Conceptual Architecture for Agent-Based Modelling of Supplier Selection Conducted by a Supply Chain Dyad

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***Abstract*— Within the fourth stage of industrialization, artificial intelligence and in particular the multi-agent systems paradigm is highly adopted. Within the agent approach, the industrial resources are defined as intelligent agents that negotiate with each other to implement dynamic reconfiguration and reach agility and higher customer satisfaction. In this paper a smart configuration of the agent-based system for multi-product dyadic supplier selection is proposed. The objective is to select suppliers for multiple products simultaneously in a vertical collaboration context between the supply chain dyad and the suppliers. Therefore, the novelty is involving the customer of the purchasing company and considering its preferences. This decision-making system includes three steps: a dyadic suppliers pre-selection, a dyad-suppliers negotiation, and a purchasing company final selection. For initial validation of the proposed conceptual architecture, negotiation experiments are conducted.**

***Keywords*—** *Supplier selection, Multi-agent, Dyadic supply chain architecture, supply chain.*

1. Introduction

The supply chain (hereafter SC) rules were relatively simple. Four main players: the supplier, the distributor, the logistics provider and the customer. The common goal is to satisfy the customer by providing the right product for his needs with the desired characteristics and delivering him in the right time and place. However, if the main goal is still the same, many practices have changed, new trends have emerged, the customer becomes pernickety to product and service quality, and the consumer habits, especially the communication of customers have largely contributed to changing the challenges related to the SC.

With the digital revolution, the play area of companies is becoming more and more extensive. Companies must be able to manage an extensive supply chain that requires the linking of actors from all over the world. However, if the geographical area gets longer, the delays must be reduced to their maximum in a supplier’s competitive environment increasingly atrocious and fierce. Therefore, supplier selection becomes a critical step, involving the identification and selection of suppliers for multiple required products with the best deals. Usually, the purchasing company needs to negotiate with suppliers to determine the concrete terms of the required products. Since there are large numbers of companies having interest in supplying the products required by the purchasing company, it will become impractical for the purchasing company to negotiate with all the interested suppliers directly. Consequently, it is necessary to screen out several qualified and competitive potential suppliers from negotiation. Including the customer of the purchasing company in the negotiation process seems to be a promising alternative to face the increasing uncertainty in the SC environment and enhance customer satisfaction and SC agility thanks to supplier selection processes.

Supplier selection is basically the buyer-seller relationship in a typical supply chain. This paper suggests a multi agent architecture integrating the buyer's customer in the supplier selection process. The proposed architecture is based on a dyadic supplier selection model for multiple products based on a collaboration-based negotiation between the three stakeholders: the purchasing company, its customer, and the suppliers. The term dyadic refers to the SC dyad composed of the purchasing company and its customer. This work intends to be a pioneering effort in dyadic supplier selection. The novelty of the proposed architecture besides the architecture itself is the collaboration-based negotiation with suppliers. Negotiation experiments are conducted for an initial validation of the architecture.

2. Literature Review

The rise of new digital industry technology, called industry 4.0 has played a major role in advancing human everyday lives and transforming industry world.

Initially appeared in 2011 [1] by the German Federal Ministry of Education, the 'Industry 4.0' evokes a 4th industrial revolution. The first industrial revolution was the transition from manual production to mechanized production in the second half of the 18th century. It is through the electrification of production systems and mass production that the second industrial revolution is characterized at the end of the 19th century. The third is the automation of production through electronics and information technology, it starts in the 1970s with the invention of the microprocessor.

The researchers propose ten technology groups that bring together a variety of approaches, methods and techniques of the Industry 4.0 [2]–[6]: Artificial Intelligence; Cyber-Physical Systems, (CPS); Cybersecurity; Cloud Computing; Big Data; the Internet of Things; Autonomous Robots; Machine-To-Machine (M2M); Simulation Systems and Augmented Reality.

Therefore, Artificial Intelligence represents one of the most advanced technologies. It enables to share information, data and instructions between all agents during all stages of the value chain and it will surpass human's capability. This will lead to the development of more autonomously operated subjects, system and decision makers at all levels. The multi-agent system-based approaches take an important role in artificial intelligence and are used in problem solving.

Multi-agent decision making architectures have been seen in power system applications in the literature [7]–[11]. One of these problematics is automated supplier selection. Literature proposes different agent-based architectures for supplier selection in line with real scenarios such as [12] and [13] where the authors have developed a Multi-agent Architecture for Multi-product Supplier Selection considering the synergy effect between products. One of the most crucial steps in this selection process is automated negotiation. Plenty of supplier selection studies were conducted to automate negotiation processes [14]. For example, in [15] was presented a multi-agent protocol for handling agent bargaining and interactions in complex multilateral and multi-issue negotiations in which the buyer must negotiate with many suppliers. In [16] and [17] authors have established a multiagent-assisted supply chain negotiation by an ontology-based approach and hybrid multi-agent negotiation protocol to incorporate both the stationary and mobile agent negotiation phases and to allow more efficient and successful multilateral agent interaction regulation. In [14] a negotiation protocol was developed to reach a "win–win" planning solution and decisional flexibility and to improve decentralized planning coordination in transport-driven supply chains. Research in this area has even launched the B2C e-logistics. In [18] a multi-lateral negotiation with fuzzy constraints was presented in the framework of an electronic agent-based marketplace. In [19] an agent-based approach able to support negotiation in catalogue-based e-marketplace has been developed. In [20] authors have presented an automated negotiation model for B2C e-commerce decision-making with a multi-strategy negotiating agent system.

However, no protocol in literature tackles supplier selection using agent paradigm and considering partners of the purchasing stakeholder. In what follows, an agent architecture is proposed to fulfil this gap.

3. Phases of Dyadic supplier selection process

The purchasing company is the buyer and the suppliers are sellers. In the supplier selection process, there is one buyer (purchasing dyad, formed

of the buyer company and its customer partner) and multiple sellers (suppliers), and the supplier selection process can be considered as a one-to-many negotiation.
The objective of the dyadic supplier selection is to select suppliers for multiple products simultaneously while considering the customer preferences of the purchasing company (buyer company). In this sense, a four-phase supplier selection process based on [21] is used and shown figure 1. As the dyadic partner of the buyer company is considered in this research, it is necessary to examine how the dyadic dimension impacts the process phases. In the pre-selection phase, the criteria of the buyer company implicitly considers the criteria of its customer. In the negotiation phase with pre-selected suppliers (final selection of suppliers) the buyer company has to involve directly and explicitly its customer partner in case the supplier's proposals are not adapted. The buyer company and its customer partner elaborate counter-proposal collaboratively which increases flexibility of offer and demand and enhance final customer satisfaction along with agility and performance of SC. As the dyadic supplier selection process is composed of the supplier pre-selection phase and the final selection phase, the dyadic supplier selection criteria should be divided into pre-selection criteria, final selection criteria of the purchasing company (the buyer partner), and final selection criteria of the customer partner of the purchasing company. In addition, the problem formulation should consider the strategy of the dyad. In this research, the strategy of the dyad is represented by the procurement strategy. The pre-selection criteria are capabilities of suppliers e.g. for multi-product transactions or for environmental regulations, and the final selection criteria are concrete commitments of the required products such as quality, delivery, service, etc. In this research, the weights assigned to the selection criteria are different due to the procurement strategies of the decision maker.
The functions of the four phases in the dyadic supplier selection process for multiple products are as follows.

Problem formulation

Indicate the products needed to be procured by the buyer-partner, and the corresponding procurement strategy set depending on the strategic orientations of the dyad.

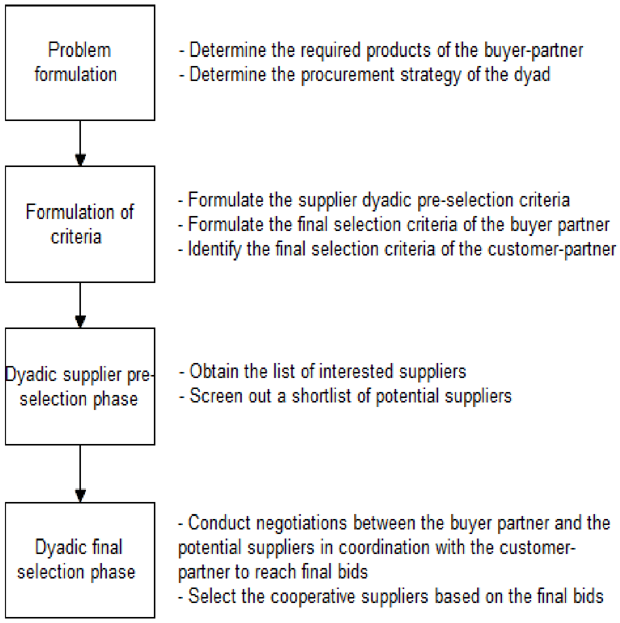


Figure 1. Phases of Dyadic supplier selection process

Criteria formulation

Formulate the criteria for shortlisting skilled and competitive suppliers from all the interested suppliers in the supplier pre-selection phase. Formulate the criteria of the buyer-partner for assessing the bids proposed by suppliers in the final selection phase. Identify from these last criteria, the criteria of the customer-partner for evaluating the bids submitted by the buyer-partner in the final selection phase.

Dyadic supplier pre-selection phase

Identify the interested suppliers list and shortlist the skilled and competitive suppliers to go into the final selection phase.

Dyadic final-selection phase

Negotiate with suppliers on specific concrete commitments (represented by final selection criteria) of products, obtain the final bids of suppliers, select the cooperative suppliers and assign for each supplier a specific order.

4. Conceptual model

According to the five-phase supplier selection process above, it is the buyer partner (i.e. the purchasing company) and the dyad that realize the problem formulation phase. The buyer partner will identify the multiple required products and the dyad will identify the procurement strategy. The four phases left are achieved by two sub-models: the supplier pre-selection sub-model and the negotiation-based final selection sub-model as shown in Figure 2.

selection criteria of the dyad, which is the decision maker of the procurement strategy.

- To shortlist the skilled and competitive suppliers with good transaction capacities. This is achievable with a pre-selection algorithm.

Negotiation-based final selection sub-model

- To articulate final selection criteria representing the concrete commitments of products.
- To identify the relative preferences about final selection criteria (negotiation issues) of the dyad, which is the decision maker's procurement strategy.

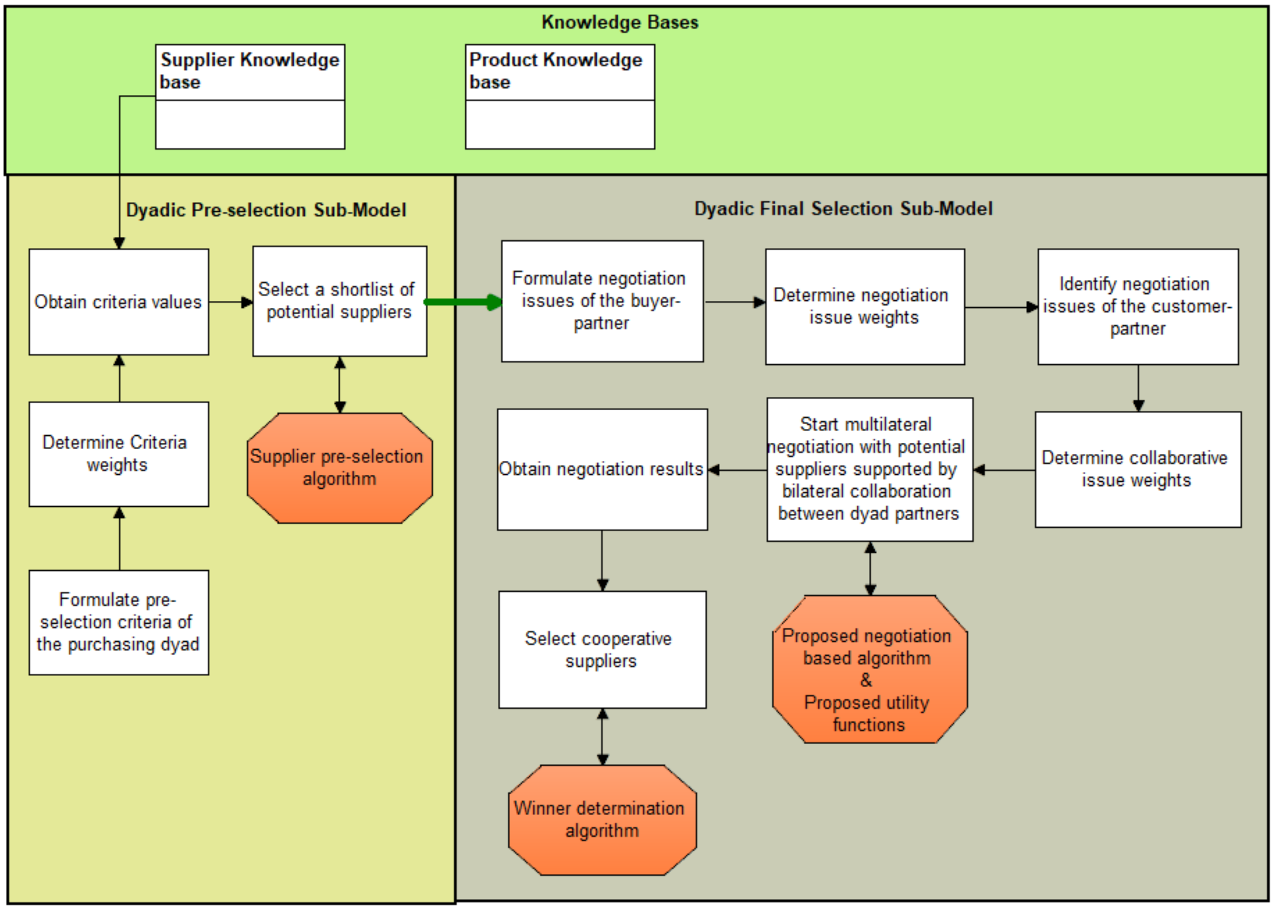


Figure 2. Dyadic supplier selection model for multiple products

These sub-models work cooperatively to realize the procurement of several products simultaneously while considering of the customer-partner preferences. The goals of the two sub-models are presented as follows:

Supplier pre-selection sub-model

- To articulate the pre-selection criteria integrating suppliers' capabilities.
- To identify the relative preferences about pre-

- To determine the bid utility functions for different products depending on the involved dyad partner and its preferences. The utility functions assess the suppliers' bids in negotiation and represents the decision maker's preferences on different products.
- To negotiate with suppliers shortlisted by the pre-selection sub-model, and reach agreements, final bids.
- To choose the cooperative suppliers according to the negotiated final bids. This is achievable with

the winner determination algorithm. The objective of this algorithm is to maximize the purchasing company's utility under given constraints.

- Winner determination algorithm is used to select the optimal combination of final bids submitted by potential suppliers.

The knowledge bases store the initial setting of the purchasing company and computation results. The product knowledge base that stores the specifications and requirements of the required products, and the supplier knowledge base that stores the basic information and history performances of the suppliers.

5. Conceptual agent architecture

The dyadic supplier selection model is modelled as a distributed MAS including autonomous agents representing different parties and functions of the process, as shown Figure 3.

Agents in the system triggers the algorithms and use data from knowledge databases to run the supplier selection system.
The functions of the agents are as follows:

DA (Dyad Agent) determines required products.

DPSA (Dyad Pre-Selection Agent) controls the interactions of agents involving the negotiation model.

DKMA (Dyad Knowledge Management Agent) accepts the knowledge of required products request from the BPA (respectively the CPA), and informs the requested knowledge of required products to the BPA (respectively the CPA)

CPA (Customer Partner Agent) creates instances of the CPNAs for all the suppliers (SAs), configure collaboration strategies of the CPNAs for all the BPNAs and controls the multi-bilateral collaboration between the CPNAs and the BPNAs.

BPA (Buyer Partner Agent) creates instances of the BPNAs for all the suppliers (SAs), configures

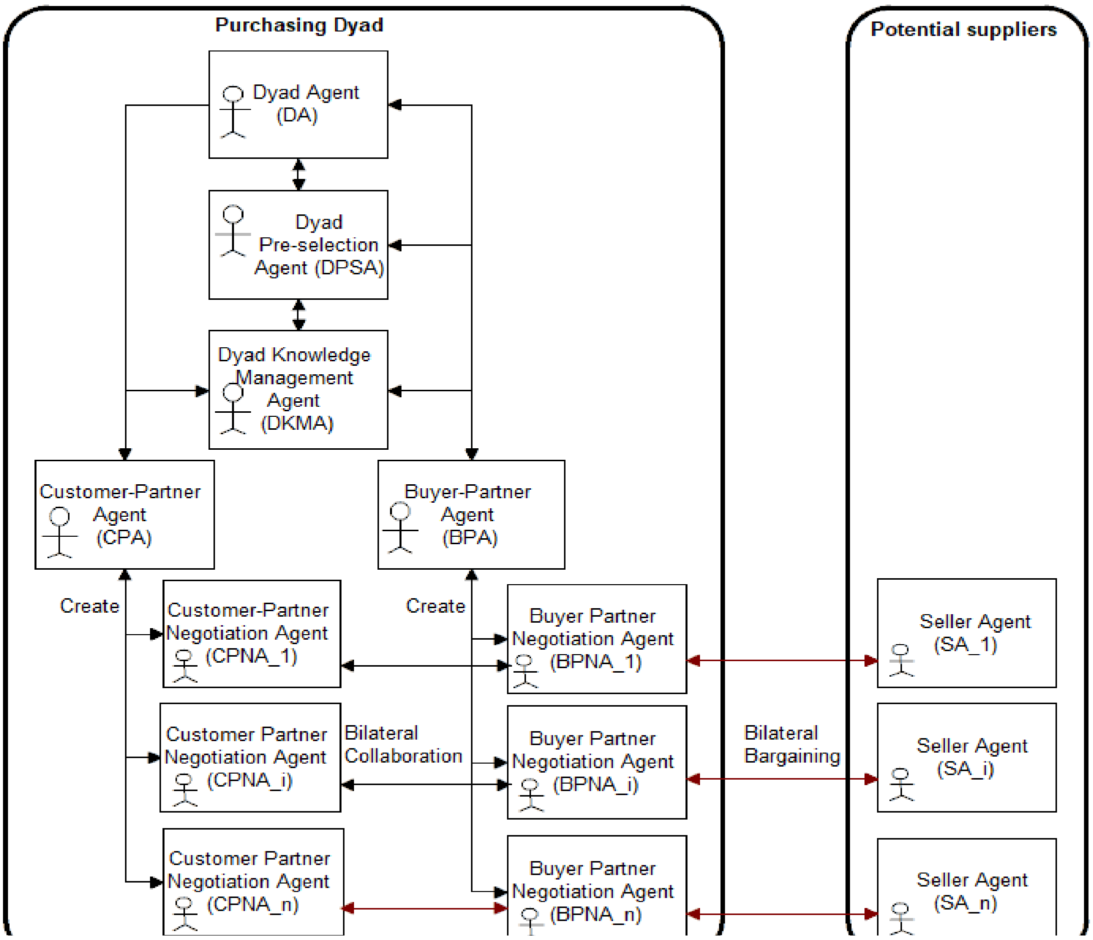


Figure 3. Architecture of the negotiation-based dyadic final selection sub-model

negotiation strategies of the BPNAs for different suppliers and different products, controls the multi-bilateral bargaining between the BPNAs and the SAs, selects cooperative suppliers for products based on the negotiation results between the BPNAs and the SAs and generates the preferred products according to the purchasing dyad preferences on products.

CPNA (Customer Partner Negotiation Agent) represents the dyadic partner of the purchasing company and conduct the bilateral collaboration with the corresponding BPNA.

BPNA (Buyer Partner Negotiation Agent) represents the purchasing company and conduct the bilateral bargaining with the corresponding SA and the bilateral collaboration with the corresponding CPNA.

SA (Seller Agent) represents supplier and conduct the bilateral bargaining with the corresponding BPNA.

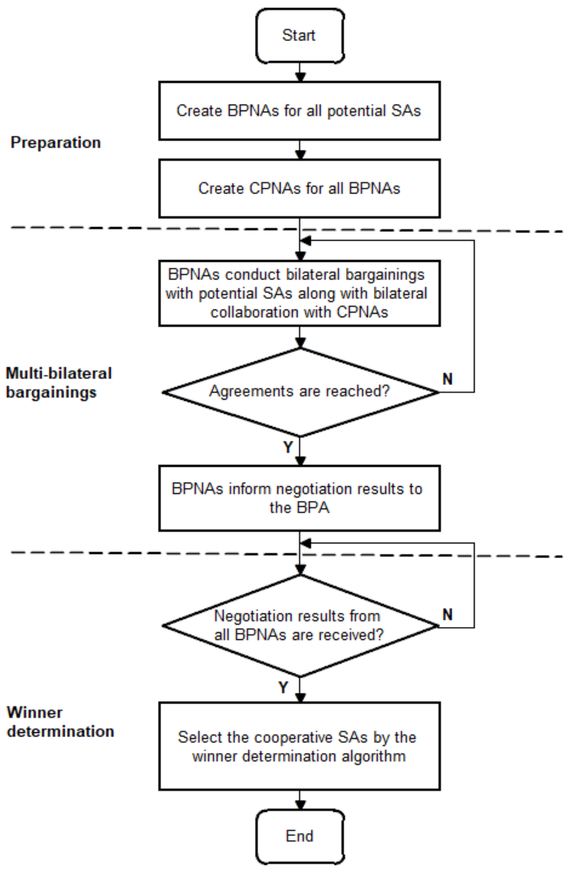


Figure 4. Procedure of negotiation-based dyadic final selection sub-model for multiple products

6. Negotiation architecture

As shown in Figure 4, the negotiation-based final selection sub-model dyadic supplier selection includes three sub-phases: preparation of agent instances required to conduct negotiations, multi-bilateral collaboration-based bargaining between the customer-partner company, the buyer partner company and the suppliers, and suppliers' winner identification (i.e. determination of cooperative suppliers).

6.1 Preparation

The preparation sub-phase holds two functions.

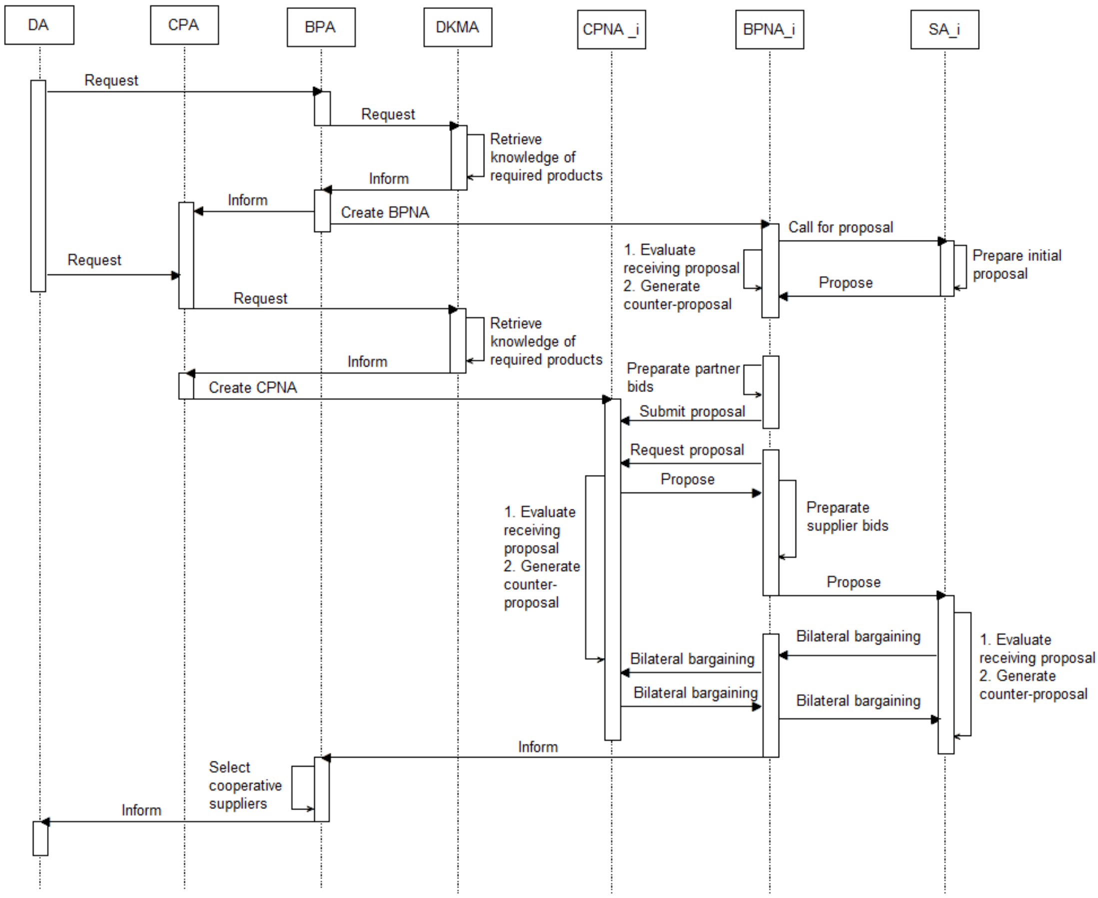
A first function of the preparation sub-phase is to create instances of the CPNA for all BPNAs and determine the collaboration strategies for different BPNAs.

A second function is to generate instances of the BPNA for all SAs, identify the negotiation strategies for different SAs, and start the multi-bilateral collaboration-based bargaining between the CPNAs, the BPNAs and the SAs to obtain the final agreements of the SAs for the required products while considering preferences of CPNAs for them.

The SAs are shortlisted by a supplier pre-selection algorithm. As example, procedures based on TOPSIS algorithm are useful. See e.g. the procedure proposed in [12].

6.2 Multi-bilateral collaboration-based bargaining

This sub-phase actually comprises several parallel one-to-one bilateral bargaining processes between the BPNAs and the SAs, and several parallel one-to-one bilateral collaboration processes between the BPNAs and the CPNAs. The objective of collaboration-based bargaining is to obtain the final bids of potential suppliers for the required products while considering the preferences of the CPNAs. The protocol of the collaboration-based negotiation is depicted in Figure 5. In JADE, the negotiation protocol can be implemented by the FIPA Request Protocol and the FIPA Iterated CNP.



DA: Dyad Agent
CPA: Customer-Partner Agent
BPA: Buyer-Partner Agent
DKMA: Dyad Knowledge Management Agent
CPNA: Customer-Partner Negotiation Agent
BPNA: Buyer-Partner Negotiation Agent
SA: Seller Agent

Figure 5. Protocol diagram of information flow

During the collaboration-based bargaining process, each stakeholder can make decision according to its own strategy. BPNAs and SAs alternatively exchange proposal which is a set of bids in turn to bargain over items of products. When the BPNA receives proposal from the SA, the BPNA initiates a collaboration process with CPNA if the SA proposal is rejected and prepares a counter-proposal in collaboration with CPNA. For this purpose, BPNA split prepares special bids for CPNA including only negotiation issues concerning CPNA. negotiation issues concerning BPNA only are removed and processed by BPNA to elaborate values of counter-proposal. When the CPNA receives BPNA proposal, CPNA generates a proposal as answer and send it to the BPNA. The BPNA receives CPNA proposal and prepares the counter-proposal for CPNA by combining the values generated by CPNA and the values generated by BPNA. Thus, the prepared counter-proposal includes values for all negotiation issues of the bids. The counter-proposal prepared thereby in collaboration between CPNA and BPNA is send to SA for evaluation, and so forth. For further details regarding the negotiation process between the purchasing dyad and the suppliers, please refer to [22].

6.3 Winner determination

After receiving the bargaining results from the multi-bilateral collaboration-based bargaining sub-phase, the winner determination sub-phase is conducted to select the cooperative suppliers based on the final bids submitted by the potential suppliers. There are multiple algorithms in literature to support the winner identification such as [23], [24], or [25].

7. Simulation

7.1 Agent Configuration

Simulation of the dyadic supplier selection model is proposed to be ran in JADE. Agents communicating using standard form FIPA-ACL.
The agent-based system of the dyadic supplier selection is composed of agent containers, distributed in different hosts over the SC network, each separate company in reality located in a different host. Each container must connect with the main container generated by JADE and formed of the AMS and DF agents. The purchasing dyad holds the main-container and several other containers. The Buyer-Partner Company BPA is located in the same container than the DA, DKMA and DPSA, as BPA represents the buyer that exchanges with suppliers. The containers of BPA and CPA connect with each other. Each supplier has its own agent containers.

Concerning the agents' instances, there is only one instance of the DA, DKMA, DPSA, and BPA. The number of BPNA instances is equal to the number of potential suppliers, since each BPNA instance interacts with one potential supplier. Similarly, the number of CPNA instances in the CPNA container is equal to the number of BPNA, since each CPNA instance interacts with one BPNA.

As shown in Figure 6, The BPA instance initializes several BPNA instances to conduct negotiation with different SAs representing potential suppliers. Similarly, the CPA instance can initialize several CPNA instances to conduct collaboration with different BPNAs representing the buyer-partner which is negotiating with potential suppliers. The BPNA can move to the remote hosts of potential suppliers to negotiate with SA. Also, the CPNA can move to the remote hosts of the buyer-partner to collaborate with BPNA. To simplify, the agents representing the buyer-partner and the dyad are set in the same host as ASM and DF, and in a different container. The suppliers only hold the instance of SA in their containers. In figure 6, suppliers during pre-selection process (interested suppliers) are shown in clear pink, and suppliers shortlisted from interested suppliers for negotiations (potential suppliers) are shown in dark pink.

Agents of the system accomplish dyadic supplier selection through message transportation.

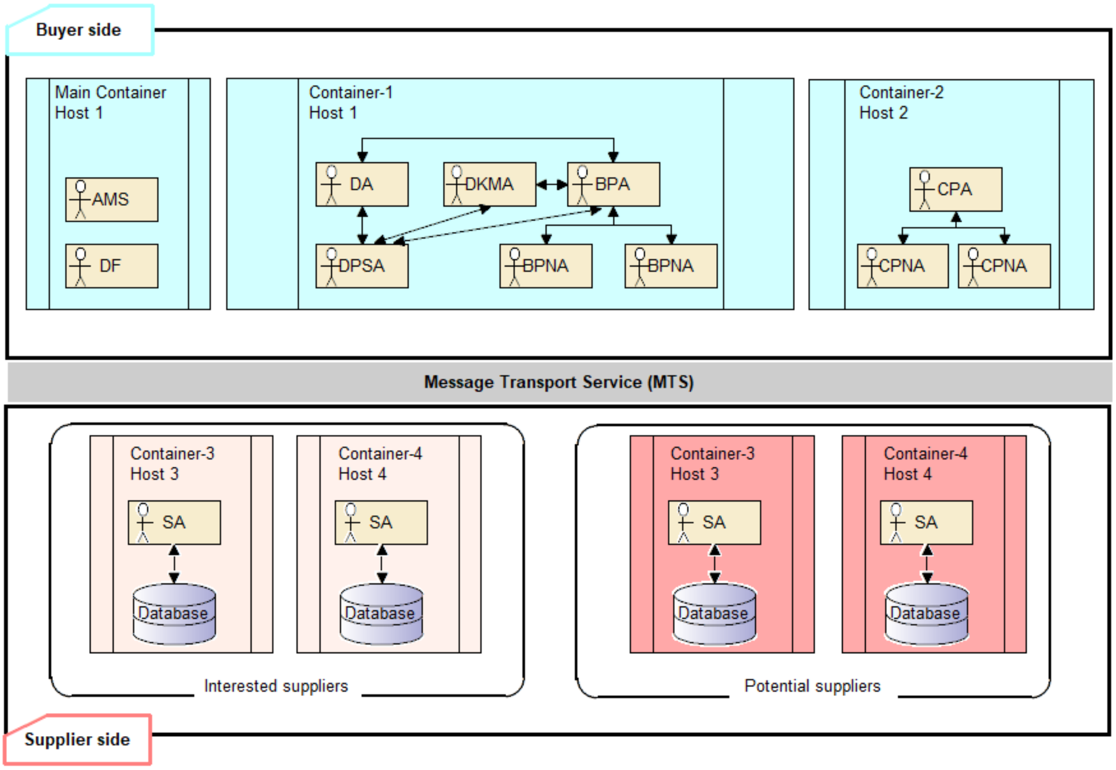


Figure 6. Configuration of the agent-based system for multi-product dyadic supplier selection

7.2 Negotiation results and discussion

In this case of study, two companies that collaborate in dyadic form, the first one has the role of the customer (CPNA) and the second is the manufacturer (BPNA). BPNA chooses to make strategic negotiations with a supplier in dyad for CPNA products manufacturing or customizing. BPNA requires purchasing 3 products represented by (Prod 1, Prod 2, Prod 3).

Table 1. Rounds of protocol interactions

Round	Product	Price	Quality	Delivery	Service
1 By the Supplier	Prod 1	650	VG	20	VP
	Prod 2	850	VP	30	VP
	Prod 3	1040	VP	40	VP
2 By (BPNA+CPNA)	Prod 1	650	VG	20	VG
	Prod 2	763	P	13	VG
	Prod 3	944,64	P	22,45	VG
3 By the Supplier	Prod 1				
	Prod 2	830	P	26	P
	Prod 3	1020	P	35	P
4 By (BPNA+CPNA)	Prod 1				
	Prod 2	778	P	16	G
	Prod 3	967	P	23,8	G
5 By the Supplier	Prod 1				
	Prod 2	810	P	22	P
	Prod 3	1000	P	30	P
6 By (BPNA+CPNA)	Prod 1				
	Prod 2	787	P	17,54	M
	Prod 3	980,58	P	26,25	M

The negotiation issues in this case are: price, quality, delivery and service and the first 3 concern CPNA.
The Table1 represents the negotiation interactions between BPNA, CPNA and Suppliers.
The data used are based on the case study of the negotiating protocol of Yu [12], [13], therefore we compare the final bids utilities of our negotiating protocol and of Yu's model.

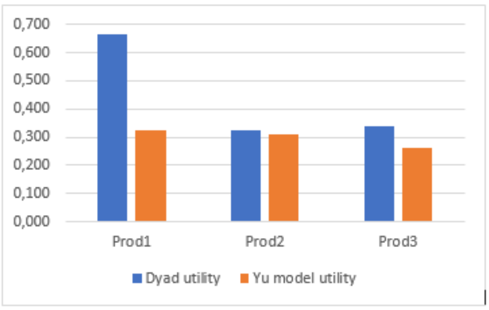


Figure 7. Utility comparison between dyadic supplier selection negotiation and classical models of supplier selection in [12] and [13]

We find that the utility of the proposed protocol is greater than Yu's model utility (Figure 7) despite the differences in each case studied. Negotiation becomes more flexible, due to the integration of CPNA into the negotiation process and so we guarantee the satisfaction of the customer.

8. Conclusion

In this paper, a new multi-agent supplier selection decision making architecture is designed based on a novel agent collaboration called dyadic. The proposed architecture combines bilateral dyadic collaboration and multi-bilateral bargaining protocol.
The objective of this dyadic collaboration is to select suppliers bidding the best deals for the purchasing company and his customer. This study has proposed also an advanced negotiation protocol integrating potential partner in the strategic process.
The proposed protocol supports two-way negotiation between the purchasing company and suppliers and two-way dyadic communication between purchasing company and its customer.
All sides deal directly with their negotiation issues and can make concessions based on their preferences.
The most salient novelty in the proposed architecture is integrating the most important stakeholder of the purchasing company in the supplier selection process. This allows exploiting the preferences of the customer to enlarge the criteria choices of the products, and hence

significantly increase the supply chain performance and the global satisfaction level.

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