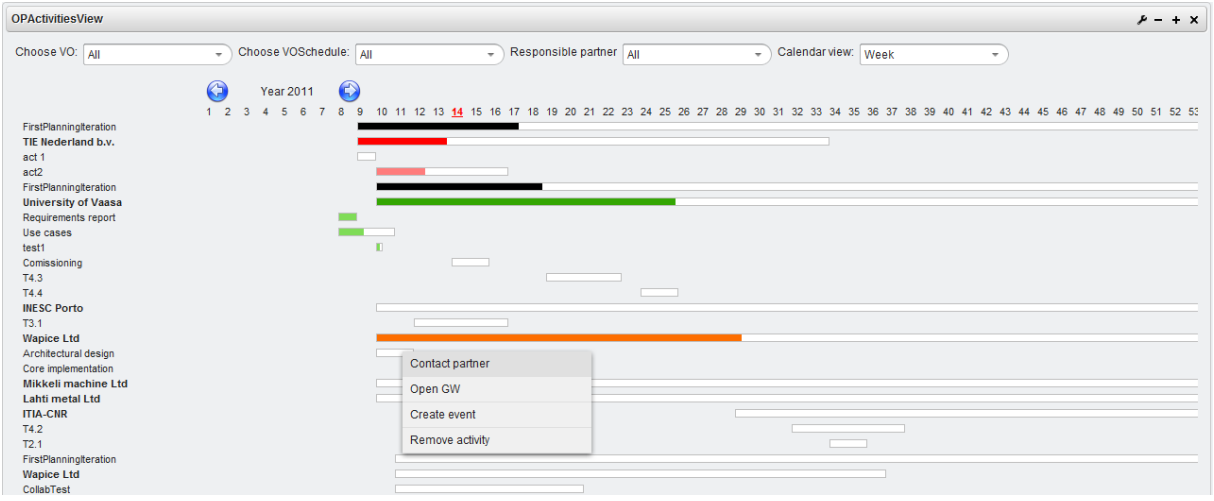

Figure 6. Gantt chart showing the individual partners' process schedule.

Each of the partners in the case business network has its predefined timetable related to its operational activities. When any partner needs to ask for specific operational progress, the partner organization can write down the required description of the operation's name and ask

for its current progress status. This query form might include information such as start and end date of the specified operation and its current progress as a percentage. Figure 7 displays a sample diagram taken from the case business network's portal. This portal visualizes the required information of a particular operational query and its instances in addition to the name of the responsible partner.

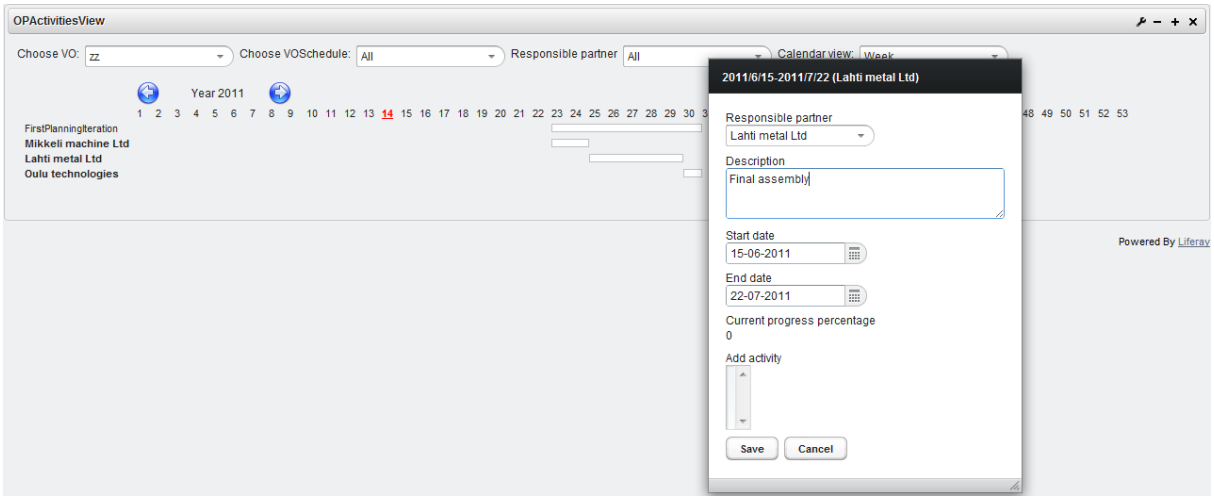

Figure 7. Updating the real time operational status of the case business network.

After receiving an information query related to process progress from a specific partner organization in the case business network, the corresponding partner updates its status information and posts it to the communication infrastructure or portal. Figure 8 visualizes the status update on a tool bar as required for the partner to know about its operational progress. For instance, Figure 8 displays that the operation named 'wheel assembly' is 50% ready according to the current timetable, and the corresponding partner organization can update this status information with respect to its operational need.

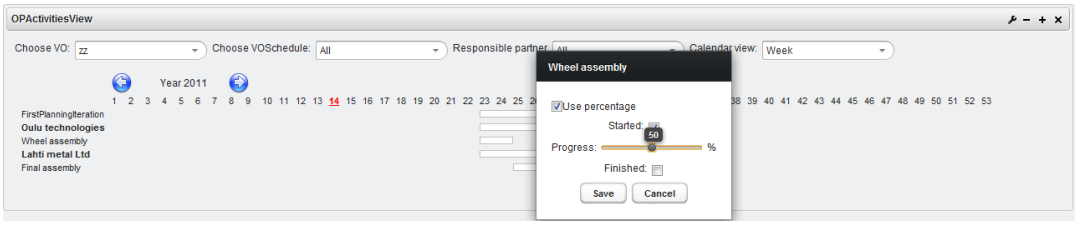

Figure 8. Display of status update on a tool bar according to production progress.

5.3 Example of collaborative business process monitoring in a networked business domain

Within the collaborative business network there needs to be continuous monitoring of the business processes with the objective of executing the operational processes smoothly. During the execution of the operational processes, different forms of abnormal situations known as events might occur which hamper the business processes within the network. These possible abnormal situations or events can be, for example production failure or production delay due to material shortage, power outage,, breakdown of machinery, or labor unrest or strike. These events can be structured or unstructured. Structured event can be estimated beforehand with a possible mitigation plan, whereas unstructured events are usually difficult to manage due to the absence of a predefined mitigation plan. Both possible structured and unstructured events need

to be monitored in order to execute effective collaboration activities within the partner organizations.

Before considering the event monitoring process, the affected partner(s) needs to create an event, which describes the abnormal situation(s) as it happens within the partner's organization. This event creation activity can consist of relevant information such as event type, time of event, partner name, etc.. Figure 9 displays an example of the procedural steps to create an event for any specific situation within the case business network. After creating an event, it needs to describe the event fully for the benefit of the other partner organizations. This description might involve various information such as add or remove this event from the event window, which partner needs to be contacted, edit status if needed, priority of the event to control it, etc.

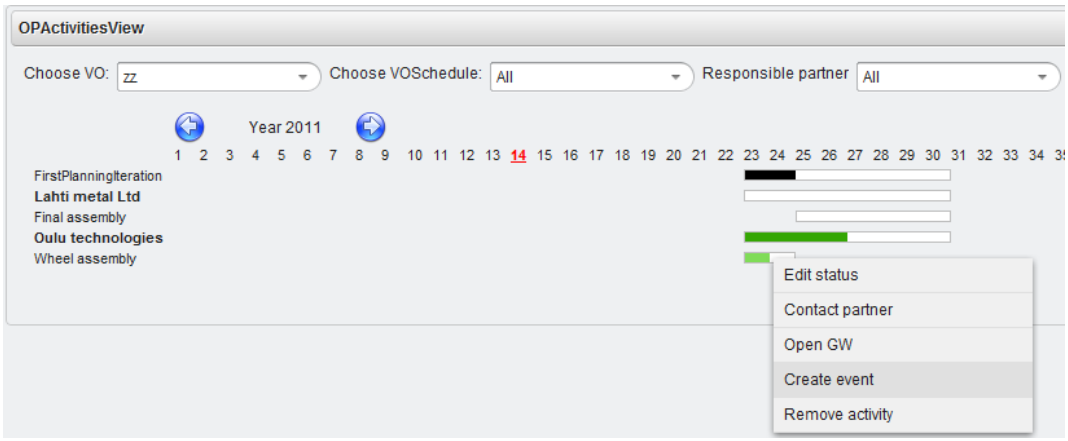

Figure 9. Generic view of monitoring an abnormal situation (event).

Figure 10 illustrates the basic information needed to create a new event within the case business network. A possible event window is seen in Figure 10 with the basic information of a new event such as event status, event name, source partner, priority level, detailed description of the event and effect range, either on the local or virtual organization (VO) level. It also displays the option of notifying the partners. During the notification process of event information to the networked partners, the priority levels of the event are made by visualizing it using different color codes. For instance, red color reflects that the event is more serious and immediate action needs to be taken, while the yellow and green colors interpret medium and low effect respectively as displayed in Figure 10. All such event information can be saved for future use.

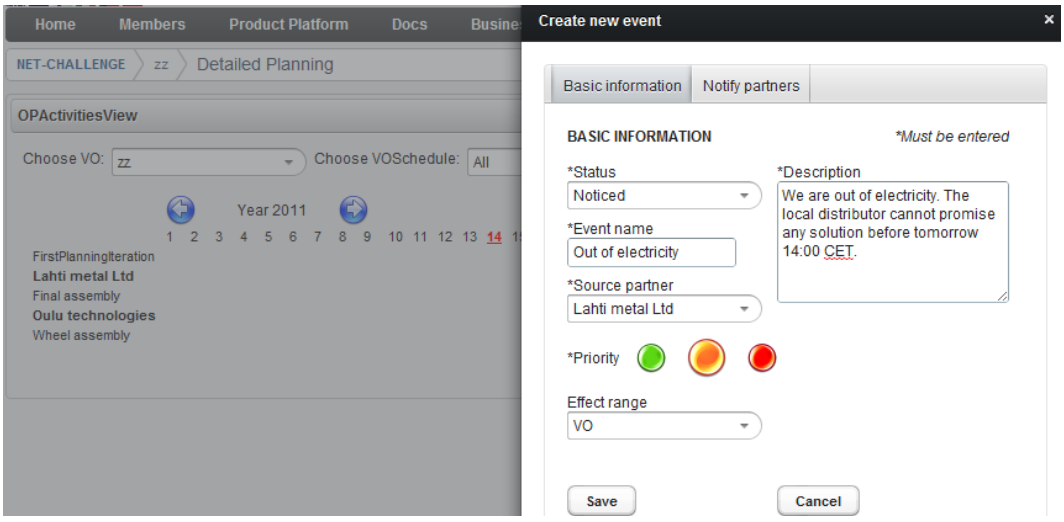

Figure 10. Display of detailed information of a possible event.

In addition to an event description window, the location of the event-creating partner can also be visualized for monitoring purposes, as displayed in Figure 11. This location identification is done by using a Google map, which is integrated with an event-monitoring interface. In case of an abnormal event, it is the responsibility of the affected partner(s) to inform the other partners immediately about its possible consequences with the objective of taking any necessary action or as a precaution to mitigate it completely or to minimize its damage level as low as possible within the case business network.

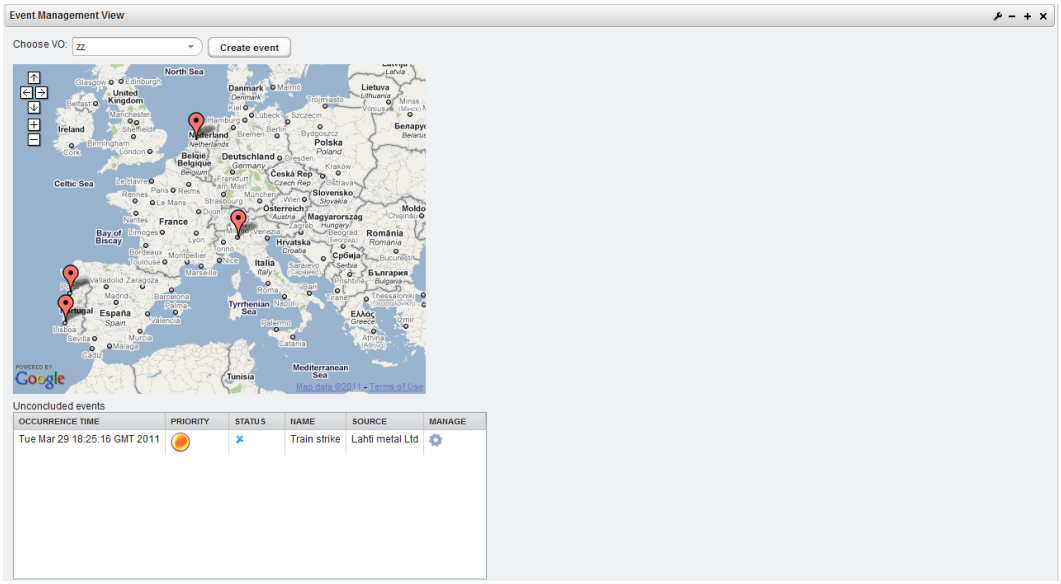

Figure 11. Display of urgency level of an event and corresponding location of the partner.

6. Managerial implications

The overall impacts of globalized business are intensifying due to the demands of individualized or one-of-a-kind products. This specific requirement is creating an extra pressure on the managers of firms to develop as many product variants as possible within their capacities and capabilities and to be competitive. To manage such varieties economically and efficiently might not be possible by an individual firm, especially for SME's due to the scarcity of costly resources and skills. In such circumstances, doing business in a collaborative environment might be a good option to stay competitive. In business collaboration, the first and foremost requirement is to build trust among potential partners (Saetta 2013). The development of trust can be strengthened as time passes.

In business collaboration of whatever the type, the partners start sharing their resources and expertise from the very beginning of the product development process and continue until the end of the product life cycle. To manage the product development life cycle within the network, managers within the corresponding partner organizations need to develop an information technology (IT) based tool in order to facilitate frequent exchange of information. This information exchange system contributes to the collaborative product design through the creation of BOM and maintaining the production scheduling and routing. Through this IT-based tool, the managers can control the complete production process and monitor any uneven situation that might occur during the production run. In collaborative business, the objective of this process monitoring and management system is to alert and manage unexpected and

potentially serious situations and to avoid or minimize the damage level, which ensures a smoother production run all the way along.

The development of the IT-based tool or platform can be extensively used in any kind of business collaboration. This tool enables the managers to use it as a dashboard, where each of the collaborative process activities can be visualized in a real-time environment. Such a process update enables organizational managers to take the necessary actions if there are any bottlenecks or problems within the operational activities. It can also be used to develop the C-BOM, operational scheduling and planning as required to develop an innovative product with reduced lead-time.

Although extended benefits are reported for the IT-based tool in terms of visualizing and monitoring the collaborative processes, there are also some limitations to the tool. For instance, it is often difficult and expensive to make the tool interoperable within the partner organizations, which can often be a problem, and it might limit the use of the tool efficiently. Often it might be necessary to reconfigure the partner organizations' communication gateways in order to establish such interoperability. The tool itself might need time-consuming reformatting before implementing it from one business network to another one based on the collaboration requirements. The information security within the IT-enabled platform can also be a limitation to its universal applicability.

The major contribution of this research is that an interactive online portal has been designed, developed and tested, where the basic phases of an innovative product; such as bill-of-materials, scheduling, production planning and scheduling with dynamic capacity management, on-time order promising, event management and business process monitoring are done in a real-time environment. This portal can be used extensively from the concept generation phase to the production phase of the collaborative product. It is believed that organizational managers would benefit from this research work in forming and executing a collaborative business environment and sharing valuable resources and skills for mutual benefit.

7. Conclusions

Global manufacturing companies are currently facing intensive challenges from the market segment both in their home country and abroad. To survive in such a competitive environment, the production strategy of global companies is changing and becoming more and more international in terms of sharing capacities and capabilities. The rapid development of information technology or web-based technology has revolutionized the scope for collaboration among global companies in terms of product design, engineering and manufacturing processes. The fundamental requirement for business collaboration is to develop a supporting platform. This changed business environment integrates distributed and diverse manufacturing systems with the objective of achieving higher competencies.

Current business operations are characterized by strong interdependencies among manufacturing firms operating in a globally distributed environment. Due to such interdependencies, firms can consider collaboration where trust is established for mutual benefit. In order to operate effectively and profitably in today's competitive environment, more and more firms are teaming up with a view to combining their resources and abilities (Zhihui et al. 2008). A collaborative environment can enable manufacturing firms to form virtual organizations with enhanced competencies through sharing their knowledge and experience (Vereecke and Dierdonck 1999). The sharing of advanced knowledge/information and expertise among firms facilitates them to become leaner, more agile and innovative (Hao et al. 2006).

In order to facilitate the sharing of knowledge and expertise among the collaborative partners, manufacturing firms need to establish a communication infrastructure, which can be based on IT or a web-based platform or tool. In this research study, a web-enabled software

system or tool is developed and implemented with the objective of interpreting its suitability for managing the collaborative business processes effectively and efficiently. The introduction of this web-based tool can be useful for managing business partners in terms of real-time monitoring of individual partners' activities and updating their progress. A case business network is illustrated in this research with the objective of demonstrating the verification and validation of the developed tool.

The three research questions presented in this research were answered through developing a web-enabled tool that supports various aspects of forming a collaborative business environment. The first research question was answered by developing a web-based tool, which can be used extensively to develop a collaborative innovative product by sharing knowledge and expertise within the partners' organizations. The second research question was answered through developing the collaborative BOM and collaborative process scheduling. The third research question was answered by using the web-based platform to monitor and manage the collaborative business processes effectively and efficiently. This web portal supports the visualization of the various collaborative business processes executed during the network's operational activities. It displays in real-time the status information of the collaborative business processes that is essential for executing the processes efficiently.

Although there are several web-enabled tools available within various business domains, the novelty of this developed tool is that it can be implemented easily in most kinds of business networks due to its usability, flexibility and configurability. This tool can be easily reconfigured and reformatted according to the collaboration needs. It is comfortably interoperable in different operational scenarios. The tool can be used to develop collaborative product development, where each partner organization can use it to design, schedule, plan and process monitoring in a real-time environment. In future research, this tool will be fine-tuned after implementing it in various business networks in order to revise and update its technical contents in more detail. This tool can also be revisited in order to check its suitability to interface different sensor-enabled technologies such as the Internet of Things (IoT), Radio Frequency Identification (RFID) and bar code technologies in order to support advanced real-time process monitoring within the partner organizations.

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