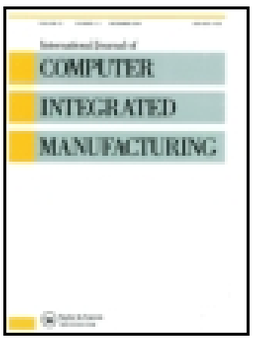

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ARTICLE

Collaborative framework for virtual organisation synthesis based on a dynamic multi-criteria decision model

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ABSTRACT

Globalisation and increased competition pushes companies to grow outside political and geographical boundaries, frequently forcing them to increase product diversification and optimise their relation with potential and effective partners and customers. In this scenario, implementing agile collaboration networks with business partners is a requirement. In this article the authors propose a collaborative framework based on a model for Historical, Present and Future evaluations, which in turn is based on a Dynamic Multi-criteria Decision Method using software agents and the Cloud for Collaborative Networked and Virtual Organization Synthesis. The model uses a dynamic decision approach for supplier and business partner evaluation, enabling software agents to autonomously capture business opportunities, select business partners/suppliers, award and process associated orders.

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KEYWORDS
Collaborative framework; Virtual Organizations; networked enterprise; multi-criteria decision method; dynamic approach; robustness; software agents; cloud

1. Introduction

Establishing contract alliances with potential business partners in order to satisfy the needs of a wider range of customers will allow companies of different sizes to potentially enlarge their share in the global market.

The growing demand for customised products is pushing companies towards supporting mass customisation business models, where products are created on an engineering-to-order (ETO) basis (Jansson and Thoben 2005). Small and medium enterprises (SMEs) face the need for integration in business networks, establishing business partnerships with other peers, in order to deliver the required product and service package (Oliveira, Camarinha-Matos, and Pouly 2010; Renna 2013).

Supporting the agile creation, configuration, operation and dissolution of these networks is of utmost importance to SMEs which want to create (initiators) or simply be a partner of the business association. These business networks may be founded as the result of strategic business decisions or as a dynamic reaction to a business opportunity detected by one or more of its members (Oliveira, Camarinha-Matos, and Pouly 2010; Camarinha-Matos et al. 2013). A flexible model running in a software platform is required to capture the opportunity, identify and select the best business partners and suppliers, assign partial orders, and process their deliverables.

In this article we propose a model for historical, present and future evaluations (HPF) based on a Dynamic Multi-criteria Decision Method (DMCDM) using a multi-agent architecture and the Cloud to increase its flexibility and scalability. The proposed HPF-DMCDM supports the creation and operation of Collaborative Networked Organizations (CNO), including Virtual Enterprises (VE), allowing their continuous reconfiguration based on market evolution, member company performance, network size and associated requirements. Therefore, one important aspect of our proposed model is being particularly focused on the process of identification, evaluation, and selection of suppliers and businesses (Germani et al. 2013), integrating services.

The model proposed is motivated by the existing real-life problems, in collaboration of Enterprises (Es) in service sector. The validation of the model is also based on the real-life data from the considered Es.

This article is organised as follows. In Section 2 we provide the background for key concepts related with the developed model and used platform. In Section 3 we present the HPF-DMCDM. In Section 4, it is presented the CNO Lifecycle. Section 5 is devoted to the illustration of the Business Scenarios for CNOs' Platform Usage. Section 6 illustrates the validation of the model and Section 7 presents some concepts about implementation of the model on the chosen platform. Finally, in Section 8 we discuss the main conclusions related with this work.

2. Key concepts review and contributions

Business agility will frequently imply a transition from self-centred to open business models. Increasing cooperation among Es during the product life cycle is a trend in the global market. 'Collaborative Networked Organizations may be defined as networks of largely autonomous organizations, geographically distributed and heterogeneous (in terms of their culture, social capital, goals and operating environment), collaborating to better achieve common or compatible goals

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using computer networks to support their interactions' (Camarinha-Matos et al. 2013).

On the last years several closely related approaches and tools were proposed in literature, which present a cloud-based collaborative environment (Ferreira et al. 2017), designed to support a mix of collaborative enterprise networks (Urbanic and Elmaraghy 2008; Schubert, Jeffery, and Neidecker-Lutz 2010; Camarinha-Matos et al. 2013). In (Sadigh et al. 2014) a Multi Agent System (MAS) to select a wining enterprise in the VE is proposed, as one of the most important steps, or contributions, of agents in VE system. In that step several agents with different goals and strategies do collaborate and compete to win the negotiation process for partners' selections.

In (Vrba et al. 2014; Buyya, et al. 2009) a community of software agents cooperate to support the operation of the network. The approach is designed to promote high levels of scalability through its modular approach based on autonomous and encapsulated components, supported by a flexible and mouldable infrastructure, based on a distributed approach, which integrates local systems to companies, virtualised systems and cloud-based services. The proposed approach aims at supporting the creation, operation and dissolution of VE or of collaborative networks (CNs), including support to the fast identification and selection of business partners that will consolidate the approach to a business opportunity identified and captured.

The main goal of our proposed model HPF-DMCDM is to assure a more robust interaction between a company and its partners than existing approaches. A business opportunity must be quickly captured and processed among the business network. This means that a Company needs to: (1) quickly select business partners in order to react to a detected business opportunity; (2) easily establish a Virtual Organization (VO), selecting adequate partners according to their skills and that may contribute for an increased business potential; and (3) quickly select the best suppliers or outsources for the fulfilment of a particular order or potential order. In order to fulfil the previous requirements, we defined an architecture based on specialised software agents. These agents are responsible for executing focused and well-defined operations in the context of the system (Oliveira, Camarinha-Matos, and Pouly 2010; Putnik and Cruz-Cunha 2014; Camarinha-Matos et al. 2013).

Moreover, our proposed platform also contributes to the cloud manufacturing paradigm, which, cloud manufacturing, is defined as the manufacturing systems with a 'direct adoption of cloud computing technologies and their structural and organizational properties, generating a manufacturing service oriented network' (Ferreira et al. 2017).

Another definition is referred in (Argoneto and Renna 2016) as 'a networked manufacturing model that exploits on-demand access to a shared collection of diversified and distributed manufacturing resources to form temporary, reconfigurable production lines …' (Wu et al. 2013, 564–579).

By these definitions, it is obvious that cloud manufacturing could be seen as a VE model. Also it could be said that cloud approaches, either computational or manufacturing, are true parts of Industry 4.0 considering that both are models of its inherent contexts, such as digitalisation and connectivity/connectedness (Moeuf et al. 2017).

Cloud-based systems, either computational or manufacturing, fulfil the main requirements by VOs/Es, since they allow to: (a) democratise access to resources among participant companies; (b) provide storage space in a scalable way; (c) minimise costs associated with information storage; (d) support storage optimisation by minimising redundancy; (e) allow for the mitigation of local or fragmented data centres; (f) improve cost reduction potential due to lower cost per storage unit; (g) minimise processing costs; (h) support infrastructure growth or shrinking according to effective processing needs; and (i) local processing structure may be minimised or even totally avoided. Hybrid models may be used in collaboration scenarios where simultaneous availability of public and private clouds is a requirement.

The used platform architecture is based on a hybrid cloud (HC), including a community component, to which only participating companies will have access to. It includes also a public component, where resources that should be made available to end customers and external partners will be made available. There are three main types of cloud computing systems, which are: Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS) (Schubert, Jeffery, and Neidecker-Lutz 2010).

Multi-agent systems (MAS) may require high processing power and large storage, implying that cloud infrastructures represent a good solution to support computer intensive MAS systems. Processing and storage resources in cloud are assigned to the system according to its size and evolution (Talia 2011).

Our proposed approach uses the Cloud to maximise availability, scalability and ubiquity.

Partner and Supplier Evaluation and Selection is a main issue in several different contexts. The author of (Wood 2016) refers that generic supplier selection from the perspective of multi-criteria decision-making (MCDM) methodologies including crisp, fuzzy (Ribeiro et al. 2014) and intuitionist fuzzy analysis of decision matrices has received much attention, in terms of comparing performance of a number of available techniques. Therefore, the author puts forward an approach based on MCDM and on a set of 30 criteria for assessing supplier selection for facilities and field development projects across the petroleum industry. The author states that bidders are assessed in terms of these criteria, with varying degrees of uncertainty and subjectivity, using linguistic scoring terms that are then transformed into crisp and fuzzy numerical sets (Wood 2016).

3. Proposed HPF evaluations model based on a DMCDM

The problem of selection and evaluation of suppliers is treated as a problem of multi-criteria decision models. Our main contribution consists on the development of a model that, jointly with using a platform: (1) supports, in a complete manner, the process of decision based on multiple criteria in the identification, selection and evaluation of suppliers; (2) uses a dynamic approach capable of integrating a variable number of criteria

(spatial variation) and their associated values over time (temporal variation, including past, present and future); (3) supports the inaccuracy and lack of confidence, using fuzzy logic for evaluation criteria, allowing; and (4) to apply different weights to different time stages or evaluation criteria, extended from previous work in (Wood 2016; Roy 2013).

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Information regarding past, present and future, represented in the form of matrices are associated through the proposed HPF-DMCDM in a dynamic and iterative way, as each iteration of this model, considers information arising from these three matrices, which is further merged and processed, based on the underlying data fusion method (Ribeiro et al. 2014).

Therefore, our HPF-DMCDM enables decision-making processes that takes into account not just proposals received from a number of suppliers or business partners, but also incorporate information related to historical performance and its future projection. This dynamic nature of the approach allows reducing the risk and improvement of the model's robustness inherent in the decision-making process, particularly when various possible solutions must be evaluated in a balanced way in the context of a comprehensive, dynamically changing set of evaluation criteria. So, to permit evaluation of different sets of criteria for past, present and future, the proposed approach HPF-DMCDM allows evaluating different product and/or service providers in a more balanced and complete way than other existing similar proposals, such as (Wood 2016; Roy 2013). Our proposal enables to better support decision-making even in scenarios with lack of completeness and/or quality of data. Another added value characteristic of our proposed model is that it was designed and based on a dynamic HPF-DMCDM for evaluating and selecting alternative proposals which are not restricted to a given business model or particular industrial sector. The proposed model allows individual companies and members of a VO to select the best partners or suppliers, within a spatial-temporal changeable context. For that purpose, it uses a combination of a dynamic decision method, based on the works (Campanella and Ribeiro 2011; Jassbi, Ribeiro, and Varela 2014), with an information fusion method (Ribeiro et al. 2014). This approach allows companies to rate a set of alternative partners/suppliers, using customisable criteria, which can change in time, and to build a partners/supplier list based on the different criteria and associated relevance and confidence in data.

Summarising, through our approach we take in consideration past, current and future information, with the aim to achieve more informed tactical or strategic decisions. It is important to have consistency in behaviour so past evaluations (historical matrix) shall affect our decisions. The current matrix reflects the latest situation and the future matrix reflects the expectations for the next period or iteration. Figure 1 depicts the proposed HPF-DMCDM of merging the three types of matrices to rate and rank suppliers at each evaluation period (dynamic process).

To improve readability the next figure assumes a fixed set of alternatives and criteria, but these can change, as discussed

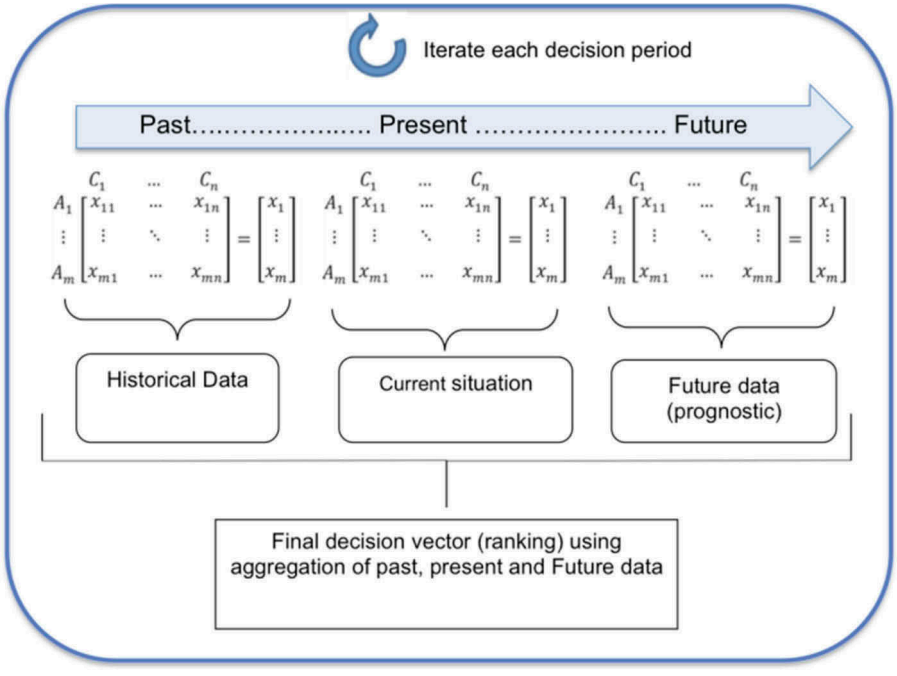

Figure 1. Extended DMCDM model with prognostic [adapted from (Jassbi, Ribeiro, and Varela 2014)].

previously. Furthermore, in the three matrices of Figure 1, xij represents the satisfaction of criteria Cj for alternative Ai.

An important challenge of this model is how to aggregate the three decision matrices to have one final matrix to represent the rating of each supplier. Hence, the first step is how to aggregate the respective criteria values of each individual matrix, resulting in three vectors, one for each matrix (see Figure 1). The second step is to merge (aggregate) the three resulting vectors into a single rating for each alternative, which encompasses, past, current and future information. There are many operators to perform the two aggregation steps and their usage in multi-criteria problems is widely spread (Campanella and Ribeiro 2011; Ribeiro et al. 2014; Jassbi, Ribeiro, and Varela 2014) and in our proposed model any combination of aggregation functions can be used.

In this work we consider that there is imprecision, in the data available, and fuzzy logic concepts are used to normalise the criteria, thus enabling numerical and comparable data to be aggregated. Specifically we use a data fusion process, proposed by Ribeiro et al. 2014, a fuzzy information fusion (FIF) algorithm. The authors propose a Data Fusion process, based on fuzzy MCDM concepts and techniques, such as fuzzy sets to normalise the variables and mixture operators with weighting functions to fuse the information into a composite of candidate alternatives. Software agents in the proposed model use an approach that combines the FIF method (Ribeiro et al. 2014), by using data fusion, with a dynamic decision approach (Campanella and Ribeiro 2011; Jassbi, Ribeiro, and Varela 2014), which, in a dynamic way, integrates historical, current and forecasting information, to support supplier selection.

3.1. Requirements

Companies belonging to Virtual Enterprise Breeding Environments (VBEs) may assume the Broker role, being responsible for identifying and pursuing business opportunities. In order to support the interaction flows in identifying and persuading business opportunities, illustrated in the scenarios described in the next section, the developed model must efficiently support: (1) partner evaluation and selection; (2) the submission of RFPs/RFQs; (3) the submission of quotes/proposals; (4) supplier and quote evaluation; (5) the evaluation of production capacity and plan execution; (6) the negotiation with suppliers; (7) the selection of the most favourable proposal/quote among a set of alternatives (supplier evaluation); (8) support the main supply steps (order assignment, invoicing, payments and so on); (9) monitoring procurement activities.

Additionally, the developed model and the used collaborative platform (Moghaddam and Nof 2015) should support (11) the registration of a new member company, acting both as a partner and supplier; (12) the registration of a company which will only supply goods or services to the VE (supplier only); (13) the communication among business partners; (14) the definition of the negotiation protocols that should be implemented; (15) the reconfiguration of the supporting VE model, automatically or manually.

At the infrastructure and operation level the used platform supports: (16) mixed usage of cloud-based and locally installed agents; (17) system integration with local backend systems using interface agents; (18) aggregated logging; (19) and monitoring.

At the architectural level, the platform enables: (20) to support multiple heterogeneous software agents; (21) allow agents to work autonomously; (22) support asynchronous agent communication, using messages; (23) be based on a scalable and modular architecture.

3.2. CN lifecycle

The first step to establish an aggregation partnership is the identification of the associated business opportunity. These tasks are part of the general CN lifecycle, illustrated in Figure 2. During the initial seed opportunity identification phase, the founding company detects the initial business opportunity.

Next the company defines and validates the business case, identifies preliminary partnership opportunities, identifies and validates requirements and decides if the opportunity should be pursued, i.e. the phase 1 'See opportunity identification' is performed through the following steps: 1.1 Business opportunity identification; 1.2 Business potential evaluations; 1.3 Requirement evaluation; and 1.4 Business decision.

Next, the CN is instantiated. The used platform is configured and prepared to support the partner selection and evaluation phase, i.e. the phase 2 'Platform instantiation' is performed through the following steps: 2.1 Pre-deploy platform configuration; 2.2 Platform activation; and 2.3 Platform integration with existing systems.

The platform supports the creation of a new CN, upon the action of the founder company. The company may invite a set of well-known business partners or, alternatively, it may search and select them using the platform itself. The partner selection and evaluation phase, the phase 3 from Figure 2, is performed through the following steps: 3.1 Potential partners' identification; 3.2 Partner invitation; 3.3 Partner screening; 3.4 Partner evaluation; 3.5 Partner selection; and 3.6 Initial partner role assignments.

The Company uses the platform to fulfil the creation of the CN, and configure it according to the business case and

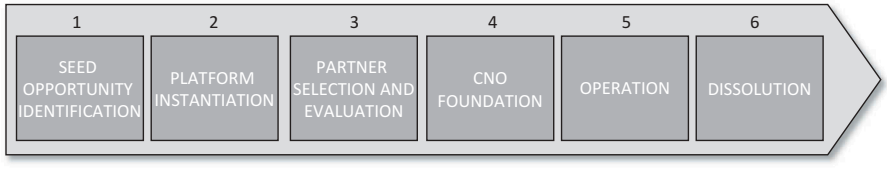

Figure 2. Collaborative network organisation's lifecycle summary.

associated requirements. The network may be configured as: (1) VBE with a broker company; (2) VE with a broker company; (3) VE without a broker company; or (4) Collaborative supply chain network. Next, partner roles are revisited, and the CNO role assignments are defined. This may include defining the companies that may assume the broker role, and which companies may coordinate outsourcing initiatives, among other options. The phase 4 'CNO foundation' is performed through the following steps: 4.1 CNO instantiation; 4.2 CNO configuration; and 4.3 CNO role assignment.

Once created, the CNO enters the phase 5 'Operation'. During this phase, business opportunities may be identified and captured in the network, and processed according to the network type and topology. Once an opportunity is captured by a broker company or one of its peers (step 5.1), partners are selected to capture it (step 5.2). Depending on the type of CNO, the captured business opportunity may cause the dynamic creation of a new VE (step 5.3). The Bidding process is started after partners have been selected and optionally a VE was created (5.4). If an adequate quote was received, the order may be awarded to best rated supplier (5.5). Otherwise, a negotiation process may be started.

The CNO may be terminated at any time. When the need for network shutdown arises, a closure plan is defined and implemented, the phase 6 'Dissolution', starting with the step 6.1 CNO Dissolution plan definition. After receiving the closure announcement (6.2), member companies will be invited to document lessons learned (6.3), allowing this information to be reused at a later time, when new CNOs are evaluated and created. All existing data will be archived and made accessible upon request, using the underlying cloud infrastructure (6.4). The final step is 6.5 CNO Instance closure.

3.3. Bidding

The bidding process starts with a request for qualifications (RFQ) submitted by the Order Agent (OA). The main goal is to determine which of the business partners may be able to fulfil the associated request. Suppliers that are interested in the offer will answer with their qualifications. The request for qualifications may include the need to comply to certain regulations, or standards, associated with the business. Additionally, it may demand potential suppliers to have specific certifications. The answer to a Request for qualifications is issued by an Order Processing Agent (OPA), which is instantiated to represent the supplier in the negotiation processes. The OA will wait until a deadline has been reached or until all RFQs have been fulfilled. Then, it will analyse the answers that were received and exclude any suppliers who do not comply with the minimum set of requirements. The process is illustrated in Figure 3.

After the screening phase, eligible suppliers are integrated in a protocol handshake process. The OA submits to the OPAs the RFQ, according to the agreed protocol, stating which values it wants to receive (for example, price, delivery time and lead time). Additionally, the OA may highlight the evaluation criteria it will use, if appropriate. After receiving an RFQ, each of the OPAs starts a budgeting process. They calculate the price and may also interact with production agents (PA), associated with their company, in order to obtain the delivery

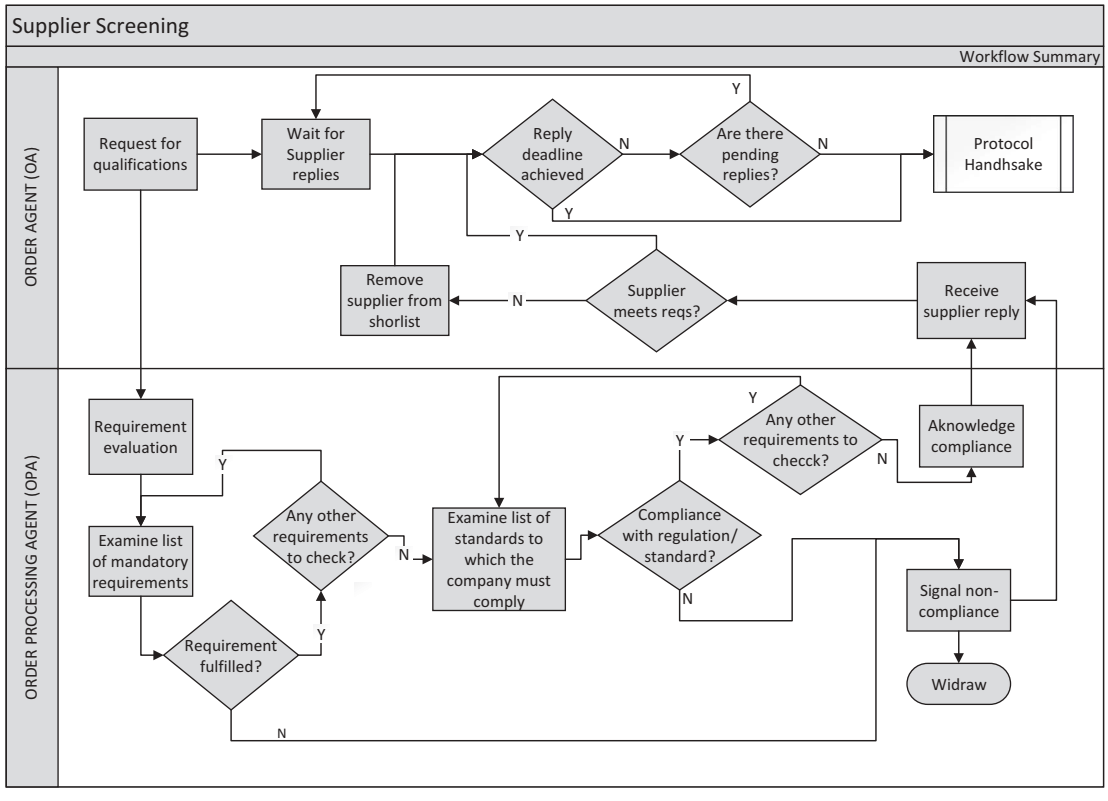

Figure 3. Supplier screening workflow.

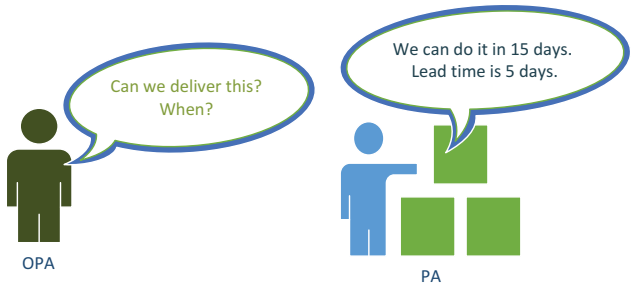

Figure 4. Budgeting and delivery time evaluation.

and lead times it can propose, according to the current production schedule. Additionally, the PA may report the production capacity during the period, if that parameter is part of the negotiation protocol. Finally, the OPA will issue the proposal to the OA, according to the defined protocol (Figure 4).

The OA which submitted the initial RFQ will evaluate all proposals/quotes it received, comparing the criteria it established for evaluation. It may include criterion associated with the proposal (price, delivery time, lead time) and criterion associated with the supplier performance (On Time Delivery Performance, Defect Free delivery, Delivery delay mitigation, Defect Mitigation). The evaluation will be performed using historical information, information contained in the received quotes and also forecasting.

If none of the proposals/quotes is acceptable according to defined criteria, the OA may initiate a negotiation process with the top ranked OPAs (5.4.4.6). This process may start with an adjustment applied to some of the terms associated with the initial request, or as a completely new RFP.

This option allows a company to divide an order in different parts if none of the proposals it received for the whole order was acceptable according to evaluation criteria. This segmentation, when possible, may generate finer grain RFQs, which trigger a new enquiry, and allowing different suppliers to be selected for different parts of the order's deliverables (Figure 5).

The contacted OPAs will then build a new proposal/quote, if that is considered acceptable on their side. This new proposal is returned to the OA for a new evaluation.

The OA will apply individual selection criteria in order to define the best supplier. First level evaluation includes criteria such as price, Delivery Time, Lead Time, On Time Delivery Performance, Defect Free delivery, Delivery delay mitigation, Defect Mitigation. After evaluation, the OA may find itself in one of the following situations: (1) it has a proposal at the top of the ranking list; (2) it has a set of proposals with similar ratings at the top of the list; and (3) the OA has no acceptable proposal or the best supplier cannot be determined. Possible actions are summarised in Table 1.

If the OA has one acceptable proposal, it sends a formal order to the OPA for the supplier. In reply, the OPA sends the proposed plan for the order delivery. Once the order has been issued, monitoring its execution is performed by a Production Management Agent (PMA), in the buying company, and by a Production Agent (PA), in the supplier. Periodically and according to the Schedule, the PMA agent will contact the PA agent to requesting an updated production status.

As soon as the work is completed, the PA agent notifies the PMA agent that delivery will occur. When that happens, the PMA analyses the deliverables, and stores in a shared repository (1) the defect rate it detected and (2) the schedule fulfilment rate. After the PMA confirmed that the deliveries fulfil the requirements presented in the purchasing order, it ends its association with the process. The same happens with the PA on the supplier side. Both can now be assigned to process future orders. The main software agent roles associated with the bidding process are resumed in Table 2.

3.4. Outsourcing

The used Platform supports the existence of several OAs in the VE/CNO. These OAs process supply requests for products, components or services that the OPA has identified as impossible to deliver, after receiving a negative reply from the Planning Agents, This negative reply can be associated with (1) insufficient available manufacturing capacity, if it is 100% reserved for the required period; (2) inability to meet delivery times; and (3) requirement to deliver products, components or services not manufactured by the VE. As such, the VE must be able to assume the role of customer, as well as the role of supplier. As a customer, the VE may start a bidding process with external suppliers, for the items or services it requires.

The bidding process is encapsulated from the customer's view. The VE enterprise will be responsible for all interaction with the end customer, including deliveries and financial interactions. Typically the end customer does not know anything about the outsourcing process. On the other hand, the broker

Figure 5. Negotiation.

Table 1. Proposal of evaluation scenarios.

Situation	Possible action
The OA has a proposal at the top of the ranking list.	The order may be assigned to the top ranked company.
The OA has a set of proposals with similar ratings at the top of the list.	If a tie is found among companies at the top of the ranking list, the agent will evaluate additional individual criteria, using an ordered list. Criterion such as Number of Previous Orders, Strategic Supplier Rating and others may be used. This ordered list is customisable and may be fined tuned according to business scenario. Alternatively, the OA may start a negotiation process, in order to obtain better values in specific key criterion, since it already has multiple alternative proposals available.
The OA has no acceptable proposal.	In this case the OA may divide the order in smaller segments, which in turn will generate new RFPs. For example, if no acceptable proposals were received for the development services needed for an Interactive application, including its design, the OA may divide the order in two different segments (development and design), each having potentially different delivery requirements, starting a new RFQ with the same companies or others. It may include other companies which may have been excluded during a previous phase due to the incapacity of full filling the whole order (for example, a design agency which does not possess any internal development competences).

Table 2. Roles assumed by agents in the bidding process.

Role	Actions	Performed By
Buyer	Establishes the negotiation protocol, monitors key stock levels, selects suppliers, issues RFQs, receives quotes from suppliers, performs supplier evaluation, and defines short list and awards orders.	Order Agent (OA)
Seller	Replies to compliance evaluation requirements, receives RFQs, evaluates of requests are compatible with the company offering, evaluates if the order can be fulfilled, interacting with the production agent, creates and sends quotes.	Order Processing Agent (OPA)
Negotiator	Derives new quotes from the original quote, evaluates optimisation needs associated with replies it receives and negotiates agreements.	Order Agent (OA) Order Processing agent (OPA)
Production Planner	Defines schedules, processes requests for delivery time and lead time, replies with time estimates based on production plan and plans production.	Production Agent (PA)
Production Manager	Monitors production status, replies to status requests issued by Production Management Agents, issues status reports and updates delivery estimates.	Production Agent (PA)
Project Manager	Monitors production status, interacts with Production Agents for updated production status and validates deliverables received from suppliers	Production Management Agent (PMA)
Financial	Issues invoices (Seller), issues payments (Buyer), issues receipts (Seller).	Financial Agent (FA)
System Integrator	Receives and converts data received from an external system; converts and updates data received from other agents on an external system.	Translation Agent (TA)

company may define that no outsourcing is allowed for one specific order, if that is an end customer requirement.

4. Business scenarios for collaborative networked organisations' platform usage

The used platform is compatible with scenarios where companies are motivated to establish business partnerships that potentially generate business added value for its participants.

SMEs frequently possess limited human and physical resources and have to depend on external suppliers and service providers. Let us say company X interacts with a network of n suppliers (Figure 6). When the company is assigned orders by its customers, it contacts its suppliers, issues Requests for Quotes or Proposals (RFQs/RFPs), analyses their responses, eventually negotiates their terms, awards smaller orders to suppliers and monitors their delivery. These are time consuming activities that have strict timing requirements. It is not unusual for SMEs to lose business potentials due to delays in the budgeting process. This company can benefit a lot from an optimised channel to support partners and suppliers, for order fulfilment.

Our platform may be used in such a scenario. In this scenario, we have one company collaborating with other companies to better achieve common or compatible goals, using computer networks to support interactions. As such it can be considered a simple form of a Collaborative Network Organization (Oliveira, Camarinha-Matos, and Pouly 2010; Renna 2013; Camarinha-Matos et al. 2013). This scenario is illustrated in Figure 7.

When Company X and its business partners assume a closer relationship and decide to approach business potentials as one single Company, provide a single point of contact to their customers, they may choose to create a VE. According to Camarinha-Matos (Camarinha-Matos et al. 2013): 'a VE may be defined as a temporal alliance between one company and its partners, that come together to share skills or core competencies and resources'. In order to support such an organisation we may follow two different approaches. The first option will be to assign the role of business broker to one of the companies, or even create a new company for that purpose. The broker company will assume the responsibility of acquiring and processing business opportunities (Oliveira, Camarinha-Matos, and Pouly 2010; Camarinha-Matos et al. 2013). Typically, the remaining companies do not directly interact with end customers, receiving business potentials from the broker and are awarded individual orders based on the negotiation process. This scenario is illustrated in Figure 8.

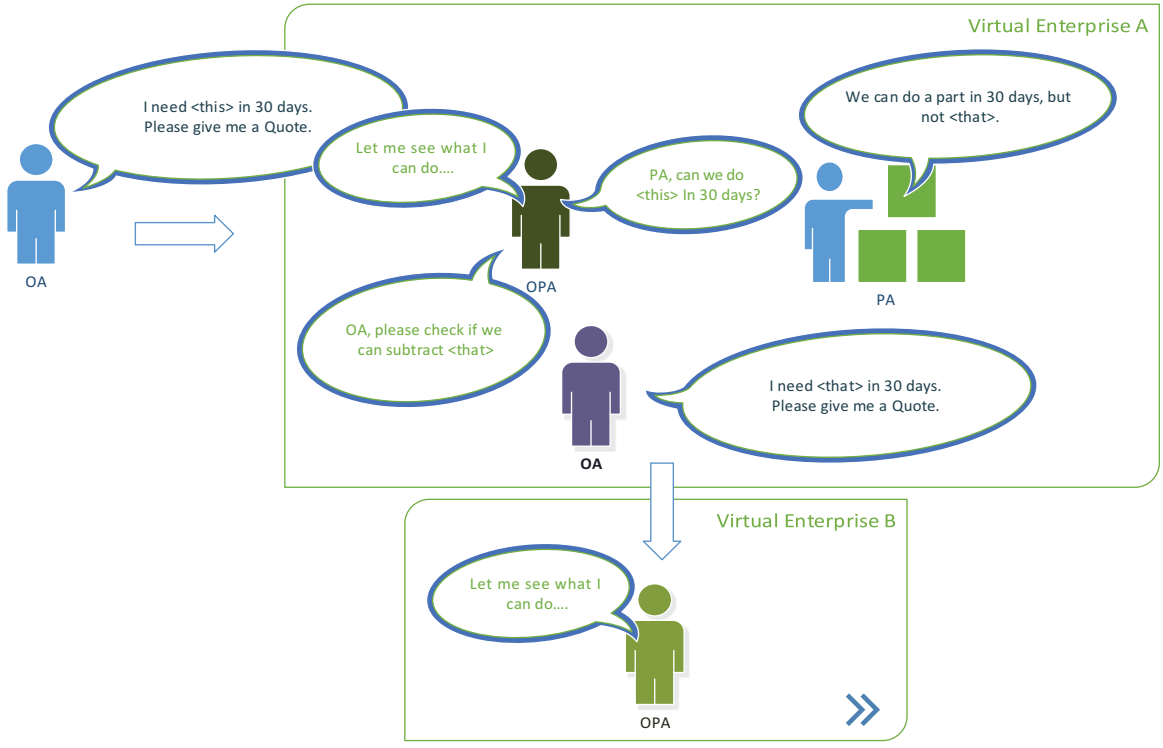

Figure 6. Virtual enterprise outsourcing scenario.

The second option for VE organisation will be to allow all companies to interact with customers, pursuing business opportunities and acquiring orders. These orders may include services or components that are fulfilled by the remaining participant companies.

The companies that acquired the order assume the responsibility of interacting with the customer and provide the aggregated deliverables. This option is illustrated in Figure 9.

Business clusters are created to maximise business opportunities for existing companies, stimulate new business, drive innovation and increase business productivity. Geographical and sectorial clusters are a common form of competence aggregation that may prove appealing for SMEs.

A cluster represents the association of companies with an effective collaboration potential, with the desire to cooperate among them using a long term agreement.

As such, it may classified as a VBE, representing a long term network structure, featuring infrastructure sharing and high confidence among participants (Camarinha-Matos et al. 2013). More than a simple hierarchical network, a VBE is characterised by numerous repeated connections between companies that constantly shift and expand. It supports the existence of several simultaneous VOs.

A VBE is in fact a type of CNO, representing an association of organisations adhering to a base long-term agreement and adoption of common infrastructures and operating principles

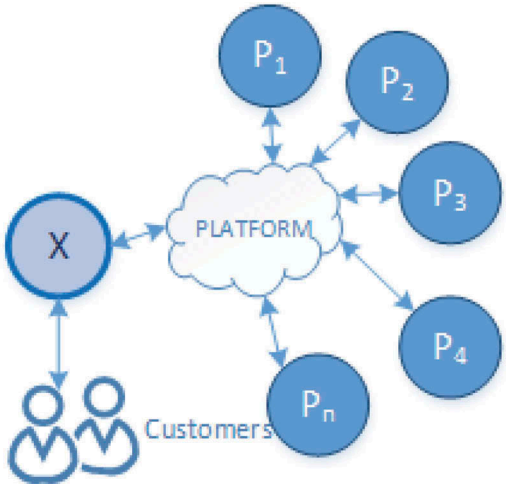

Figure 7. Virtual Enterprise optimisation using a collaborative network.

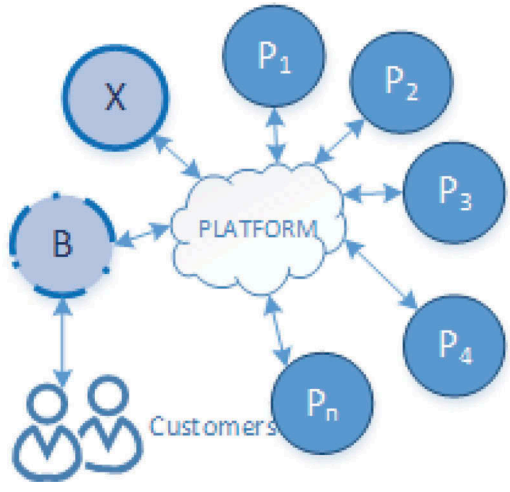

Figure 8. Virtual Enterprise with a broker company.

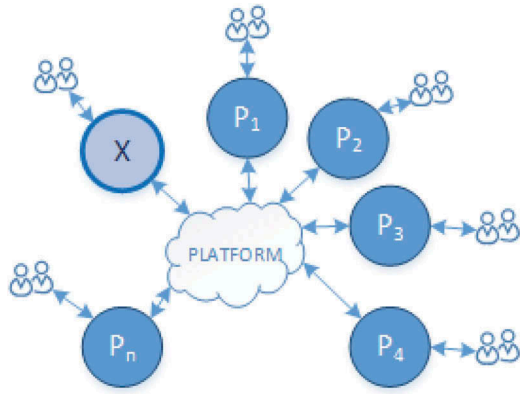

Figure 9. Virtual Enterprise without a broker company.

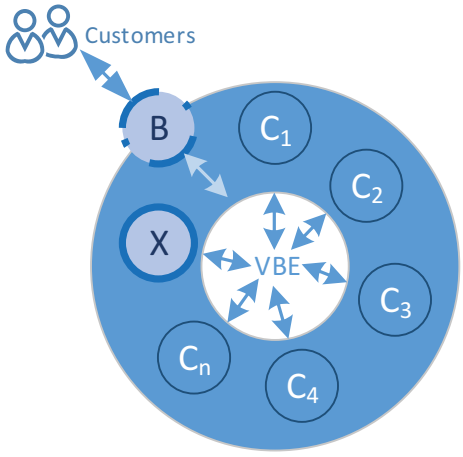

Figure 10. Virtual Breeding Environment with a broker company.

(Camarinha-Matos et al. 2013). Typically a VBE includes a single Broker that assumes the responsibility of acquiring and processing business opportunities. As response to new business opportunities, new VE may be dynamically created in the VBE. Those VEs may be terminated after the corresponding orders have been fulfilled. This scenario is illustrated in Figure 10.

5. Validation of the HPF evaluations model based on a DMCDM

The main aim of our proposed platform consists on enabling an improved support in terms of VE creation, operation and dissolution in the context of a CN. Therefore, one of its main pillars consists on its ability to support decision-making, for instance, in terms of: which are the best partners to establish the network, which are the most suitable companies to integrate a VE, and which are the best companies or business partners to implement the provision of services or components required to meet the requests about some set of received orders.

To evaluate the potential associated to our proposed model we decided to analyse to what extend the underlying dynamic approach (DMCDM) really can be of value added to support the process of evaluation and selection of the best proposals in terms of business partners.

To evaluate the performance of the proposed HPF-DMCDM, it was decided to carry out simulations of its application using the dynamic generation of proposed applications and the evaluation of the responses received.

The evaluation was based on three different approaches: (1) a complete dynamic evaluation, covering the use of historical matrices (resulting from proposals received) and forecasts (based on our proposed DMCDM); and other two other simpler alternative approaches, which are common in multi-criteria decision models, which are: (2) assessment based on historical and present information; and (3) evaluation exclusively based on the proposals received (Campanella and Ribeiro 2011; Jassbi, Ribeiro, and Varela 2014). Therefore, the complete dynamic model (HPF-DMCDM) underlying to our proposed platform was applied through a simulation process, to a set of 6 potential business partners available for carrying out the production of a given product, in order to better clarify the potential of our proposed approach and corresponding software prototype to be validated.

The first step of this simulation process consists on the definition of its main parameters. This set of parameters includes the number of iterations to be performed, the number of queries to simulate by iteration, the group of businesses to be consulted, the number of evaluation criteria to be used and the approaches through which they are used. Additionally, matrices are configured about historical provisional data, along with the histograms used to simulate the behaviour of businesses.

Next, it is needed to define the criteria for HPF evaluations.

To make the clearest illustration in terms of prototyping, it was selected a representative set of used criteria, which are described next, and this data was used jointly with the information provided through the criteria used for historical and future evaluation of business delivery times.

For the implementation of the dynamic model, the various evaluation criteria were mapped on their type ('higher is better' or 'lower is better'), uncertainty confidence levels (Campanella and Ribeiro 2011; Jassbi, Ribeiro, and Varela 2014). In addition, underlying α and β confidence values were defined for each criterion and $\lambda = 1$ (Campanella and Ribeiro 2011; Jassbi, Ribeiro, and Varela 2014).

To evaluate each potential business partner the criteria were used three approaches related to our proposed dynamic evaluation model (HPF-DMCDM), which were the following: 1. HPF evaluations (complete dynamic model); 2. historical and present evaluations (partial evaluation model, HP), and 3. Only present evaluation (simplified evaluation model, P). Therefore, these three approaches require the use of one up to three evaluation matrices (Campanella and Ribeiro 2011; Jassbi, Ribeiro, and Varela 2014).

In this approach was considered the same reference time for all repetitions of query request, performing successive simulations of the application of the evaluation approaches at the reference time, and next the results were compared.

Each of the consulted businesses submits a proposal for providing a unit of the considered product, randomly generating values proposed for the unit cost and for the total time

of delivery (corresponding to the sum of the production time and the order preparation time). To support the randomness in terms of generation of proposals, each business has been classified according to four main areas: (1) delivery optimisation potential, emphasising the efforts each business has provided, along with its effort to reduce the delivery time; (2) potential changes in prices, reflecting the trend observed by the business to increase, decrease or maintain the prices offered; (3) risk of late delivery, reflecting businesses' performance in terms of delivery and the potential of further delays; and (4) the risk of defects, reflecting the likelihood of defects in future deliveries.

The presentation of data was also thought through an adequate visualisation interface for each type of data analysis and matching results projected at each step of the businesses evaluation and selection process, allowing different views, with more or less detailed information according to each specific need. Therefore, the developed simulator prototype allows alternative views of results, along the detailed simulation process. Namely, allowing following the evaluation process of winning proposals for each of the alternative approaches considered, and consultation of the corresponding total costs associated.

The prototype also provides an additional mode of simulation, to facilitate the generation of a large number of records and their subsequent analysis. Supporting the definition of the number of iterations (n) and consultations (m), and the same are associated with the 6 businesses, for the illustrative example of use considered in this case study. So, in this case study, the prototype generates x*m*6 random proposals and evaluates them using each one of the three approaches considered. Once the evaluation is performed, the prototype selects the most advantageous scenario, considering the profile of each business, and the resulting costs, namely regarding the evolution of the difference in cost between the three approaches and the best solution obtained on each iteration, as illustrated in Figure 11.

In this case study were used data extracted from the real-life cases of the Es in the service sector. The simulation process was executed through 100 iterations, each of which includes 20 proposal requests (resulting in a total of 2000 consultations, which generated 12,000 proposals, and these have been evaluated in the context of each of the three approaches under consideration, resulting in a total of 36,000 ratings). According to defined profiles, the complete dynamic approach (HPF) was the only one that did enable to generate the best solution in 1071 consultations. Moreover, in 1808 cases it reached the best solution in conjunction with one or both alternative approaches.

The results were recorded in databases, enabling to further make queries and export data and results for further analysis, namely through external tools such as SPSS and Microsoft Excel. Comparing the cost of each of the solutions generated through each of the three approaches, it is possible to realise that the complete dynamic approach (HPF) was the one that did produce the economically most advantageous solution, as we can realise through Figure 11, which expresses the cost of each solution and the cost reached through the best one.

The robustness of the HPF model (r) can be observed in Figure 11.

In practice, since the complete dynamic approach is responsible for the largest number of best proposals in economic terms, its value is always closest to the best solution value found. Therefore, it demonstrates to be the most robust and appropriate approach, among the three variants considered.

6. Logical architecture for the supporting platform

A technological platform assures a collective impact, vigilance, learning and action, a social pattern that we intend to assure. For any federated resource, its specifications or relations must be appropriately described and semantically classified (Zelitchenko 2010).

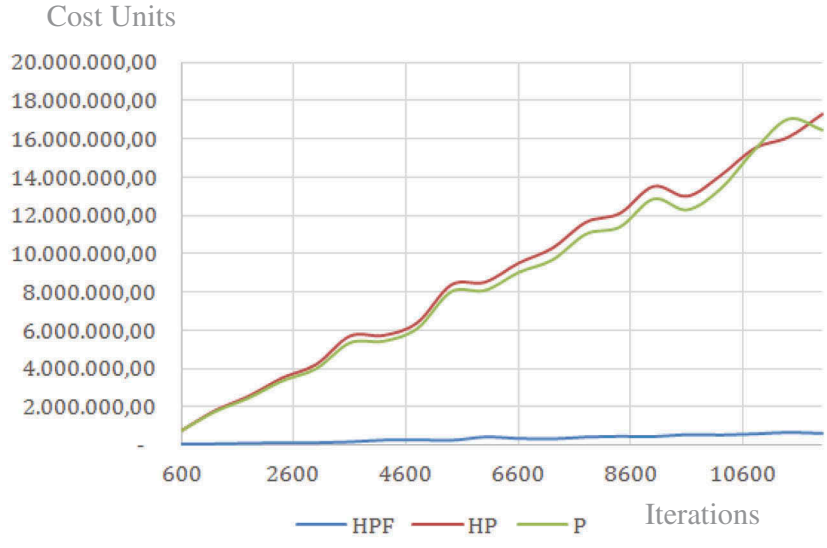

Figure 11. Evolution of the difference in cost between the three approaches and the best solution obtained on each iteration.

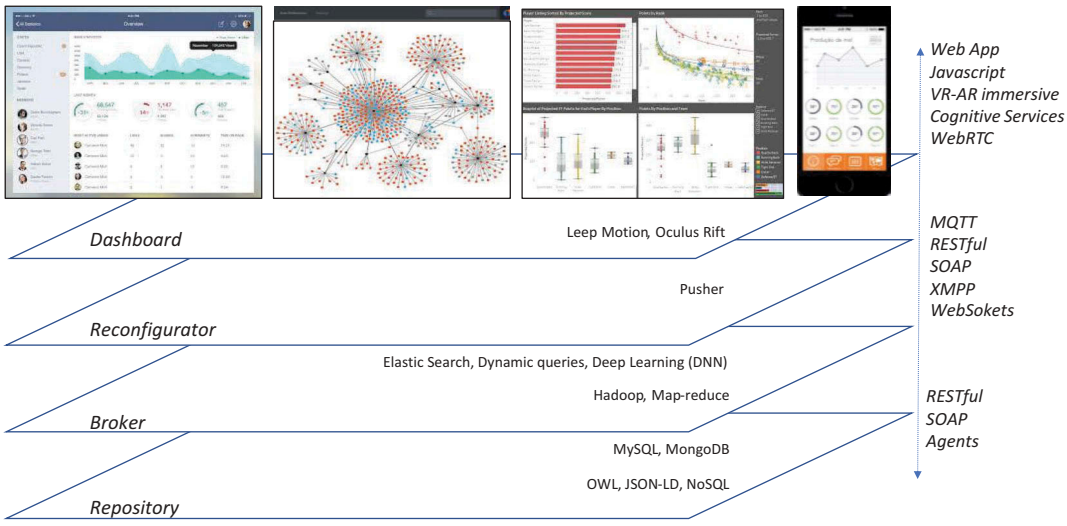

Figure 12. Full technological stack.

This overall dynamic reconfiguration needs the perfect composition of two technological supporting tools:

A brokering engine must assure the effectiveness on the selection of resources. The context changes all time and to velocity to deal with the huge volume, variety and several others heterogeneous resources specifications, require high performance and processing capacity, cluster classification and generative inference rules. Big data processes and infra-structures together with Artificial Intelligence (AI) algorithms shall be used. Cloud computing distributed storage and processing infra-structures and frameworks (Hadoop, Map-Reduce), dynamic queries and elastics searches algorithms, will assure Big data requirements; On the other hand, Deep Learning with deep neural networks will be potential algorithms to support patterns recognition and generative infer rules. The capacity to find the not-evident or expected resources, depends on this generative capacity and, having this, predictive scenarios will be available.

Visualisation and Advanced Decision Support tools. Having the capacity to monitoring the set of potential alternative resources, and accepting the recognition of Kurzweil '(…) how the link between pattern recognition and human intelligence could be used to build the next generation of artificially intelligent machines (…)' (Kurzweil 2012) we believe that the co-decision, having humans actively participating and collaborating on context valuation and validation, is essential. For this: (a) the capacity to get a real-time useful and appropriate data visualisation (3D); (b) the capacity to browse deeply in those data, using Virtual and Augmented Reality visualisation devices (Oculus Rift); (c) be able to support an immersive navigation and control (Leep Motion); and (d) get informed or assisted on the proposed resources ranking alternatives, as well as a set of tools to collaborate and co-create new information or scenarios, will be real useful innovative and effective features. Extensible Messaging and Presence Protocol (XMPP) (Moffitt 2010), Web Real-Time Communications (WebRTC) and WebSockets-based services agents will be used for that, offering synchronous communication and collaboration tools for the intended rich User Experience (UX) interfaces; Responsive dashboards will organise a set of cross-platform and interoperable widgets, using multichannel event publishing technology (like Pusher) to broadcast changing events. Related JavaScript frameworks and libraries will be the base technology for client application interaction support. Cognitive Services (like Face, Vision services from Microsoft) will be explored.

Thus, the full technological Cloud Architecture is constituted by a set of agents, implemented as RESTful or SOAP autonomous Services, as a cloud hosted process or as a middleware, hub or broker service infra-structure. Figure 12 represents the main technological stack.

7. Conclusions

In this article we propose a model (HPF-DMCDM) and an underlying collaborative platform for supporting multiple business scenarios, involving potentially heterogeneous companies that have the will to reach new customers and access new markets, through partnership. The main goal of our proposed model is to assure a more robust than existing ones, for better supporting the establishment of interaction between a company and its partners, when applied in the context of varying CN organisation scenarios (Kirn et al. 2006).

The scenarios include supply chain collaboration networks (CN), in which a group of companies optimise their interaction to better support market changes and to be more agile in the context of a globalised environment.

The scenarios also include VOs, in which the participating companies take one step further in their partnership, eventually fusing themselves in a single virtual Company, allowing them to reach a wider market. By using specialised software agents, cooperating in order to achieve their individual goals, the used platform facilitates its preventive and corrective maintenance. Additionally, by using focused agents, assuming targeted and well-defined roles, the platform's evolution potential is increased, as well as its flexibility and adaptation capacity to evolving business scenarios. Moreover, our platform uses encapsulation level achieved by using the proposed approach which also facilitates the creation and addition of

new components, without interfering with existing ones, which makes the platform more scalable. On the other hand, the development of a HC makes it easier for new Companies to participate, minimising the computational and maintenance resources required for them to be members of a CN.

Also, cloud services introduce flexibility that enables to guarantee that resources will be available when the network grows and requires them, also further maximising its scalability. Summarising, our main proposal is a model for supporting supplier and business partner evaluation and selection, based on supplied quotes, historical information and forecasting that is able to automatically reconfigure itself, based on its member's performance, capabilities and evolution, according to the information that is stored, each time some decisions are made along with information that arises in a dynamically and in a real-time basis from businesses within the VO through the underlying CN.

The platform proposed shows that the collaboration dynamics in the real-life Es, considered for testing and validating, could be significantly improved.

Future work will include: (1) parameterisation of the proposed platform in order to enable the creation of new platform instances, (2) inclusion of other models for partners evaluation and selection, (3) analysis of more complex industrial cases, in particular in the context of Industry 4.0.

Disclosure statement

No potential conflict of interest was reported by the authors.

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