Group Decis Negot
DOI 10.1007/s10726-016-9482-x

A DSS-Based Framework for Enhancing Collaborative Web-Based Operations Management in Manufacturing SME Supply Chains

Jorge E. Hernández[1,2] · **Andrew C. Lyons**[1] · **Konstantinos Stamatopoulos**[3]

Abstract The precision engineering sector lies at the heart of the UK's manufacturing capability. Companies that operate in this sector support major economy-driving industries such as aerospace, defence, motorsport, nuclear, off-highway equipment, oil and gas, and renewable energy. The main companies that constitute this sector are small and medium-sized enterprises (SMEs). Successful precision engineering businesses are required to master process innovation and supply chain solutions, and in these types of business, the implementation of innovative, collaborative solutions has become a necessary strategy for enhancing SME decision-making capability as well as for improving overall business competitiveness. The aim of the research described in this paper is to present how, by mentoring and supporting SME organisations through on-line based collaboration, it is possible to engage in improved collaborative alliances and how precision-engineering SMEs can benefit and are able to enhance their performance. The research is supported by a description of a case study undertaken in a precision engineering SME, from the UK northwest region, in order to demonstrate the application of the collaborative decision support systems approach.

Keywords Collaborative operations management · Supply chain integration · Web-based decision support system

This work has been supported by the C2I ERDF funded project in UK.

✉ Jorge E. Hernández
J.E.Hernandez@Liverpool.ac.uk

1 University of Liverpool Management School, Chatham Building, Chatham Street, Liverpool L69 7ZH, UK

2 Universidad de La Frontera, Avenida Francisco Salazar, 01145 Temuco, Chile

3 AMF Precision Engineering Ltd, 2 Caldbeck Road, Croft Business Park, Wirral CH62 3PL, UK

Published online: 02 May 2016

1 Introduction

Nowadays, business is undertaken on a global scale and enterprises have to be prepared for intense global competition and for reacting to unexpected changes in the market environment, for instance, in situations where high demand variability occurs. The basis of competition is multi-faceted and competitive performance is partially predicated on the quality of the flow of information across enterprises. Hence, and as established by Ellram and Cooper (1990), supply chains can be regarded as global networks revolving around a core enterprise and its products while facilitating the cash flow, information flow and goods flow from purchasing materials to delivering the finished products to the final client. Moreover, the size of these enterprises will influence the way in which information is treated and how the decision-making processes are supported. Large companies have a tendency towards medium and long-term relationships. For this, they utilise robust information technologies to mitigate potential information disruptions in addition to adding value to their processes. On the other hand, SMEs operate mainly on a short-term basis and are often dependent on, and driven by, the requirements of large enterprises.

According to Axelson (2007), SMEs are the mainstays of the European industrial structure and they are the impeller of contemporary economics. Ghose (2001) noted that SMEs contribute the most to any national economy. Moreover, SMEs play significant roles in the innovation and knowledge transfer of a country. Nonetheless, SME survival is difficult in these competitive global environments. This is partly attributable to the relatively lower labour productivity and profitability of SME's when compared to large companies. Therefore, continuously re-engineering the business processes and improving the performance of their operations are critical to SMEs. Consequently, it is necessary to consider efficient, agile, flexible and reliable solutions in order to tackle the requirements for SMEs, particularly for job shop and low-volume based batch precision engineers. It has been stated in the Precision Engineering report [Precision Engineering Sector Report (2012)] that precision-engineered products constitute a significant proportion of UK exports, and the use of technologies in the industry to support the exchange of information is becoming every day more relevant. Nevertheless, as stated by Ponis and Christou (2013), the use of technology-based decision support systems in SME environments is a rather under-explored research area, and presents a relevant research challenge for academic researchers and practitioners. Recent studies, such as the one from Ramaseshan et al. (2015), suggest that a well-defined market strategy and readiness to allocate resources to support the adoption of internet-based technologies are the core factors for successful adoption and implementation of business-to-business electronic commerce in SMEs. Therefore, and under the scope of the C2i ERDF project (C2i 2014), the aim of this paper is to present a real application of a web-based solution in a real SME from the UK's precision engineering sector, but and even more important and relevant, not from the classical Information's Technology (IT) developing point of view, but also from the main managerial implications point of view, which present a lack on scientific research contribution in this particular field. Therefore, this paper adds value to the Decision Support System (DSS) research field. This is because it also disclose how these kinds of SME's can benefit from the use of such IT systems in order to support their individual decision-making processes by accessing shared information in a cloud-based environment. Within this, a conceptual DSS-based framework for the main decision-making process is presented with the purpose of theorising the elements of the case study under consideration for the SME production planning decision-making. Hence, the purpose of the web-based solution is to enhancing the customer demand visibility, thus to make the SME capable to react to the customer requirements.

Therefore, the contribution from this paper can be seen from the provision of a clear view about the demonstrable applicability of a well-known web-based solution in a complex SME, which deals with local and international requirements. Thus, it is highly expected that any SME, under this domain, can potentially take advantage of this contribution for dealing with the implementation of its own requirements and collaborative solutions, but also more important being to realise, in advance, the expected impacts of such endeavour. In this context, and in order to achieve such challenging and novel research work in the DSS field, this paper, at first, provides a review for understanding the implications of manufacturing operations management within a collaborative supply chain environment. Secondly, a holistic and conceptual framework model is introduced for providing the main description of the process and information flows from the SME perspective. This is primarily focused on the collaborative production planning process in manufacturing precision engineering industries and explains the main elements selected for addressing the web-based solution. Following this, and supported by the report from the EMSI (2014) in terms selecting the industry domain, the next section presents the case study of one precision engineering SME from the UK northwest region. In fact, guidelines are provided to articulate the implications of the web-based solution and the online support for the decision-making process. Following this, a discussion about the implications of implementing such web-based solutions in SME's is provided. Finally, conclusions and further research are presented.

2 Background

In this section, a literature review is presented to support the proposed model explained in detail in Sect. 3. The review method is as follows: firstly, a review of the scientific literature was undertaken and concerned an analysis of existing approaches that support the development of collaborative operations management processes in supply chains. Secondly, for the purpose of completing the aforementioned analysis, a review is undertaken from the SMEs' point of view and their role in enhancing the supply chain decision-making process.

2.1 Collaborative Operations Management and Decision-Making in Supply Chains

According to the level of collaboration and the number of participants involved, supply chain collaboration can be classified as: collaboration among members, a value chain and as a supply chain network (Poirier 2002). Therefore, it is important to consider that collaboration will imply the creation of semantic descriptions that provide a mutual understanding between the firms or nodes that, directly or indirectly, are wishing to collaborate (Chen and Doumeingts 2003). Thus, realising that there may be different types of collaboration among the nodes in the supply chain which, in turn, could belong to different supply chains, and also that there could also be different collaborative behaviours, models should address each case since the generation of a single model to homogenise collaboration is difficult to manage (Poler et al. 2008). There are many definitions that can be found for the collaboration concept and in relation to the framework that is addressed in this scientific research contribution, the definitions presented by Hernández et al. (2011), Hernández et al. (2014d) stand out as a key support for this purpose. These authors consider that collaboration could be defined as the way in which firms, belonging to the supply chain, will work together to accomplish shared and private objectives by means of the information exchange and the consideration of negotiated decisions. In addition to this, Cao and Zhang (2011) established that the most important way for supporting the information exchange across supply chains in collaborative environments is by considering that every supply chain node will tend to favour a collaborative relationship. This concept was originally defined by Lewieki and Litterer (1985) and establishes that all the participants in a network, or at least the vast majority of them, will collaborate to become more competitive with regard to other supply chains. Sapena et al. (2008) suggested the collaboration process can be divided into three sequential states. The first relates to interchanging messages (or information). The second contemplates defining the restrictions associated with the processes and, therefore, defines the variables with which nodes will assess the results. The third and final one considers the ways to model restrictions to obtain model generation-based solutions, architectures and tools to support supply chain collaborative policies and mechanisms. Moreover, with this collaboration terminology, the chain could become more competitive in terms of quality, costs and times as it would be more efficient (Soosay et al. 2008). Conversely, Chen and Chen (2005) consider that collaborative relationships in the supply chain context will have a positive impact on the integration of the chain's replenishment processes and its coordination mechanisms. This means that the advantages which collaborative relationships offer are related to the profits gained by not only each member of the chain, but also by the whole chain (Cao and Zhang 2011). Thus, there will be a tendency to distribute these profits throughout the chain rather than them being used at a local level by chain members. One example of this can be found in the logistics area of distribution where collaborative management in a supply chain will better support the constant modifications made in aspects such as defining objectives, distributing raw materials, transport planning and requirements to support information interchange. The supply chain will tend to be more flexible in terms of physical distributions and will, therefore, seek to diminish any inefficiency encountered in chain management and planning (Kwon et al. 2007). According to Reiner and Trcka (2004), and since supplier nodes will be able to identify other suppliers and/or customers' requirements, a supplier must be allowed to communicate (downstream) and access the supply chain's requirements and needs to the customer in order to perform a collaborative behaviour across the supply chain network.

Manthou et al. (2004) pointed out that the appropriate use of technologies can help strengthen relationships among supply chain members and will, therefore, favour integration and collaboration between the various transactions and events present in the different supply chain processes. In this way, each node could analyse and improve its plans at a local level by considering this external information (Dudek and Stadtler 2005). Therefore, collaboration in the supply chain will address the joint creation of information interchange processes, followed by the implementation of information systems that support these processes. Essentially, the support of these systems considers the chain's physical aspects such as the nodes' geographical distribution, as well as data or information aspects such as demand patterns or product characteristics (Holweg et al. 2005). So from the supply chain collaboration viewpoint, it is important to bear in mind that technologies should be able to rapidly and comprehensively respond to customer demand, which is generally variable over time (Tolone 2000). Hence, the use of technologies with algorithmic functionality must be employed to support the changes made in demand patterns. One solution to this is presented by Deng et al. (2011) who consider using bi-level linear programming to support supply chain management. Integrating between technologies and tools to support data analysis and information can help improve decision-making processes in supply chains (Jiang and Chen 2010). In line with this, decision-making processes should contemplate the different behaviours of the decision makers in the supply chain (manufacturers, retailers, customers, etc.) to maximise the chain's profits (Cruz 2009).

In light of this, a prominent characteristic is that collaboration in the supply chain requires efficient information exchange. This information will support planning processes in chain nodes. In other words, nodes should regard information exchange as a fundamental pillar to support collaboration within the chain. However, it is important to contemplate those technologies that are linked to collaborative processes, as they should help to include information in the supply chain and to define those architectures that help the collaborative processes in the chain. Therefore, the information interchange process is a complex task which relates the decisions made about what and how much information is to be shared, and also establishes the suitable times for these interchanges to take place to favour the collaboration and synchronisation in supply chain processes. Solutions must be able to be replicated in each chain node, and will also become an architecture which will provide the models and modelling languages required to support the different perspectives of collaborative processes. Moreover, from a real supply chain management viewpoint, supporting SMEs' planning processes in an increasingly collaborative context must consider a study of the collaborative relations and how they are framed within the chain's different configurations. However, conceptualisation of flows and business languages will be of much importance to permit the inter-node communication.

2.2 The Role of Manufacturing SMEs in Collaborative Supply Chain Management

Local as well as international SMEs increasingly recognise their importance in the global economy as well as their relevance to supply chains. However, these supply chain systems are often not well aligned within the requirements of a global, dynamic and very volatile market environment. Koh et al. (2007) realised that the relationship between supply chain management practices and operational performance indicates that supply chain management practices might directly influence the operational performance of SMEs. Furthermore, the increasing trend for product customization and service provision associated with products requires choosing the right partners and effectively organizing the collaborative processes. In light of this, the SMEs' environment is a key domain to be studied, which constantly requires to be analysed in order to implement new required technology-based solution. This is in order to help the decision-making process for their planning and management activities across supply chain networks. Ayyagari et al. (2007) noted that SMEs play a central role in local economies because the high employment and key contributions to local and regional activities Goldberg and Palladini (2008) and if SMEs improve their management practices they can become more competitive in international as well as local markets (Cortes-Lobos 2013), hence they are potential contributors to national economy growth.

Therefore, as pointed by Hernández et al. (2011, 2014a, b, c, d), it is established that an effective collaboration leads to collaborative advantages and also to better partnership performance (Hernández et al. 2011), hence, the use of compatible technologies amongst them are key and relevant. Moreover, during the last ten years, web technologies have provided users with a large set of new tools for remote collaboration and information sharing (Kuo 2010). In this context, managers at SMEs are moving toward the use of improved information sharing and forecasting mechanisms throughout the network in order to remain competitive (Byrne and Heavey 2006). This also will support SMEs to become more competitive and enhance their innovation processes from a collaborative point of view. Co-innovation networks integrate external inputs and resources and adopt web capabilities and facilitators to achieve the targeted values. From Wolf and Harmon (2012) and Afsarmanesh and Camarinha-Matos (2008), it is apparent that at the service delivery frontier, business processes and business services have the responsibility to support and establish co-working and sharing between stakeholders, partners, internal strategic business units, and customers. For supporting this communication, IDEFx, BPMN, UML, EPC and even execution languages (namely, WS-CDL, BPEL) are some of the popular methods used for this purpose. A further review of these languages can be seen in Hernández et al. (2014a). Hence, to consider a maximum level of preparedness for collaboration, and to support integration possibilities within collaboration networks, suitable business process modelling languages can support the co-innovative environment and provide an extendable standard structure, formalism-based robustness, and easy-to-use mediator.

Considering the global trends of the economy, supplementary technologies and standards might be adopted such as WSDL and OWL-s to ensure the extensibility of the customised SME models and solutions. Moreover, co-innovation business service taxonomies might also be considered in order to relate the structure of business services to the resources. The purpose of this is to achieve the core competences of the supply chain structure. Hence, the proposed framework in Sect. 3, is orientated to support the creation and execution of integrated service structures, providing an adequate service-oriented co-innovation/collaboration framework, and service structure to enhance the decision-making process, especially under dynamic service perspectives, when non-existing services are designed when users request it (Rao and Su 2005).

3 The Conceptual Framework for the Collaborative Operations Management Decision-Making Process in Precision Engineering SMEs

Manufacturing SMEs have an inherent competitive disadvantage because of their lack of economies of scale. A chronic problem in most countries, it is exacerbated in developing nations, where SMEs are the most numerous establishments in the economy. This makes their performance critical to the country's overall economic competitiveness (Cortes-Lobos 2013). Moreover, and according to the Global Competitiveness Report 2012-2013 (Schwab 2012), there are three levels on which a country can be classified: (1) factor-driven, (2) efficiency-driven, and (3) innovation-driven. From this perspective, and according to Organisation for Economic Co-operation and Development (OECD 2014) countries can be classified according to those three levels. Most European countries are classified as level 3.

3.1 The Conceptual Holistic Approach for the SMES's Decision Support System Based Framework

The innovation capacity issues in SMEs have been analysed for many years. Nevertheless, innovation in SME product and services remains as a key issue (Sepulveda et al. 2014). Oke et al. (2007) noted a clear link between innovation and SME sales turnover. Policies and government initiatives directed at SMEs tend to encourage the development of radical innovations, supported in most of the cases by R&D grants and programmes, and enhancing the possibilities of entering into new markets. Therefore, and considering the modelling methodology from Hernández et al. (2014d), a holistic framework approach for supporting the decision-making process in SMEs is proposed to provide feasible solutions for designing, implementing and enhancing sustainable and collaborative operations management decision-making and co-innovation in manufacturing SMEs (see Fig. 1). The proposed framework provides a clear identification of the core supply chain-based manufacturing SME decision-making elements. These elements include: product design, management and manufacturing. In addition, a service perspective is also considered to enhance the SME's information, communication and technologies (ICT) platforms.

As depicted in Fig. 1, the right selection and provision of models, tools, and collaborative technologies, will enable a faster and more effective business strategy for handling the products and customer service perspective of key SME processes. Hence, and considering the main SME environment characteristics, the proposed framework also considers the high disruptions on demand and the volatile market behaviours as part of its modelling methodology and structure. Therefore, the holistic perspective is adopted in order to assess different kinds of dimensions in terms of the SME performance, such as: the services that contribute to enhance the products, the related manufacturing processes and the SME's network related to the main operations management decisions. In terms of co-innovation, this framework also establishes the holistic view for capturing the values, risks and sustainable conditions for transforming the traditional product life cycle into a product-service life cycle. Moreover, and driven by real-life SME industrial needs, the solutions established from the proposed

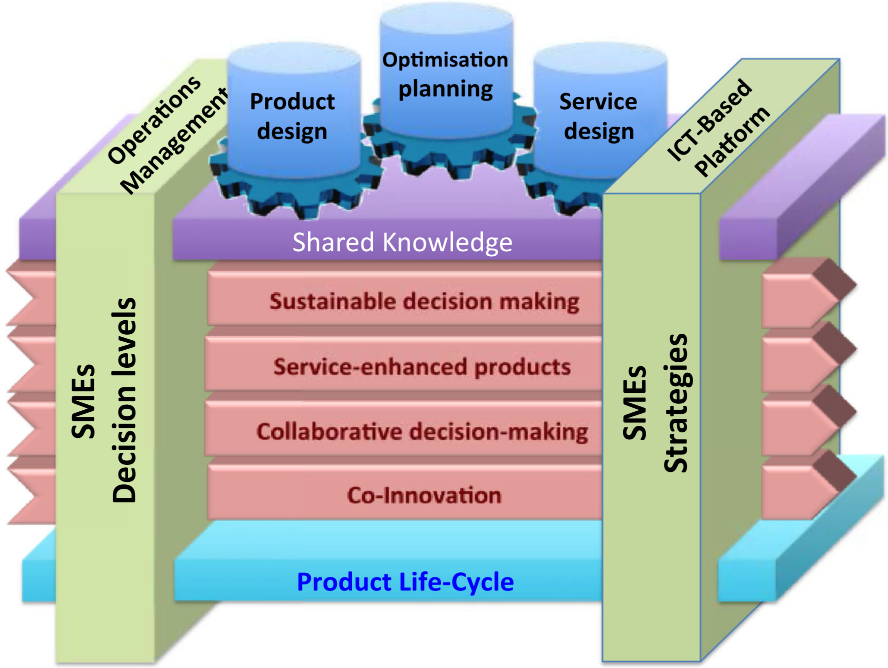

Fig. 1 Conceptual framework for collaborative operations management and decision-making in manufacturing SMEs

framework take into account the structure for coping with SME operations management requirements dynamically, in real-time and through the consideration of a synchronised supply chain with agile response capabilities supported by collaborative mechanisms and structures with customers and suppliers. This is to be applied in the following section (Sect. 4), from which a web-based model is provided.

In this context, the mass customisation of products is also pursued by considering high-customer involvement under a co-design approach to meet their individual needs/choices with regard to the variety of different product-service features. Furthermore, in order to support national and regional SMEs with their dynamic operation at multiple locations in the co-innovation processes, the involvement of the customer with local suppliers and other stakeholders, particularly those geographically close to the customer, are also pursued. However, it is important to highlight that this framework was conceived based on the recognition that co-innovation involves many manufacturing processes and requires a network of stakeholders to be built in order to generate an agile and robust system for producing these service-enhanced products. Therefore it is regarded as a realistic approach to be useful for end SME users. Then, through warning signals of any unexpected behaviour from predicted life-cycle processes, stakeholders will be advised when it is necessary to reconfigure the service-enhanced products. In this way, a re-adaptable and real-time based system oriented to meet, cope and cover existing and new stakeholders' expectations is also considered. Thus, the requirements for enhancing the operations management and co-innovation decision-making processes in SME environments are dealt with in this holistic framework in the following ways:

- by addressing the product and customer service level from the full end-product life-cycle perspective;
- by considering an holistic vision, including not only the finished goods and customer service level dimensions, but also the organizational aspects related to the multiple stakeholders that need to be involved;
- by taking into account local specifications from the market where customers are located and also where local stakeholders are to be involved in co-innovation processes.

3.2 Web-Based Modelling Approach for Supporting SME's Operations Decision-Making

The modelling domain encompasses the production planning process under a collaborative regime (see Fig. 2). The inputs and outputs of the process have been identified based on the literature and the SME interviews.

From many modelling languages, the IDEF0 approach was selected, since the main governances for these models are the information flow and the decision flow (see Fig. 3). In this context, the production planning process is to be related to the information transformation of the materials requirements from the end customers to the lower-tier suppliers and the decision-making reflection from the suppliers to the customers.

Therefore, the collaborative production planning process, in the precision-engineering SME (PE–SMEs), is built on the real-time demands of the products from the customers of the manufacturer and the real-time material demands sent from the manufacturer to its suppliers.

As depicted in Fig. 3, one important activity in the model is the traditional MRP (Materials Requirement Planning) process calculation, which is determined by a traditional ERP system. The output of the MRP is considered as a part of the input

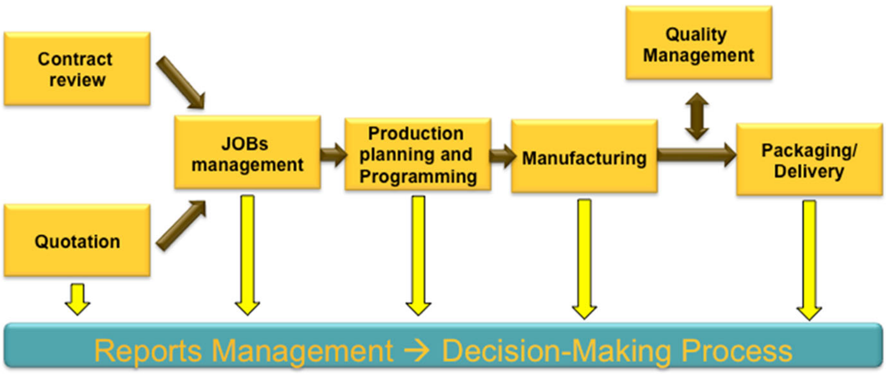

Fig. 2 Decision-Making Process Flow Across the Precision Engineering SME

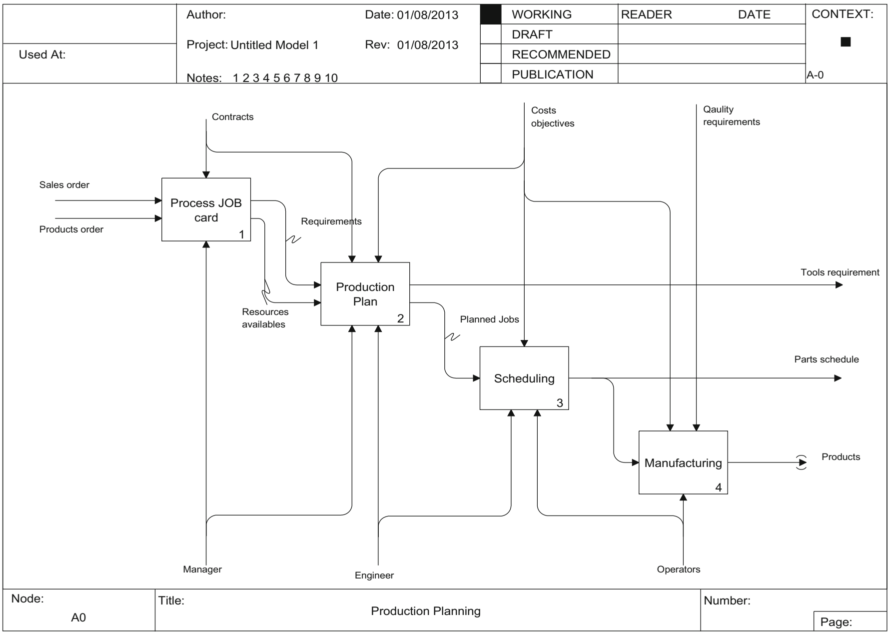

Fig. 3 Standard IDEF0 Model Representation for the Production Planning Information Flow for PE–SME

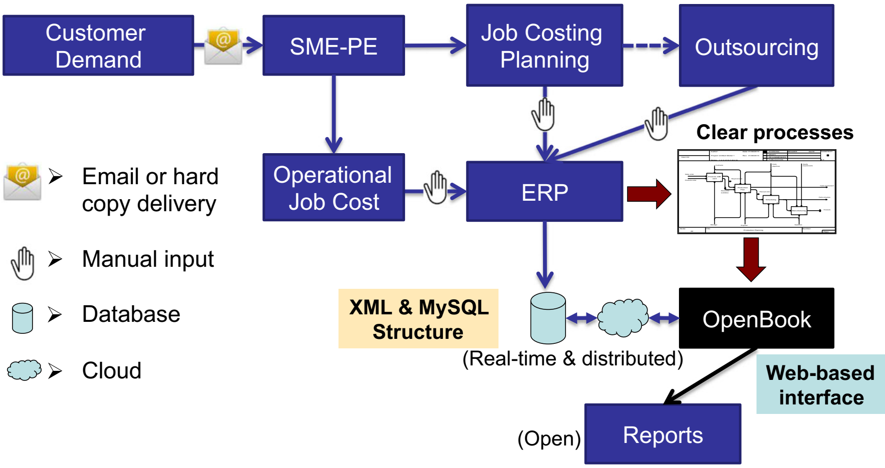

Fig. 4 The Conceptual Solution for Enhancing the Decision-Making Process in the Precision Engineering SME

information of the production planning for suppliers. The MRP outputs generally include the components, real-time finished goods inventory and the real-time requirements planning (see Fig. 4). Therefore, the outputs of the MRP will be automatically be updated to the collaborative platform online.

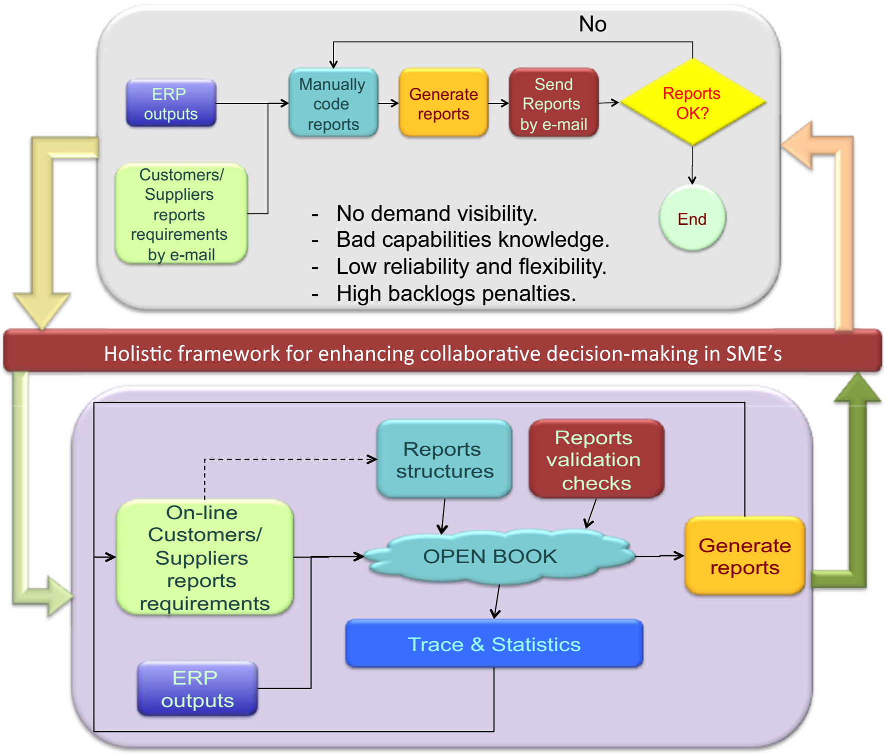

Fig. 5 The Conceptual Solution for Enhancing the Decision-Making Process in Precision Engineering SMEs

In this case, the suppliers and the PE–SME will make their production plan based on the MRP outputs of the customers. Meanwhile, the decision flows in the suppliers, manufacturer and customer are also defined in the model. The conceptual web-based solution for the PE–SME is presented in Fig. 5.

Hence, and assuming that there are three main roles in the process, Fig. 5 shows that suppliers and customers can be seen as a group of individuals with similar manufacturing management characteristic behaviours in terms of information provision. The customers normally represent the large companies, which produce the finished precision-engineered products; the manufacturer and the suppliers are normally linked to the companies that produce the components for the customers. Then, the operators will compare the forecasted quantities against the real sales in order to make the product replenishment decision. Therefore, through the web-based solution, operators can log-on to the collaborative platform and receive the MRP information from the shared ERP database system. Collaborative reports will be generated and shared amongst the supply chain parties through the network. The manufacturer can log-on to the OpenBook® and view the customers' MRP and the material requirements. Manufacturers are able to check their finished goods inventory and support their decision-making processes collaboratively. Consequently, suppliers and manufacturers will be able to report their quotation, capacity, schedule, inventory and productive time to the customers. In this way, the individual decision-making process is now enhanced by up-to-date, shared, accessible and ready-to-use information available in the collaborative web-based system.

4 The Web-Based Implementation in a UK Precision Engineering SME

The case study is based in one precision engineering SME from the North West region of the UK. This PE–SME is oriented to manufacture and assemble parts required by large first tier semiconductors manufacturers. In this process, the PE–SME makes the order of parts to the corresponding material suppliers (MS), mainly located in Germany and UK. In addition to this, the supply chain environment on which this PE–SME is involved, also considers the ordering of special material that are requested directly to the material mills (MM) and fabrication suppliers (FS), which main constraints are due to pre-established minimum order quantities, thus decision-making activities are performed in terms of establishing the material requirements planning, this by considering the original equipment manufacturer (OEM) requirements, who in the end connects with the global markets such as Sony®, Samsung®, Apple®, among others. Therefore, visibility of demand is crucial for every supply chain layer (depicted in Fig. 6) of this international economy environment. But, considering the regular fact that for SME's, in especial for the ones related to the precision engineering environ-

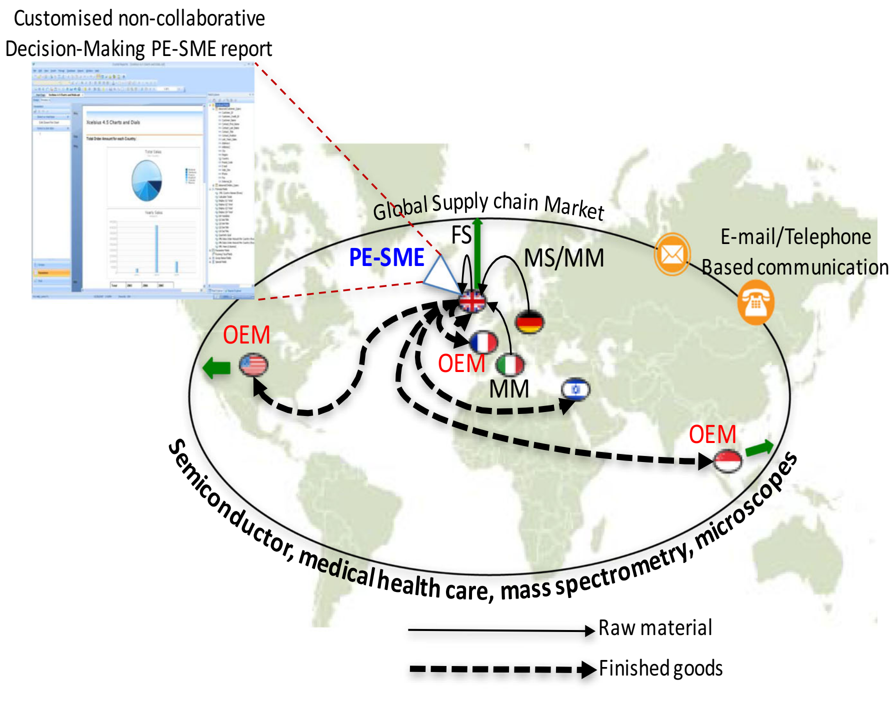

Fig. 6 As-Is PE–SME supply chain non-collaborative environment

Fig. 7 SME's precision engineering finished goods (*source*: http://www.amfengineering.co.uk/)

ment, customers are in the most of the cases the developers of machinery, for which they require specific component to precision engineering manufacturers. Thus, since PE–SME does not focus on the design, the directly approach to large organisations is not easy, and intermediaries are required, such us: MM, FS and/or FS.

Currently, the PE–SME under study is a leading subcontract manufacturer of precision engineering components. It has experience in supplying the highly-engineered components and assemblies to customers across the world. The main capabilities of this SME concern CNC machining, wire and spark erosion, precision welding, sheet metal and fabrication, electromechanical clean assembly, testing and finishing solutions. It also operates in many industry sectors such as semiconductor, medical and life sciences, subsea, energy, oil and gas. To better visualise this, finished precision-engineered products are displayed in Fig. 7. In most cases, neither the production manager nor the operators know what the finished precision-engineered products will be useful for. They are just required to be precisely manufactured and deliver on time in the right quantity and quality.

The company uses a commercially available reporting system as a traditional way for reporting its operations' details and performance, and for extracting data from its ERP system. However, operating the reporting system is complex and time consuming. The reports are not customised to the users; once any error occurs or new data needs to be added to the reports, the operator has to start from afresh. Moreover, the ERP and the reporting system are the local systems, and the data from the ERP and the reports made by the reporting system are not visualised and made open to the SME partners. Therefore, users are able to to graphically design data connections and report layouts to suit individual reports. For this purpose, the PE–SME uses ®Crystal-Reports platform. Within this, even if the outcomes from this platforms are in terms of PE–SME users be able to layout and generates individual reports, there are many disadvantages in this common approach, such as: (a) formulas to manipulate data series and to support MRP updates have to be manually introduced; (b) reports have to be regenerated manually

Table 1 PE–SME SWOT analysis

Strengths	Opportunities
High level of knowledge in precision engineering machinery and tooling	Generation of customised reports for enhancing their operations Decision Making
ERP system is being used for supporting some of their operations decision making	Create better communications interfaces between customer and suppliers
	Create shared blackboard for support collaborative process such as planning, forecasting and replenishment
Weaknesses	**Threats**
Lack on capacity visibility	Unexpected cost will rise if orders are not properly managed
Lack on generating customised report easily updated	Negative impact over Customers service level performance

every time when they need to be updated; (c) customized reports cannot be shared with other stakeholders, thus a lack on visibility is present in this kind of domains; (d) the report customization process is to be a time-consuming activity and user mistake errors when introducing the data is far common and, finally, (e) the operational system is difficult to use, so it cannot be widely used by all personnel, thus horizontal and vertical, as well as internal and external lack on visibility is depicted from using this kind of platforms. Therefore, from a realistic point of view, it is clearly depicted that disadvantages far outweigh the advantages.

In addition to this, it is important to consider that the management of the operations, in particular the production planning activity, is undertaken without due dates consideration from the customers and suppliers under a real-time basis information. Thus, consequently, this seriously limits the opportunities for introducing more lean and agile approaches in the manufacturing decision-making processes. Moreover, the delay on information and the ineffective information transfer processing leads to inaccurate production planning and product shortages. This means the level of customer service is undermined. Therefore, it is always highly expected that SME's should be able to improve its business operation processes in order to achieve its goals. But, because of the well-known SME's organisation structures, this is always a major challenge and, this paper expects to contribute and advance the knowledge on this by providing a generic solution. Therefore, to this end, the Strengths, Opportunities, Weaknesses and Threats (SWOT) analysis has been conducted (see Table 1) on this research. This, within the purpose of establishing the main potential to establish the web-based solution for enhancing the collaborative PE–SME decision-making, which positive impacts has been already been proved in Hernández et al. (2011, 2014a, b, c, d). This SWOT analysis has been performed from the PE–SME point of view in order to provide a realistic perspective about how possible is to set the aforementioned collaborative web-based decision support system.

Table 2 Ease for collaborative solutions implementation at PE–SME

PE–SME collaborative decision-making implementation issues	Action	Severity low/med/high	Urgency low/med/high
Reports customisation	Use the Job costing process as a first process for analysis	High	High
Collaborative planning	Model and map the current production planning process. Extend it to the network perspective	Med	Low
Consolidate supply chain collaboration with companies in the same consortium	Make the collaborative decision-making tool available	High	High

From Table 1, can be depicted that solutions for supply chain based decision-making can be oriented to support the re-engineering of its business processes for improved production planning. In fact, this solution has been supported within a collaborative planning approach that considers a collaborative web-based tool (OpenBook®, 2014) that is provided by the DNA Agile Group. More solutions to be considered in further improvements can be obtained, for instance, from Kim et al. (2013), OpenBook® 2014, Peris et al. (2013) and Precision Engineering Sector Report (2012). Therefore, three main aspects were considered in order to evaluate the relevance of considering a collaborative approach. As depicted in Table 2, three main angles are seen as relevant for PE–SME in order to decide whether or not supporting implementations of any collaborative decision support system.

From Table 2 is realised that reports and consortium collaboration are considered as the highest priorities. Thus, and by taking into account the supply chain structure from Fig. 6, a flexible and realisable solution has to be considered in order to commit the most of the SME's information management requirements, but also to commit main OEMs supply chain demand. In this context, the OpenBook® (2014) is a cloud-based system applied in the wide area network. It can be customised to connect all the parties in the supply chain in a collaborative manner. The database can be seen as a cloudy drive and it fulfils the data connectivity and logic in the cloud. Therefore, SME's can take advantage of this by re-engineering their processes over these types of web-based and online environments. For this, a generic conceptual structure is proposed to handle such PE–SME cloud bases environment (see Fig. 8).

Moreover, from this PE–SME case study, it was realised that current decision for ERP investments, was highly dependent on the main customer decisions, which makes PE–SME highly unreliable once customised products or new customers are to be considered in the portfolio, even if the main customer covers most of the investment, especially for the database connections availability. But, in practice, PE–SME face many database and connection implementations issues, specially, due to the high

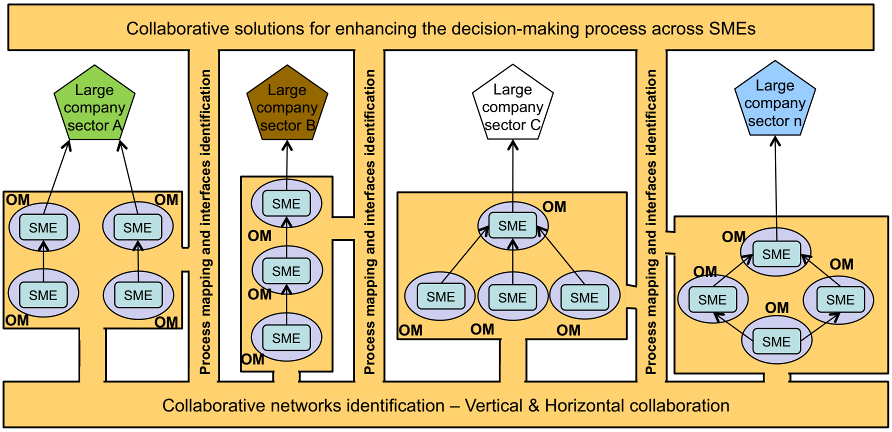

Fig. 8 PE–SME proposed collaborative web-based structure to handle the Openbook® web-based solution

amount of time that is required to update databases information and structure. In fact, regarding the PE–SME expertise, implement sophisticates ERP systems could take longer than manufacture a single part. Therefore, as shown in Fig. 8, the collaborative structure is proposed in order to make supply chain nodes supporting their own decision-making for the production planning process. Therefore, under this research OpenBook® (2014) was considered for enhancing PE–SME's visibility with respect to the customers. In this way, the web-based tool connects the data of both, customers and suppliers, to the PE–SME main database throughout user-friendly interfaces. Therefore, every decision-maker, from every company that belongs to the supply chain, can log-on to the OpenBook® (2014) and for: (1) extracting the data from the ERP database and (2) sharing it on the cloud. At the same time, the rest of the employees in the company, or in the partner companies, are now able to visualise the reports on a real-time basis.

In this way, the operators in the companies can securely present the real-time business data to other employees, suppliers and customers and enable them to analyse the internal and external real-time based business status and risks. Hence, the collaborative decision-making solution can be seen as a customised tool for conveniently producing the reports and charts to help the users to view and analyse the trends and performance of the business processes. For instance, reports can be customised and data can be shown in different formats such as tables, bar charts and line charts as is shown in Fig. 9.

After the application of this web-based tool, there were many benefits gathered by the PE–SME and its suppliers and customers. Firstly, the web-based solution helped the PE–SME employees and their partners, in the supply chain, to exchange information in real-time basis. For example, this can help operators promote informed decisions to avoid the related risks due to inaccuracies in the production planning process information when network environment is considered (see Fig. 10).

Also, the web-based solution for the precision engineering SME has also improved the internal performance of the company by integrating the resources into the collaborative planning process. Therefore, all suppliers and customers in the supply chain can

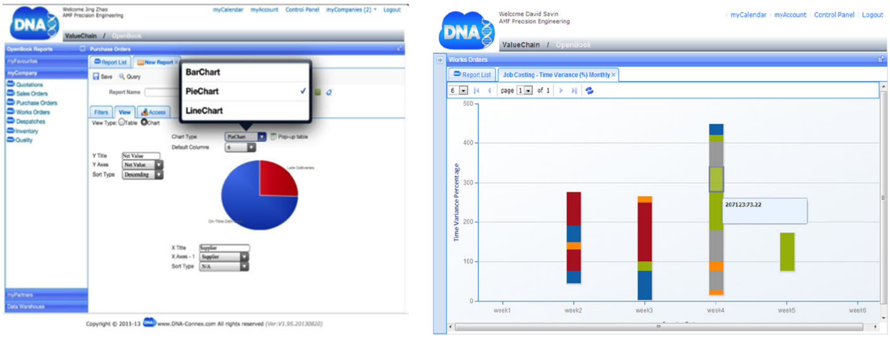

Fig. 9 Customised chart output report for the PE–SME in OpenBook®

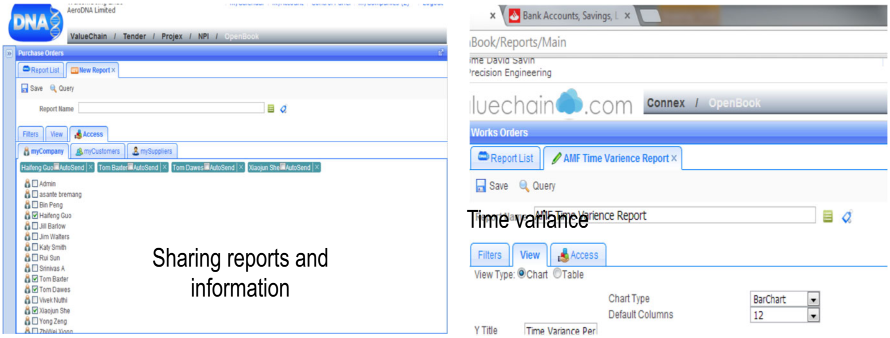

Fig. 10 Supply chain network perspective—scollaborative decision-making in OpenBook®

improve their competitiveness and performance by having a convenient web-based mechanism for implementing collaborative supply chain management. In fact, as can be seen in Fig. 11, the communication flow under the application of this web-based solution in PE–SME, facilities the enhancement of information visibility across the network. Thus Figs. 9 and 10 are seen now from its integrative and collaborative purpose point of view.

As depicted in Fig. 11, collaborative reports now govern the global supply chain domain. Hence, collaborative decision-making will be seen not only from just sharing information, but also by that environment which will support proper use of information in order to add value to existing production planning processes. But also, in comparison to the As-Is view from Figs. 6, 11 highlights the fact that, after the final web-based implementation for supporting and enhancing the collaborative decision-making, the supply chain structure is the same. Thus, collaborative solutions can be seen even less invasive and reliable than non-collaborative solutions, and positive impacts are expected. Therefore, the following Sect. 5 addresses the analysis and discussion about the impact on implement such solutions which, in the end, will disclose the impact of proposing the collaborative model for handling the collaborative solution from Fig. 1.

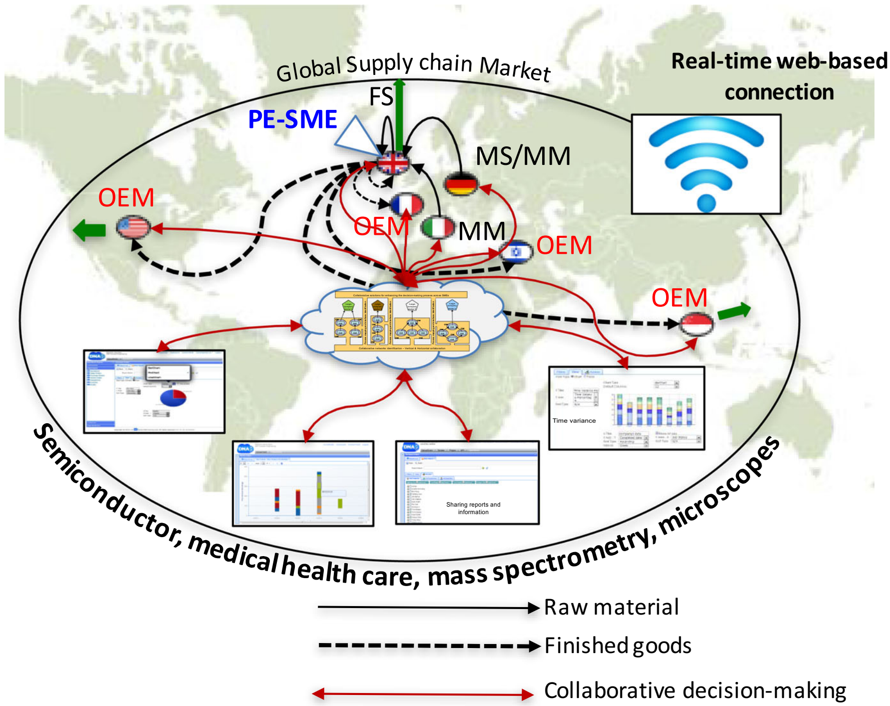

Fig. 11 To-Be PE–SME Supply Chain collaborative web-based environment

5 Discussion and Analysis

Under this PE–SME supply chain environment, it was realised that every supplier is also an SME, who are also willing to develop partnerships and win-win relationships. Naturally, within the implementation of the web-based collaborative solution, it was understood, from practice, that conflicts across the supply chain partners are inevitable. Due to the nature of the PE–SME supply chain domain covered in this research, delivery dates, for raw materials and parts, are not static, but also highly dynamic. Thus, SME's have to consider additional inputs to their internal planning. For instance, introduce make-to-stock, make-to-order or a combination of those policies in order to make raw materials and parts available when they will be needed. This is specially oriented to satisfy the customer demand, to avoid stock-outs and to minimise the costs, for instance regarding the excessive holding periods of raw materials in warehouses. Therefore, negotiation mechanisms are also depicted in this process. For instance, PE–SME use negotiation in order to set-up the right relationship between price and stock holding. Hence, payment terms are major issues to deal with due the stock holding policies. But, the domain is one of the major angles to be considered once negations have to be set. For instance subsea, oil and gas industry are more related to material quality and full traceability, as is the case of materials coming from US, it has to be fully traceable and certified by third bodies from the beginning. Thus for this PS–SME, the crucial issue is more about decision-making and parts flow than negotiation.

The application of the proposed holistic framework through the web-based application OpenBook® (2014) has considered the following perspectives and structures: (i) the exercise was focused on the development of additional, relevant services regarding the job costing function, (ii) the collaborative approach for the production and manufacturing process has considered the materials requirements/demands (to determine the production quantity and lead time); the sales and marketing information, such as the demand forecasting and real sales data (to determine the production quantity and scheduling); the manufacturing information (to determine the work force arrangement and inventory); the financial accounting information, such as the job costing (to determine the financial capacity adjustment and quotation) and the capacity information, such as the mechanics and engineering designs (to determine the production rate and shop floor arrangement).

In addition to this, from the implementation process, it was realised that a cloud-based system represents a good solution that, potentially, will help to create specific reports that will be easily shown and shared across the supply chain partners. Considerer the current well-known mobility aspect in technologies, agile and instance access to data is every day more required, but also a great challenge. Thus, and recalling the information from Tables 1 and 2, the cloud based ERP was presented as a reliable solutions for SMEs involved in large supply chain environments. This regarded to the fact that disaster recovery plans are certainly accomplished with expert knowledge in that subject. In the end, the collaborative web-based solution was presented as cost effective solution, since it requires less hardware, hence less space, which implies access and backups at anytime and from everywhere.

The successful implementation of the web-based solution OpenBook® (2014) was also accompanied by a strong partnership established between the PE–SME, the DNA-Agile team and the academic team based on close communication between analysts and technicians from each party in order to tackle integration obstacles and day-to-day problems. Moreover, and as depicted in Fig. 12, clear positive impacts are realised from the innovation perspective as well as for supporting collaboration. However, the initial goals were too optimistic and additional organisational improvements are also required in order to establish a more integrated and disseminated solution.

Finally, it also possible to address the fact that the enforcement of a rapid learning curve on the technical site as well as the shop-floor area is also a major challenge and requires constant monitoring. From Fig. 12, some positive elements were already working properly before the C2i project intervention, such as data and information and operations. This is a clear meaning that the main issues in this kind of small and medium-sized enterprise are not really related to the data and information availability or even due to the lack of operations performance activities, rather to other aspects, such as innovation management of the customer and supplier and effective collaboration (see Fig. 12). Thus, to enhance these deficiencies through the use of collaborative web-based decision support systems, the SMEs should focus on precision engineering activities with their business partners from the supply chain network under a "*lessons-learned*" mode in order to make it easier to benchmark their performance against other SMEs in the same network. This necessarily will imply a need to find ways to improve the knowledge exchange between the supply chain partners, which is achievable through web-based technologies as proven by this project outcome. For

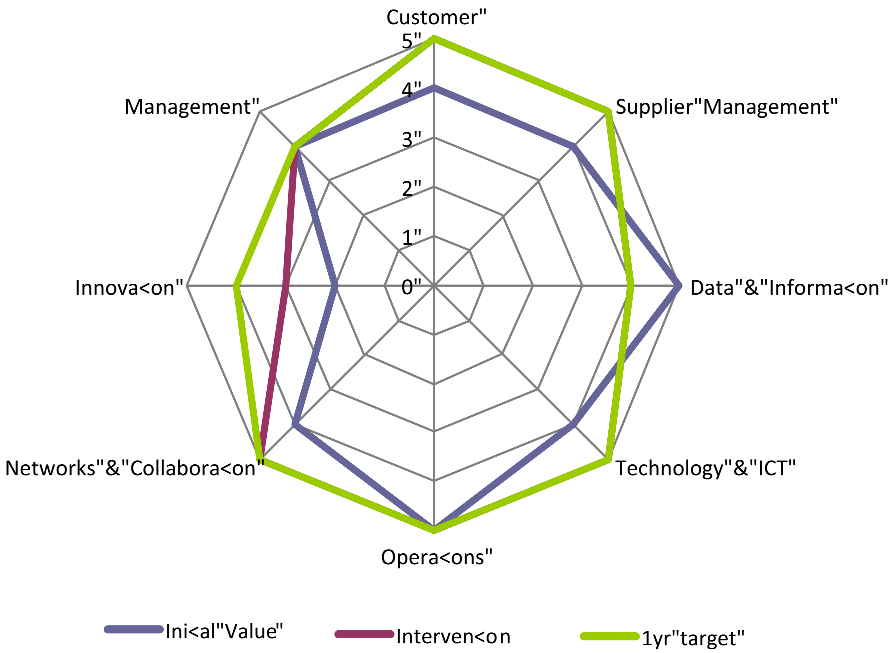

Fig. 12 Collaborative decision-making PE–SME impact. (*source*: ERDF C2i project outcomes)

further examples, see Verhagen et al. (2012), where research challenges in this field are addressed and analysed. Therefore, and considering the contribution by Verhagen et al. (2012), and in terms of identifying the requirements for establishing the collaborative platform in precision engineering businesses, it is relevant for SMEs to focus in the area of manufacturing industries to support their benchmarking activities. Moreover, it is important to highlight the fact that through the interaction between the different stakeholders the conceptual holistic framework was conceived in order to support the design of the collaborative platform. Therefore, the main impact to this manufacturing SME (as depicted in Fig. 12) from the collaborative platform was the manner in which the feedback from a variety of supply chain units was considered, such as: service / product contracting, sales and marketing for services and product, customer service and support, logistics and finance and others.

6 Conclusions

In overall terms, this study has provided a detailed analysis of an SME and the concepts of business process re-engineering and enterprise resource planning. This paper will be of particular value to companies who are looking to enhance their decision-making process collaboratively and also want to improve their management systems or operational practices which, in most cases, require a dramatic improvement in the organisation's core competences. It has been shown through this real decision support system development experience that business re-engineering can help companies to develop more effective management systems and more reliable relationships with partners. Another consideration is that those companies, which have problems with their MRP systems, should strongly consider web-based technologies when seeking transparent and collaborative solutions with their customers. Many of the issues in ERP are just now beginning to be explored, and there is significant opportunity and need for future research and development in this area. Different information users of different enterprises have different demands on information integration. An individualised case study of ERP solutions for different business sectors with different market targets would, to some extent, fill the gaps left by previous studies. It will be interesting to see the evolving influence of ERP systems on small and medium-sized companies' supply chain design and management. A further piece of research concerns the test of this proposed solution in different SMEs from different sectors across the UK and EU as well as considering different coordination mechanisms to ensure the companies are accessing on-time and real-time information for supporting their operations management and decision-making process through collaborative decision support systems.

References

Afsarmanesh H, Camarinha-Matos LM (eds) (2008) The ARCON modeling framework. In: Collaborative networks: Reference modeling. Springer, New York

Axelson R (2007) Enhancing the competitiveness of EMSs in Europe—a strategic framework for support service. United Nations Economic Commission pp.1–32

Ayyagari M, Beck T, Demirguc-Kunt A (2007) Small and medium enterprises across the globe. Small Bus Econ 29(4):415–434

Byrne PJ, Heavey C (2006) The impact of information sharing and forecasting in capacitated industrial supply chains: a case study. Int J Prod Econ 103(1):420–437

C2i (2014). Collaborative to Innovate project. European Regional Development Fund. http://www.agilitycentre.com/c2i.htm. Accessed 31 Mar 2016

Camarinha-Matos LM, Afsarmanesh H, Ortiz A (eds) (2005) Collaborative networks and their breeding environments. Springer, Boston

Cao M, Zhang Q (2011) Supply chain collaboration: impact on collaborative advantage and firm performance. J Oper Manage. doi:10.1016/j.jom.2010.12.008

Chen D, Doumeingts G (2003) European initiatives to develop interoperability of enterprise applications–basic concepts, framework and roadmap. Annu Rev Control 27:153–162

Chen T, Chen J (2005) Optimizing supply chain collaboration based on joint replenishment and cannel coordination. Transp Res E 41:261–285

Cortes-Lobos R (2013). PROFO: promoting SME business association projects in Chile. https://innovationpolicyplatform.org/sites/default/files/rdf_imported_documents/Case%20Study-PROFO.pdf. Accessed 31 Mar 2016

Cruz JM (2009) The impact of corporate social responsibility in supply chain management: multicriteria decision-making approach. Decis Support Syst 48(1):224–236

Dargam F, Delibasic B, Hernández JE, Liu S, Papathanasiou J, Ribeiro R, Zaraté P (2013). Proceesindgs, EWG-DSS Thessaloniki-2013, EURO working group on decision support systems workshop on "Exploring new directions for decisions in the internet age" . IRIT Res Rep: IRIT/RR–2013-28—FR

Deng W, Wu Q, Li J (2011) Methodology of fuzzy linear symmetrical Bi-level programming and its application in supply chain management. J Softw 6(1):82–90
Dudek G, Stadtler H (2005) Negotiation-based collaborative planning between supply chains partners. Eur J Oper Res 163:668–687
Ellram LM, Cooper MC (1990) Supply chain management, partnership, and the shipper-third party relationship. Int J Logist Manage 1(2):1–10
EMSI (2014). Highlights of Our 2014 Data Update: Part 4—Regional variations. 2015 Economic Modelling Specialists Intl., a CareerBuilder Company. http://www.economicmodelling.co.uk/2014/03/11/highlights-of-our-2014-data-update-part-4-regional-variations/. Accessed 31 Mar 2016
Federici T (2009) Factors influencing ERP outcomes in SMEs: a post- introduction assessment. J Enterprise Inf Manage 22(1/2):81–98
Ghose AK (2001) SMEs and environment protection. Productivity 42(2):210–216
Goldberg M, Palladini E (2008) Chile: a strategy to promote innovative small and medium enterprises, vol 4518. World Bank Publications, Washington
Hernández JE, Poler R, Mula J, Lario FC (2011) The reverse logistic process of an automobile supply chain network supported by a collaborative decision-making model. Group Decis Negot 20(1):79–114
Hernández JE, Lyons AC, Poler R, Mula J, Goncalvez J (2014a) A reference architecture model to support the collaborative planning integration in multi-level supply chain networks. Prod Plan Control. doi:10.1080/09537287.2013.808842
Hernández JE, Lyons AC, Zarate P, Dargam F (2014b) Collaborative decision-making and decision support systems for enhancing operations management in industrial environments. Prod Plan Control 25(8):636–638
Hernández JE, Lyons AC, Mula J, Poler R, Ismail HS (2014c) Supporting the decision-making process in a multi-level automotive supply chain with a collaborative multi-agent system. Prod Plan Control 25(8):662–678
Hernández JE, Mula J, Poler R, Lyons AC (2014d) Collaborative planning in multi-tier supply chains supported by a negotiation-based mechanism and multi-agent system. Group Decis Negot J 23(2):235–269
Holweg M, Disney S, Holmström J, Småros J (2005) Supply chain collaboration: making sense of the strategy continuum. Eur Manage J 23(2):170–181
Jiang WR, Chen J (2010) Using business intelligence in supply chain management. Adv Mater Res 171–172:769–772
Kim HD, Lee I, Lee CK (2013) Building Web 2.0 enterprises: A study of small and medium enterprises in the United States. Int Small Bus J 31(2):156–174
Koh SL, Demirbag M, Bayraktar E, Tatoglu E, Zaim S (2007) The impact of supply chain management practices on performance of SMEs. Ind Manage Data Syst 107(1):103–124
Kuo TC (2010) The construction of a collaborative-design platform to support waste electrical and electronic equipment recycling. Robot Comput-Integr Manuf 26(1):100–108
Kwon O, Paul G, Lee K (2007) MACE-SCM: a multi-agent and case-based reasoning collaboration mechanism for supply chain management under supply and demand uncertainties. Expert Syst Appl 33:690–705
Lewieki RJ, Litterer JA (1985) Negotiation. Irwin, Homewood
Manthou V, Vlachopoulou M, Folinas D (2004) Virtual e-Chain (VeC) model for supply chain collaboration. Int J Prod Econ 87:241–250
OpenBook (2014). http://www.dna-agile.com/docs/DNAredthorn%20Brochure.pdf. Accessed 31 Mar 2016
Organisation for economic co-operation and development (2014). http://stats.oecd.org/. Accessed 31 Mar 2016
Oke A, Burke G, Myers A (2007) Innovation types and performance in growing UK SMEs. Int J Oper Prod Manage 27(7):735–753
Peris M, Blinn N, Nuttgens M, Lindermann N, von Kortzfleisch H (2013) Acceptance of professional Web 2.0 platforms in regional SME networks: an evaluation based on the unified theory of acceptance and use of technology. In: System sciences (HICSS), 2013 46th Hawaii international conference on (pp. 2793–2802). IEEE
Poirier CC (2002). Advanced supply chain management and e-business. CRM Today, July 24, Mexico City, Mexico

Poler R, Hernandez JE, Mula J, Lario FC (2008) Collaborative forecasting in networked manufacturing enterprises. J Manuf Technol Manage 19(4):514–528

Ponis ST, Christou IT (2013) Competitive intelligence for SMEs: a web-based decision support system. Int J Bus Inf Syst 12(3):243–258

Precision engineering sector report 2012 from ClearWater (2012). http://www.ascendant.hr/media/reports/pdf/Precision_Engineering_Report_2013.pdf. Accessed 31 Mar 2016

Ramaseshan B, Wing WT, Tsao HY (2015) Determinant factors on the success of adoption of B2BEC for manufacturers (SMEs) in Singapore. In: Marketing, technology and customer commitment in the new economy. Springer International Publishing, Chicago, pp 190–194

Rao J, Su X (2005) A survey of automated web service composition methods. In: International workshop on semantic web services and web process composition (2005), pp 43–54

Reiner G, Trcka M (2004) Customized supply chain design: problems and alternatives for a production company in the food industry. A simulation based analysis. Int J Prod Econ 89:217–229

Sapena O, Onaindia E, Garrido A, Arangu M (2008) A distributed CSP approach for collaborative planning systems. Eng Appl Artif Intell 21:698–709

Schwab K (2012) The global competitiveness report 2012–2013, World Economic Forum, Geneva. http://www3.weforum.org/docs/WEF_GlobalCompetitivenessReport_2012-13.pdf, Accessed 31 Mar 2016

Sepulveda J, Alfaro M, Vasquez E (2014) Management of innovation in Chile: a case study for enhancing innovation capability of SMEs. J Innov Econ Manage 1:115–128

Soosay CA, Hyland PW, Ferrer M (2008) Supply chain collaboration: capabilities for continuous innovation. Supply Chain Manage Int J 13(2):160–169

Tolone WJ (2000) Virtual situation rooms: connecting people across enterprises for supply-chain agility. Computer-Aided Des 32:109–117

Verhagen WJ, Bermell-Garcia P, van Dijk RE, Curran R (2012) A critical review of knowledge-based engineering: an identification of research challenges. Adv Eng Inf 26(1):5–15

Voice over internet protocol challenges (2013). http://www.articledashboard.com/Article/Voice-over-Internet-Protocol-Challenges/2142209. Accessed 31 Mar 2016

Wolf, C. and Harmon, P. (2012). The state of business process management 2012. http://www.bptrends.com/bpt/wp-content/surveys/2012-_BPT%20SURVEY-3-12-12-CW-PH.pdf. Accessed 31 Mar 2016