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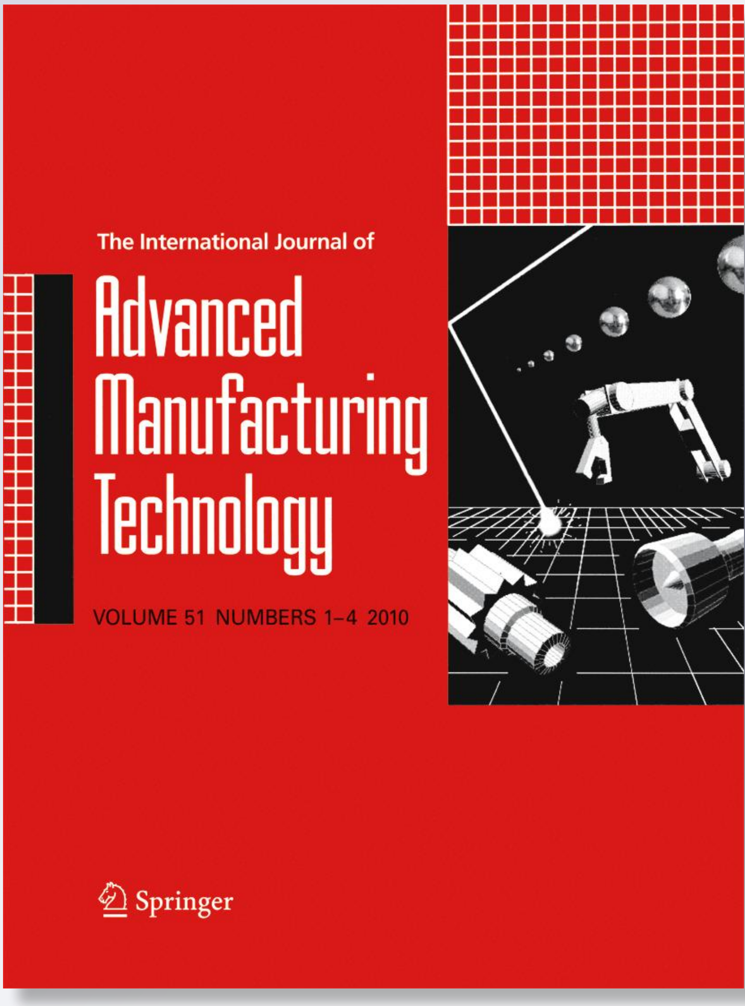
The International Journal of Advanced Manufacturing Technology

ISSN 0268-3768
Volume 51
Combined 1-4

Int J Adv Manuf Technol (2010)
51:383-396
DOI 10.1007/
s00170-010-2606-6



Springer

Int J Adv Manuf Technol (2010) 51:383–396
DOI 10.1007/s00170-010-2606-6

ORIGINAL ARTICLE

A communication protocol among agents for exchanging data in the extended enterprise

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Received: 2 October 2009 / Accepted: 2 March 2010 / Published online: 20 April 2010

Abstract To compete in the current interconnected world, manufacturing companies shall explore varied forms of collaboration in order to maintain the creation of value-added goods and services. The *extended enterprise* is one of the proposed approaches to improve collaboration among individual enterprises. Such paradigm is based on the fact that core capabilities must be shared by participating firms so they can exploit jointly the best resources and practices each firm provides. Nevertheless, data exchange is not carried fluently due to poor coordination among the firms. We claim that business processes help define the dynamics of data exchange associated to core capabilities being the basis to establish a communication protocol among software agents. The resultant multi-agent system coordinates data flow among organizations. Agents are given autonomy and intelligence to make decisions regarding the data that is either needed or offered, as defined by the corresponding business process. We present a case study to validate our proposal.

Keywords Business process · Communication protocols · Agent programming · Extended enterprise

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1 Introduction and problem statement

It has been claimed elsewhere [1] that the entire manufacturing system incarnates a coherent and extended whole in the context of the value chain. The *extended enterprise* is thus defined as a long-term agreement among individual and complementary industrial units formed to manufacture goods in a well-defined yet evolving market segment. Companies remain separate legal entities that keep control over their own systems [2] and resources while providing their own *core capabilities* (i.e., information about product, processes, and resources displaying superior performance). To facilitate data exchange in the extended enterprise, the use of standardized data models has been proposed as a solution [3]. Nevertheless, we address two major obstacles to exchange data associated to core capabilities fluently.

One issue refers to establishing coordination mechanisms for requesting and providing information along the product life cycle. We take advantage of business processes. A business process (BP) is defined as either a chain of activities whose final aim is the production of a specific output for a particular customer [4] or a collection of activities that takes one or more inputs and creates an output that is of value to a customer [5]. Data exchange is pivotal for operating the extended enterprise because data represents both value-added input and output to design and manufacturing activities.

The supporting software for sharing and exchanging data is the second problem to overcome. Should information systems remain locally owned by the constituent companies, communication is compulsory, for which stand-alone applications are not well-suited. Hence, a central unit must possess the ability to acquire company-specific data and propagate it along the network. Multi-agent systems (MAS) are appropriate to achieve distributed information processing [6]. The application of agent technology to inter-enterprise collaboration has also been devised by [7], where it has been stated that both suppliers and customers are mutually dependent on shared data and knowledge being vital the quality and volume of transparent data. The usage of existing agent technology has been discussed as a sound approach to enhance data exchanging in the extended enterprise [8]. Such claims are fully justified since agents can request data, acknowledge its reception, process it, and transmit new data to another agent that finds such information valuable. In this scenario, messages uttered with the Agent Communication Language (Foundation for Intelligent Physical Agents, FIPA-ACL) take the role of information carriers. Yet, to coordinate the sequence of messages, a well-defined pattern must be devised. We propose a list of business processes to model the dynamics of data exchange and a system of intelligent agents to actually request and provide information obeying the activities defined by business processes.

To summarize, our solution to coordinating data exchange in the extended enterprise comprises:

1. Definition of a communication protocol among agents mapping business processes.
2. Definition of a multi-agent system structure having central processing of data and being distributed along the network of enterprises.
3. The underlying intelligence and decision-making capabilities associated to software agents.

The organization of the paper is as follows. Section 2 presents related work on MAS and extended enterprise. Section 3 contains the models of the business processes that we suggest as the basis for coordinating data exchange. Section 4 is devoted to the multi-agent system (structure, communication, and intelligence). A detailed description of the case study is provided in Section 5. We conclude the paper in section 6.

2 Related work

2.1 Business processes and agents

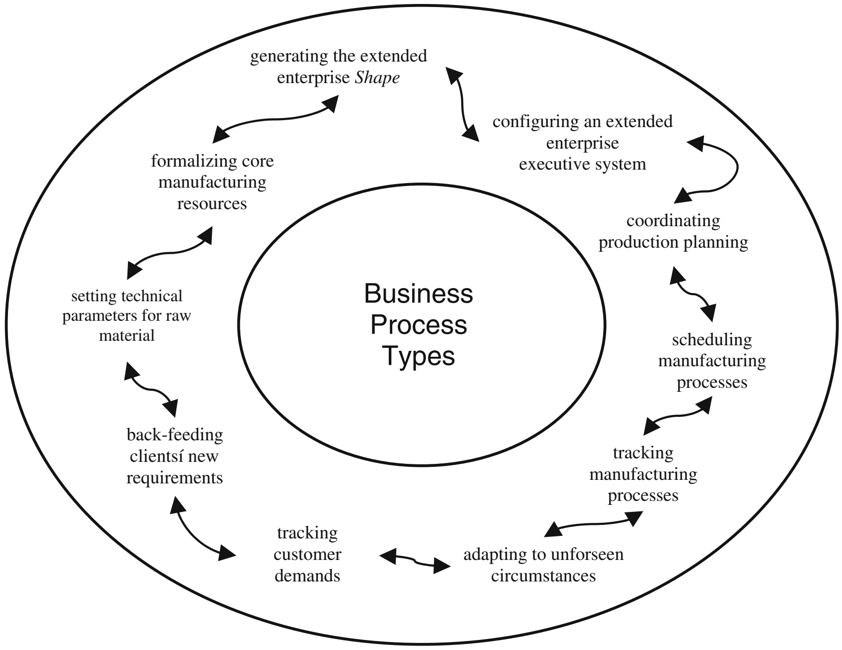
Several proposals to include agent technology for the extended enterprise (or the like) have been developed. Agents have been implemented for optimizing utilization of resources in value-chain contexts [9]. A multi-agent system evaluates capabilities of individual firms so an extended enterprise can be shaped, exploiting standardized data models [10]. Production planning in an extended enterprise context has been tackled by implementing a multi-agent system [11]. Similarly, ExPlanTech [11] integrates existing software modules and wraps them into agents improving the planning processes because the system monitors the status of suppliers and other collaborators. Information technology has been aligned with the activities that take place in an extended enterprise [12]. Web services and agents are merged to execute inter-organizational business processes [13,14]. In [15], if a software agent receives requests for executing tasks, then it searches for possible contractors and grants a contract to the winning bidder among a list of member agents offering their capabilities. The multi-agent approach has been explored to acquire data from heterogeneous information systems [16], integrating data sources of products and processes. In an approach to merge business processes using an agent-oriented programming, agents synchronize the execution of BPs activities [17]. Similarly, a business protocol specifies messages exchanged among two or more interacting agents that behave as autonomous business partners [18]. It has been stated that agent-based cooperation among enterprises offers more resilience and agility in competitive environments [19].

2.2 Information sharing models in the extended enterprise

It is widely recognized that information sharing is a pivotal issue should individual enterprises decide to cooperate in order to remain competitive. This topic possesses several edges within the extended enterprise context: cooperation models, partner selection, interoperability of information systems, and market analysis to name but a few. As for cooperation models, symbiosis theory has been proposed as inspiration to draw relationships between individual enterprises trying to obtain mutual benefits [20]. It has been claimed by [21] that the complexities of the extended enterprise can be minimized by employing fractal models with self-organizing policies, recursion, and iteration. The use on Intranets have been proposed as a framework to facilitate cooperation of heterogeneous information systems and make publicly available core competencies [22]. Cross-enterprise colaboration can be seen as a problem of grid formation according to [23]. It is claimed that grid manufacturing may provide more services to the extended enterprise while being more flexible in their formation. It favors the use of a process-oriented framework to facilitate cooperation among enterprises [24]. When companies decide to open their information systems, it is compulsory to guarantee that the right users will employ the right data. On this subject, a formal access model is proposed in [25].

Interactions among manufacturers and suppliers are complex. These types of processes can benefit from information sharing and cooperation models as depicted in [26]. It proposes the creation and use of ontologies to homogenize concepts along the network of enterprises and facilitate data exchange [27]. Interactions among individual enterprises have been taken from the CIMOSA architecture. Those interactions have been modeled with Petri nets and

Fig. 1 Business process types for the extended enterprise



then they have been implemented on web-based systems [28]. A negotiation scheme among self-interested individual enterprises is presented in [29]. This is useful when it comes to decide on what partner offers a high reward for the engagement to materialize. An Ant colony algorithm to select partners is described in [30], transportation costs being the selected criteria.

A comprehensive list of product features is pivotal to establish manufacturing processes, material, and suppliers. We perform this activity with a simplified version of the quality function deployment method; however, some authors present variations of the method, like [31]. Yet, the aim is to gather market data and process it so a product can be conceived and realized.

2.3 Discussion

All the related initiatives address relevant ideas revolving around cooperation and data exchange within the extended enterprise; nevertheless, some important aspects have been overseen. First, cooperation protocols are not set. Our proposal defines communication protocols at different levels and for different purposes. Secondly, it has not been entirely defined what sequence of events and what data must be exchanged among the participating firms. By establishing business processes, we make explicit both the sequence of activities and the information needed during every interaction. Third, our approach facilitates decision making for material and enterprise selection. Altogether, we propose an advantageous manner to define and automate a series of activities along the extended enterprise. It is our contention that the establishment of business processes promotes definition of common practices and explicit knowledge for operating an extended enterprise. Multi-agent systems provide communication and intelligence so the data exchange is performed more coordinately along the network. We describe our proposal in the following sections.

3 Business processes for the extended enterprise

BPs for the extended enterprise defines sequences of actions to achieve a design and manufacturing goal. Even though any list of BPs might be considered neither definitive nor complete, our proposed set is broad enough to clarify what interactions take place in a distributed manufacturing environment.

The business process reference model depicted in [32] is our chosen modeling framework. It defines a business

Table 1 Setting technical parameters for raw material

Business process ID	Extended enterprise business process 1
BPT name	Setting technical parameters for raw material
Objective	To obtain raw material along with the technical requirements it must fulfill to comply with product design specifications
Inputs	Product identification
	Qualitative functions
Outputs	Raw material and technical parameters
Performance attributes	Material type
	Fulfillment of qualitative functions

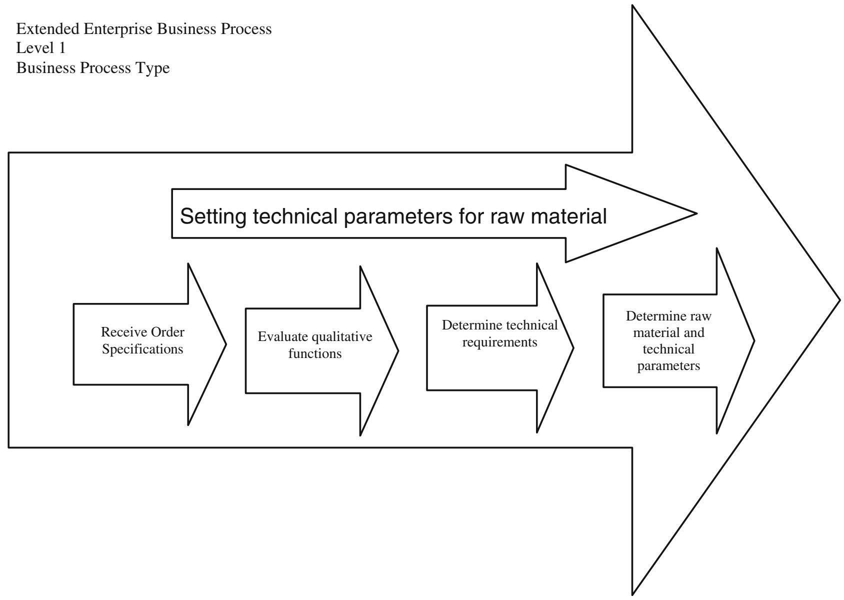


Fig. 2 Business process type: setting technical parameters for raw material

process type (BPT) to represent BPs at a general level. Then, business process variations (BPVs) refer to specializations of business process types. Finally, business sub-processes contain sequences of actions to implement a business process type. We propose the following set of business process types (see Fig. 1):

1. setting technical parameters for raw material
2. formalizing core manufacturing resources
3. generating the extended enterprise *Shape*
4. configuring an extended enterprise executive system
5. coordinating production planning
6. scheduling manufacturing processes
7. tracking manufacturing processes along the extended enterprise
8. adapting to unforeseen circumstances
9. tracking customer demands
10. back-feeding clients' new requirements

We envision a cycle of business process types that encapsulates a product life cycle. The launching BPT is called "*setting technical parameters for raw material*", which restarts when clients' newer requirements are input again. The interaction between any pair of BPTs enforces the actors (i.e., agents) to confirm what data is being exchanged versus what data has been solicited. Validation

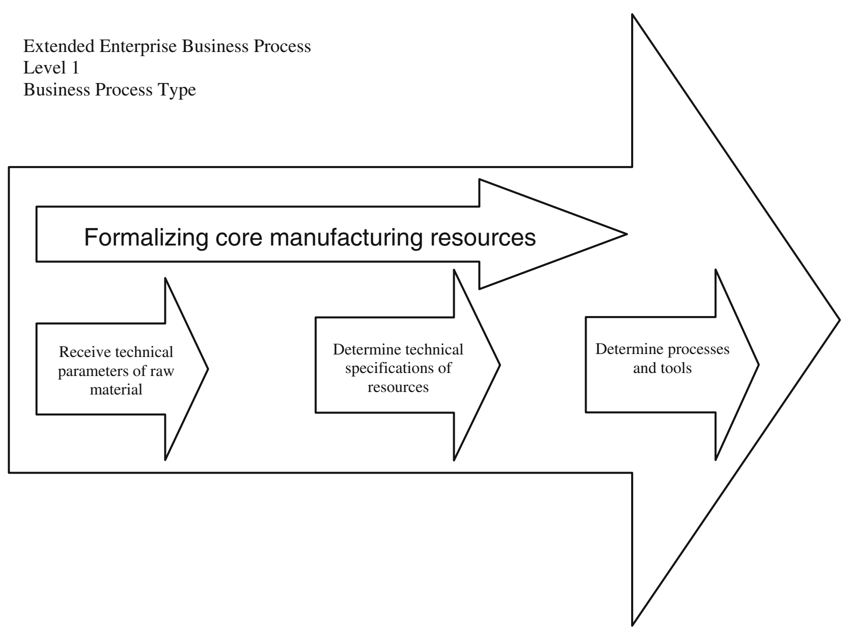


Fig. 3 Business process type: formalizing core manufacturing resources

Table 2 Formalizing core manufacturing resources

Business process ID	Extended enterprise business process 2
BPT name	Formalizing core manufacturing resources
Objective	To establish manufacturing resources and associated processes and tooling
Inputs	Product identification
	Raw material parameters
Outputs	Resources, processes and tooling

of data source and message carrier (the actual *performative* used, taken from the FIPA-ACL) is also required.

Table 1 describes the major elements associated to BPT "*setting technical parameters for raw material*", while Fig. 2 presents its corresponding BPVs.

In a similar fashion, Fig. 3 is a graphical representation of BPT "*formalizing core manufacturing resources*", whose description is presented in Table 2. The last BPT we describe in this paper is termed "*generating the extended enterprise shape"* (Fig. 4), whose corresponding description is presented in Table 3. The "shape" of the extended enterprise is a concept being defined in [3].

The specification of business process types completes the modeling of activities, actors, and data to exchange. To actually implement such interactions, a multi-agent system is devised of which details are given next.

4 Design of the multi-agent system

The multi-agent system is illustrated in Fig. 5. It follows a fractal-like structure where two layers can be distinguished. The upper layer (UL) is comprised by coordinator agent, product agent, organization agent, manufacturing agent, and resource Agent. The lower layer (LL), in contrast, lacks a coordinator. The agent structure for the LL is repeated along the individual firms. Each node is in charge of manipulating data that each participating organization possesses about its resources, products, and manufacturing processes. The LL organization agent is the mediator between its peers and the UL coordinator agent. Agents at the upper layer drive the BPTs and make decisions when necessary. The UL agents, therefore, display intelligence and decision making capabilities, while LL agents deal with data acquisition at the level of individual enterprises.

In Fig. 5 the following abbreviations apply: (1) AP stands for process agent, (2) AR: resource Agent, (3) AM: manufacturing agent, (4) AO: organization agent, (5) EE ES: extended enterprise executive system, and (6) EPi OS: operational system enterprise i; $i=1, 2, \ldots, n$.

To execute the BPTs defined in the previous section, a communication protocol is modelled. Our proposal is presented next.

4.1 The communication protocol

The communication protocol is modeled with a sequence diagram of the agent unified modeling language [33].

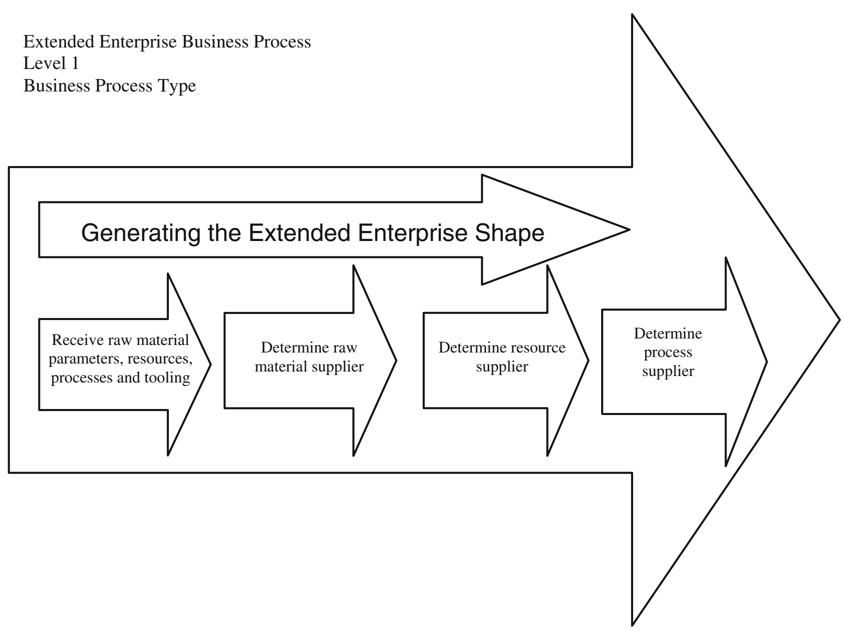


Fig. 4 Business process type: generating the extended enterprise shape

Table 3 Generating the extended enterprise *Shape*

Business process ID	Extended enterprise business process 3
BPT name	Generating the extended enterprise *shape*
Objective	To determine the shape of the extended enterprise
Inputs	Product identification
	Specification of material
	Resources and processes parameters
Outputs	Shape of the extended enterprise

The template considers three alternative courses of action, each of which depends on particular information needs.

First, coordinator agent informs to one of its peers what input data is required. X-agent (X=product, process, resource, or organization) confirms data reception and then runs its process to make a decision. This produces an output (either for a BPT or BPV), which is sent to coordinator agent. For example, the material to employ, as decided by product agent, is the corresponding output of the first BPT. The first group of messages mirrors this process. These messages are illustrated in Fig. 6.

Figure 7 illustrates the second group of messages, which represents the contract net protocol [34]. This is executed in order to grant a contract to the best supplier of material, resources or manufacturing processes. Candidate suppliers are the organizations residing at the lower layer. The contract net protocol defines a complex conversation among several agents, starting when coordinator agent has received a decision of what is needed (i.e., material to employ). Coordinator broadcasts a call for proposal to every LL organization agent, which informs to its corresponding LL peer about the requested information. Organization agent can possibly make an offer to the

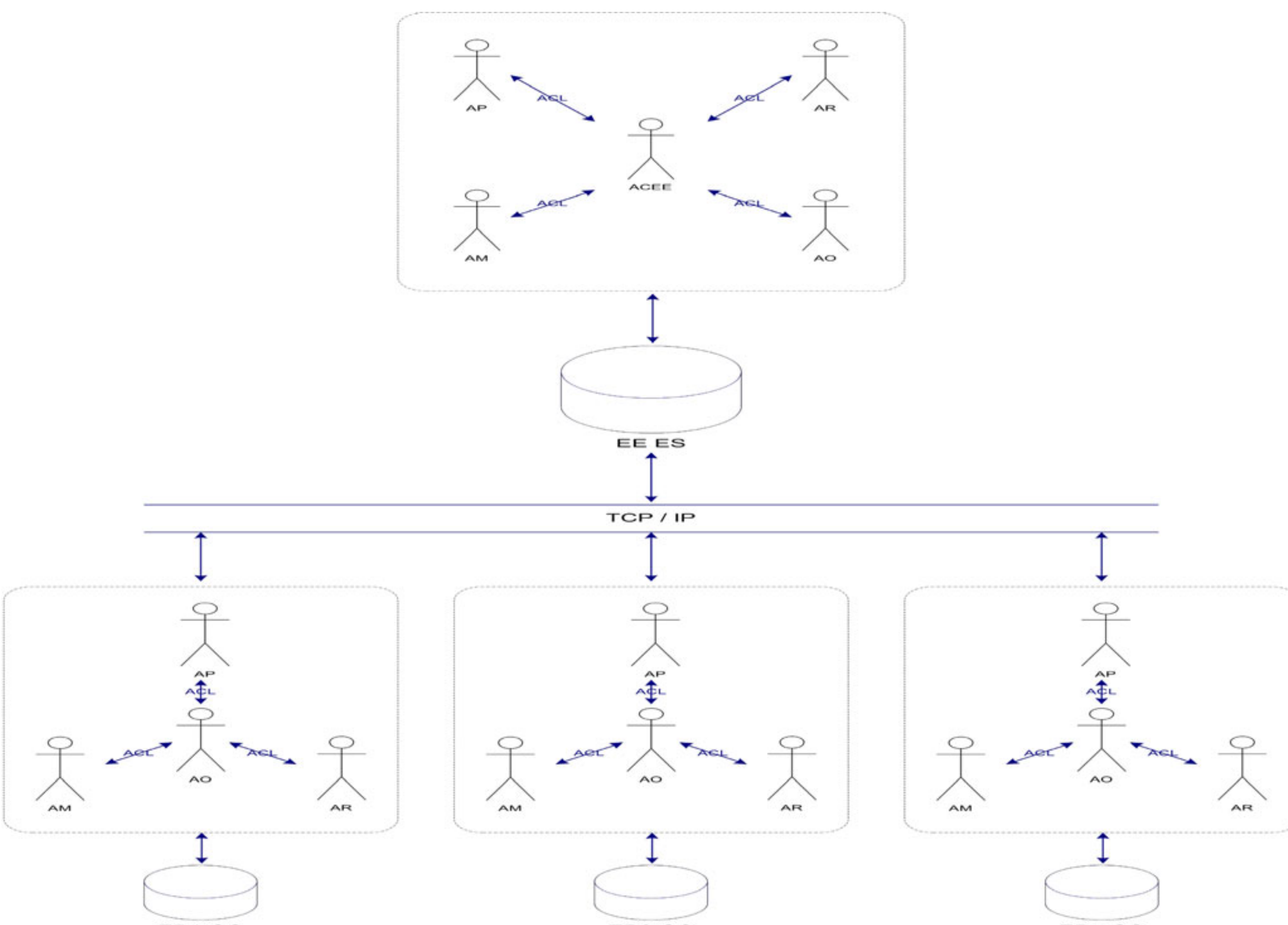


Fig. 5 Structure of the MAS for the extended enterprise

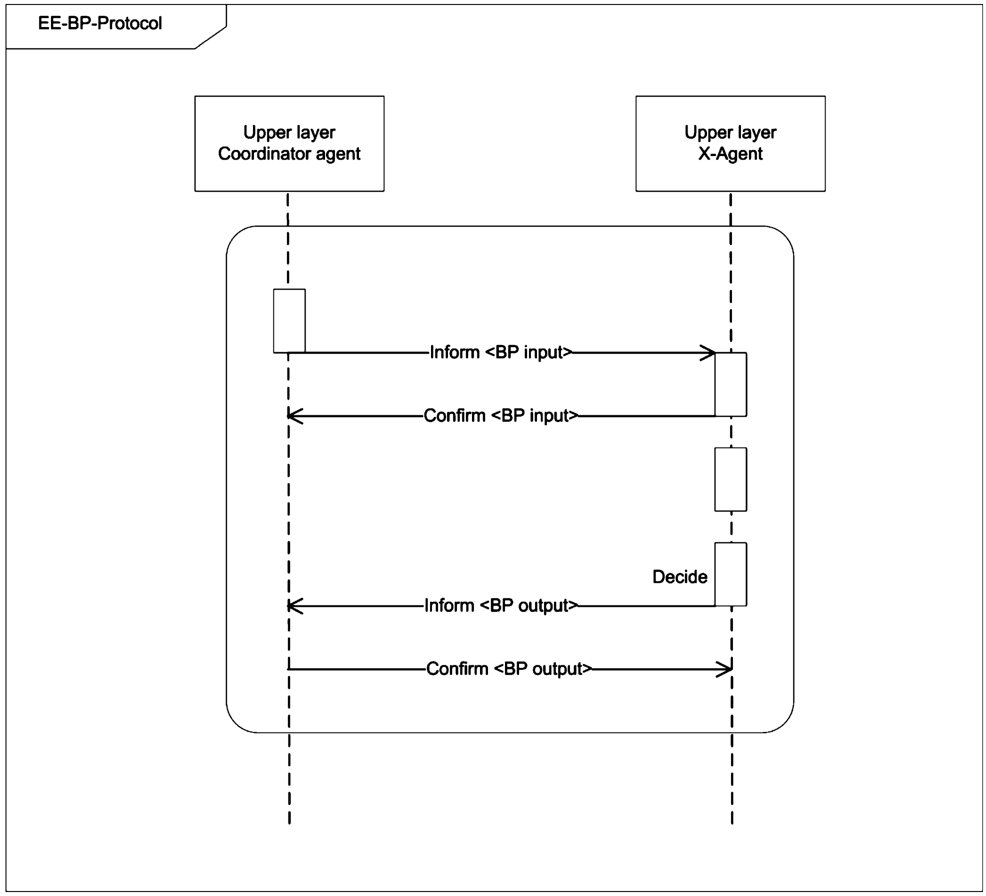


Fig. 6 Communication at the upper layer

coordinator or not, depending on the information it receives. From its perspective, coordinator can receive one or more offers coming from different LL organization agents. When this happens, coordinator informs to the UL X-agent about the terms of the proposal. Then, UL X-agent evaluates the proposal and tells the coordinator to accept it or to refuse it. The contract net protocol ends when the first accepted offer is granted.

However, some BPTs do not require a negotiation among agents. For these BPTs, another conversation can be followed. This is represented by the third group of messages shown in Fig. 8, between coordinator and X-agent at the upper layer. At this regard, coordinator agent receives data coming from BPTs and informs it to the X-agent, which runs its own decision process, generates a given output, and informs this data to the coordinator which finally confirms data reception. The communication protocol just described is general enough to model, in terms of messages among agents, situations that arise when the dynamics of BPTs are implemented.

It is important to recall that one of the major features associated to the notion of agency is the capacity to decide what course of action ought to be followed. In this sense, each of the agents has been programmed the corresponding protocol and the intelligence to initiate a conversation. The actual implementation of the protocol is a matter of extensive agent-oriented programming, for which we employ the JADE platform [35].

4.2 An illustrative rule base

Some decisions have to be made either to request or provide information. For example, it is important to define the right material to use. This is obtained by processing a number of variables such as weight, malleability, etc. These variables are synthesized on a rule-based system in order to automate decision making.

We present an example of the rule base that is employed by the UL product agent. Even though the case study is further explained in Section 5 suffices to say that it refers to producing spoons made of steel. The following variables are considered: (1) density, (2) hardness, (3) stainless, and (4) polishness. Illustrative data is presented in Table 3.

To exemplify the type of decisions made by UL product agent, let us go back to business process type "*setting technical parameters for raw material*". This BPT receives a list of qualitative functions that a given market segment treasures and outputs a prioritized list of technical parameters. For the case study, technical parameters are formed by the following variables: (1) weight, (2) shape, (3)

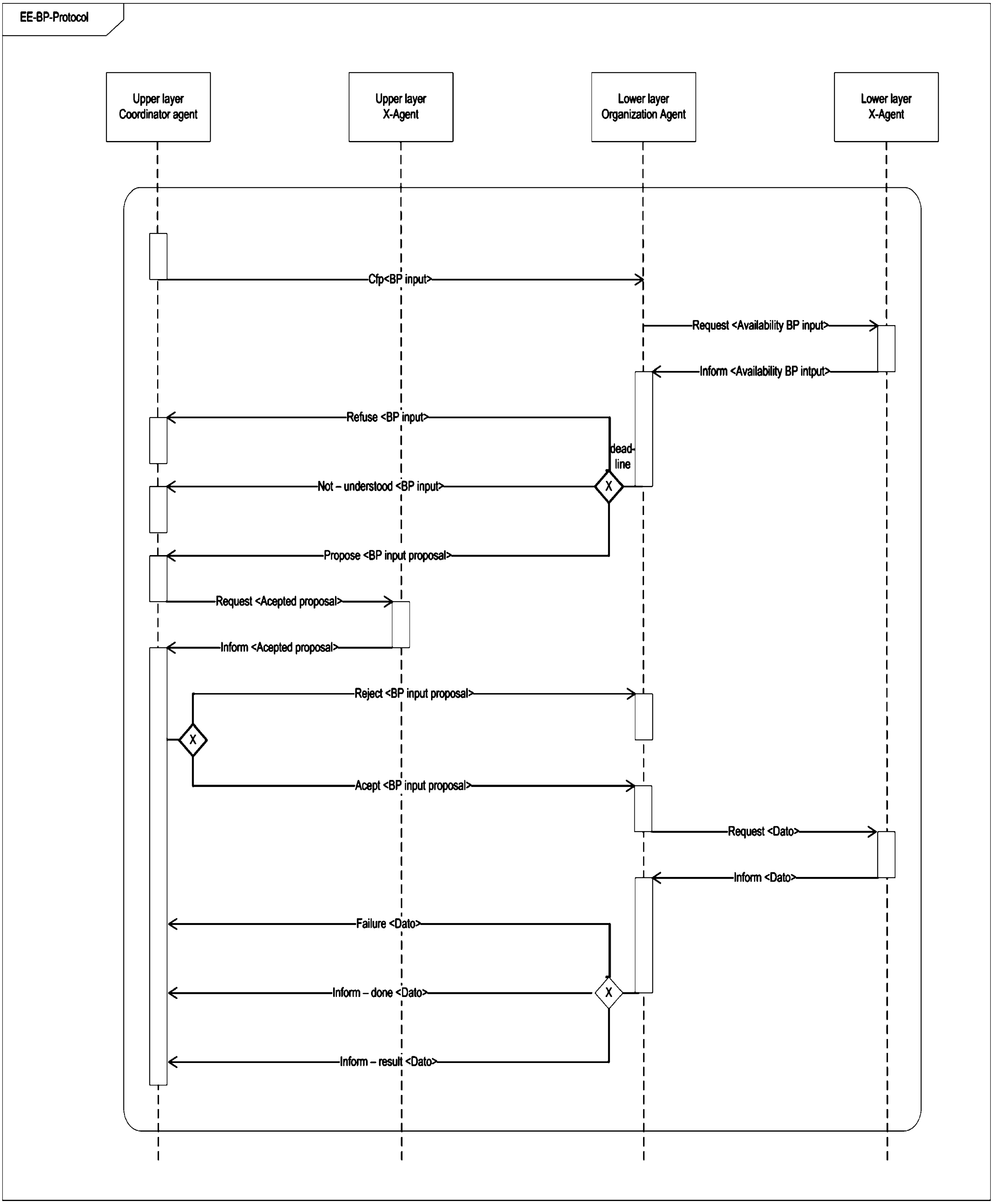


Fig. 7 The contract net protocol

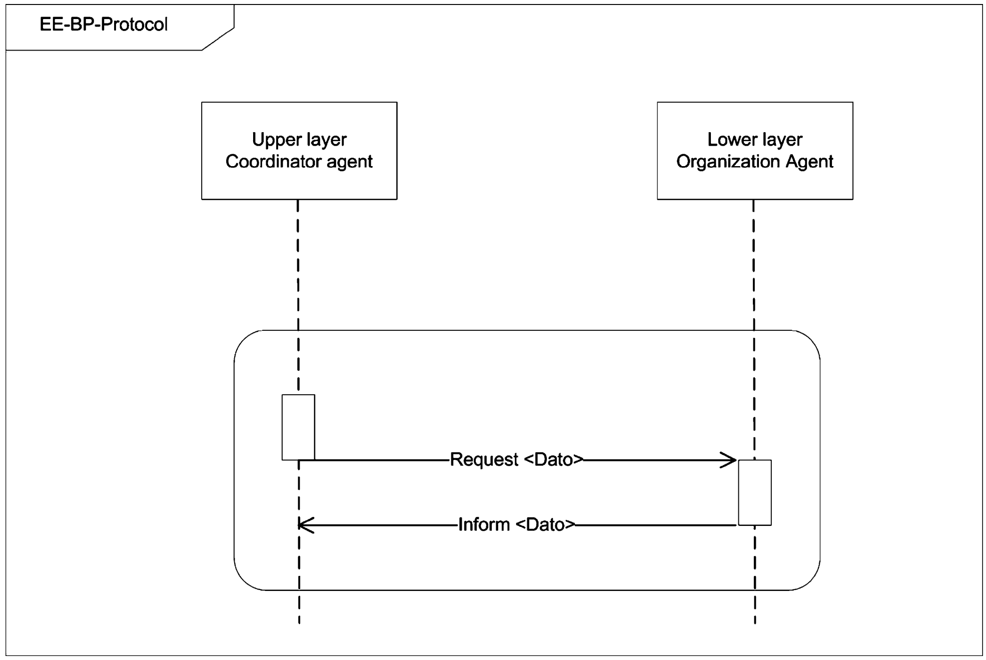


Fig. 8 Communication between coordinator and lower layer organization agent

stainlessness, and (4) finishing type. Every one of those variables is given a priority calculated to comply with the qualitative functions of the product (spoon).

To estate it succinctly, the calculations of priorities is a procedure where qualitative functions of the product are evaluated. Such an evaluation balances, in the first place, the design features. Those features must be translated into technical parameters associated to the raw material. To comply with design, some technical parameters have a higher priority than others. In turn, some materials comply with those priorities better than others (Table 4).

For example, a given market segment might prefer a light spoon. This is translated into technical parameter *weight*, which then obtains a certain priority. If the same market segment fancies a nice holder design, then it should be mapped into a material that can be molded easily. Thus, shape is given a priority. All the priorities are relative to each other, but the right material is decided by finding a balance among the qualitative functions translated into priorities of technical parameters.

Nevertheless, this is a domain-specific task for which customized rule-based systems must be constructed. Table 5 is a decisional matrix on which the rule base for the case-study is constructed.

For example, an IF-THEN rule is obtained after analyzing first row of Table 5:

$$\begin{aligned}\text{IF weight priority} &= 1, \text{shape priority} = 2,\ \text{stainlessness priority}\\ &= 3.\ \text{and finishing type,priority}\\ &= 4,\ \text{THEN selected steel} = 420\end{aligned}$$

The rule base is provided to product agent of the upper layer. To clarify, we present the case study in the coming section.

5 Case study: spoons and steels

The case study refers to producing spoons made of steel. Firstly, it is launched BPT "*setting technical parameters for raw material*". This BPT is thought to merge qualitative

Table 4 Features of several steel types

Density (g/m3)	Hardness (Brinell)	Stainless	Polishness	Steel Type
8.0	160	Yes	Yes	304
7.7	165	Yes	Yes	410
7.75	155	Yes	Yes	416
7.64	225	Yes	Yes	420
7.86	235	No	Yes	A-2
7.69	240	No	Yes	D-2
7.86	265	No	Yes	D-3
7.85	228	No	Yes	O-1

Table 5 Combinations of technical priorities to decide steel type

Weight priority	Shape priority	Stainless priority	Finishing type priority	Steel type
1	2	3	4	420
1	2	4	3	410
1	3	2	4	410
1	3	4	2	420
1	4	2	3	420
1	4	3	2	420
2	1	3	4	410
2	1	4	3	410
2	3	1	4	420
2	3	4	1	O-1
2	4	1	3	420
2	4	3	1	O-1
3	1	2	4	304
3	1	4	2	410
3	2	1	4	304
3	2	4	1	O-1
3	4	1	2	420
3	4	2	1	420
4	1	2	3	304
4	1	3	2	410
4	2	1	3	304
4	2	3	1	304
4	3	1	2	304
4	3	2	1	304

data (i.e., tactile sensation) with technical data associated to the raw material (i.e., hardness as measured on Brinnel scale). The outcome is a steel type that fulfills both design qualities and manufacturability. Data that has been gathered by surveying the target market segment is fed to the MAS through a graphical user interface attached to the coordinator agent (Fig. 9). Then, a new product's identification is established (Fig. 10).

Qualitative functions for the production of steeled spoons are evaluated according to how they matter to the market segment (Fig. 11). Coordinator agent receives these values and sends them to product agent.

Qualitative functions are arranged in four categories:

1. usability (*usabilidad*)
2. performance (*desempeño*)

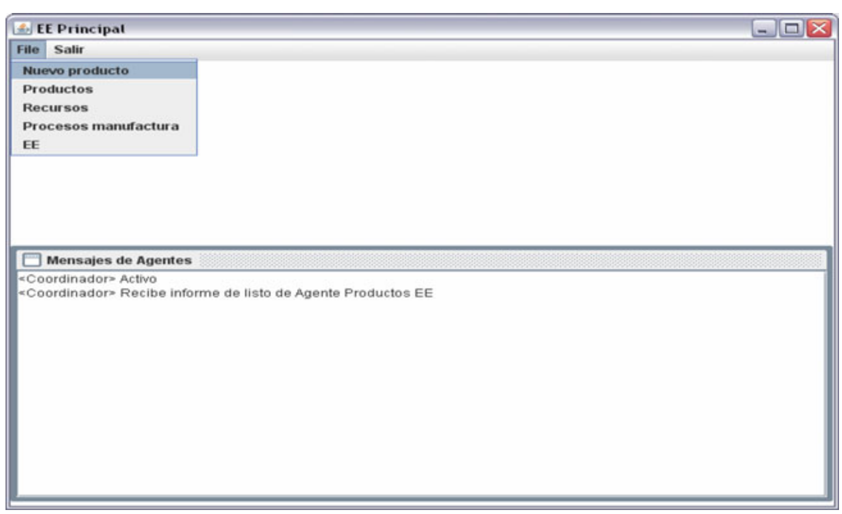


Fig. 9 Extended Enterprise manager launches the MAS

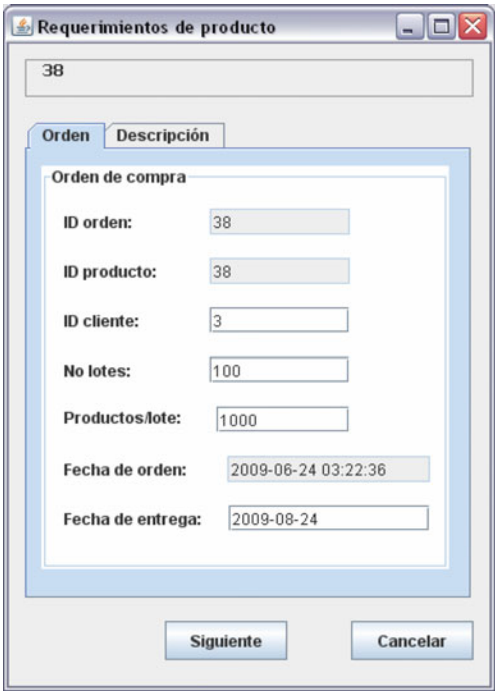


Fig. 10 Coordinator agent receives data for product identification

3. tactile sensation (*tacto*)
4. hygiene (*limpieza*)

Each category, in turn, contains the actual functions to be evaluated. In Fig. 11, under the performance category (desempeño), qualitative functions lightness (peso ligero), and holder shape (forma del mango) are given an evaluation of 2 (on a 1-5 scale); no movement restriction (no restringe movimientos), safe (seguro) and attractive (atractivo) are each evaluated with an importance of 1 (the lowest). Therefore, a spoon easy to grasp is treasured.

Once this valuation is terminated, business process variations "*receive order specifications*" and "*evaluate qualitative functions*", belonging to business process type "*setting technical parameters for raw material*", are finished.

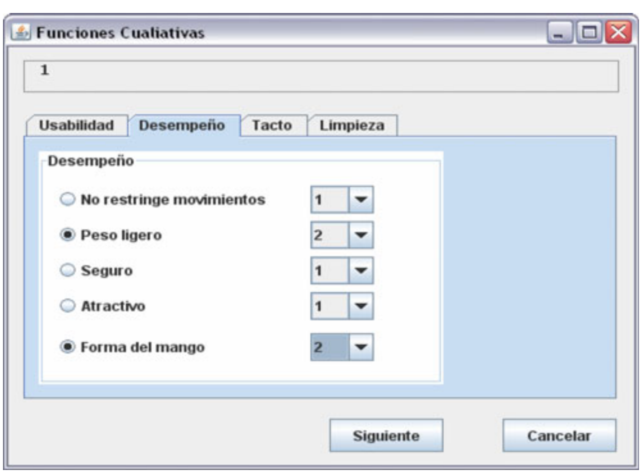


Fig. 11 Coordinator agent receives product's qualitative functions

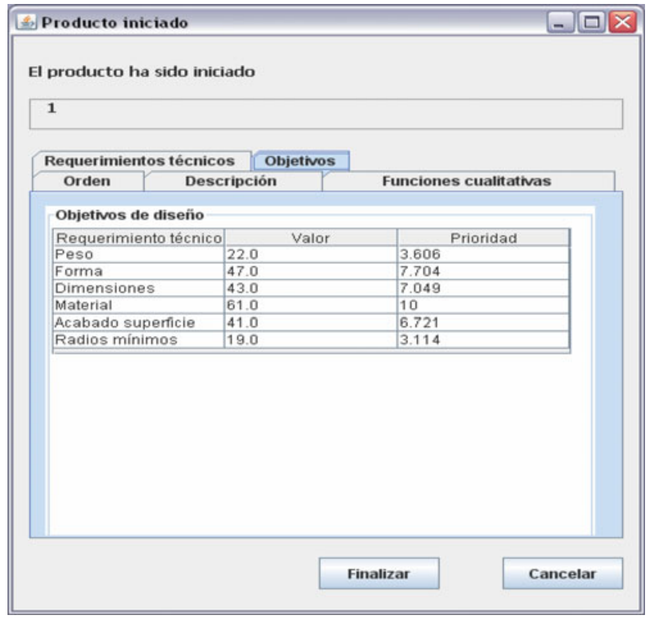


Fig. 12 Product agent establishes priorities for design objectives

It is still necessary to determine the right steel. This data is obtained by executing business process variation "*setting technical objectives*". On this BPV, an expert decides to what extent a series of technical objectives influence the

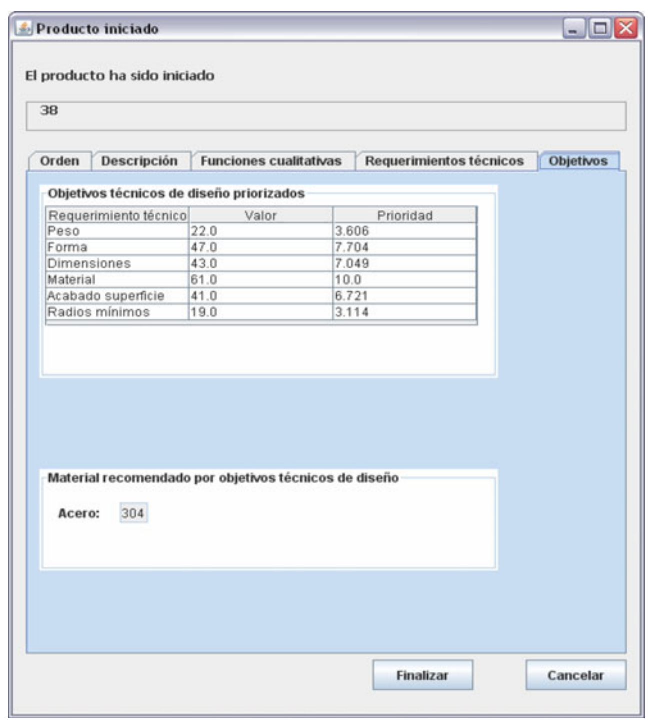


Fig. 13 Product agent determines steel type

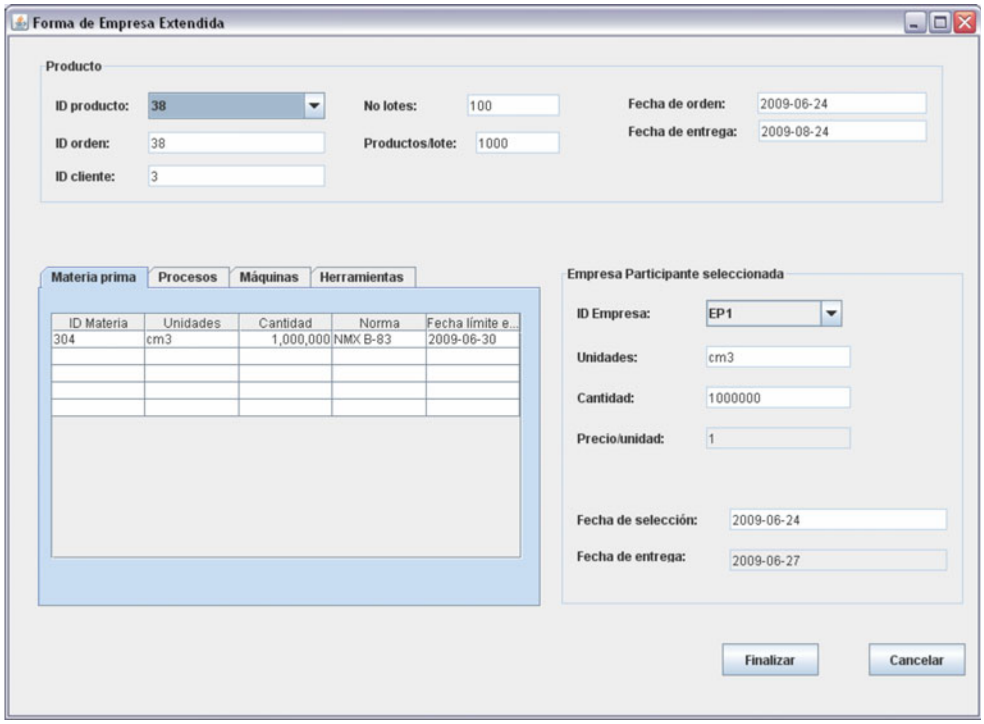


Fig. 14 Coordinator updates the extended enterprise executive system

material to select. The expert provides its valuations and product agent of the upper layer prioritizes them.

The outcome of this BPV is displayed in Fig. 12. According to the results given by product agent, steel features (stainless) obtains 10 points, making it the highest ranked technical parameter. Therefore, the priority given to this technical requirement is 1. Similarly, shape (forma) obtains 7.704 points, with a priority of 2. Finishing type (acabado de superficie) gets a score of 6.72, with a priority value of 3. Weight (peso) gets 3.606 points (priority=4).

To decide the right type of steel, product agent inputs such priorities to the rule base shown in Table 5, and the resultant material is steel type 304 (Fig. 13). This data represents the output yield by business process variation "*determine raw material and technical parameters*". Therefore, BPT "*setting technical parameters for raw material*" is accomplished. Figure 14 illustrates how the extended enterprise executive system is updated once the material is selected.

Once the type of steel is decided, it is now necessary to specify core manufacturing resources and shape the extended enterprise.

Formalizing core manufacturing resources consists of defining processes, machines, and tooling. Input to this BPT is the material type and its technical parameters. Parallel to this BPT, the contract net is carried to select the individual enterprises that will provide raw material, equipment, tooling, and data for manufacturing processes.

Specifically, product agent selects what material to use. In this case, it requires a steel type 304. This is informed to the coordinator agent. Then coordinator launches the contract net protocol, allowing steel suppliers to make offers about the instance of steel 304 that are able to provide. It is important to highlight that subtle differences on steel composition exist among instances of steel type 304 (as for every steel type). Hence, to determine the better steel type, national standards are used as reference. In this case, we refer to the Mexican standard MX-B83 for steels. Thus, the supplier that best adheres to this standard is chosen to participate in the extended enterprise. This particular decision is carried by forming a rule base after the specifications found in the referred norm.

Following the communication protocol, coordinator receives the steel that is offered by every supplier, and informs the upper layer product agent. This agent determines whether the offer is good enough or not, based on the following criteria:

Compliance to the national norm
Delivery time
Capacity to deliver the desired amount of steel

The contract is awarded to the first steel supplier that fits such criteria. Business process types "*formalizing core manufacturing resources*" and "*generating the extended enterprise shape*" continue iteratively to select manufacturing processes, machines, and tools. The shape of the extended enterprise is defined and updated in the extended enterprise executive system. Even though we present three of the business process types, data exchange goes on as depicted in Fig. 1.

6 Conclusions

Along the article, we have provided a solution to overcome two barriers that impede exchanging information in the extended enterprise, primarily associated to core capabilities of the participating firms. One impediment refers to the supporting software for sharing and exchanging data. Because information systems remain locally owned by the constituent companies, cooperation is needed. Therefore, we developed a multi-agent system to achieve distributed information processing and to make intelligent decisions by interacting with a customized rule-based system.

The absence of a coordination mechanism is the second problem we solved by taking advantage of business processes. Since agents request data, acknowledge reception, process information, and transmit new data to another agent, messages act as information carriers. To coordinate the sequence of messages, we established a pattern out of business processes. The actual communication among agents is a protocol that mirrors what is dictated by business processes.

Our solution to coordinating data exchange in the extended enterprise consists of a multi-agent system, with central processing of data and distributed along the participating firms. Also, a communication protocol among agents was designed, and it is general enough to support the execution of business processes. Finally, intelligence was provided to some agents by means of IF-THEN rules.

Even though the proposal is validated by a case study, there are opportunities to improve this line of research. We suggest that business processes be standardized at the ontological dimension so the interactions in the extended enterprise follow a common pattern. However, a modeling framework for BPs must be open in order to integrate subtleties of specific manufacturing domains. Another possible improvement refers to the protocol itself, which can incorporate more powerful negotiation mechanisms. The combination of standardized data models, the capabilities inherent to MAS and coordination patterns are indeed a powerful strategy to model and implement complex dynamics proper of the extended enterprise.

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