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A Semantic Framework for Agent-based Collaborative Manufacturing Eco-systems

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Abstract: Manufacturing eco-systems aim to connect data and services between factories, suppliers and customers. Most of them are built as agent-based eco-systems which act as web-based operating systems for business connections between enterprises. The connection of supply and demand entities participating in an eco-system by exploiting knowledge and data from the business entities has become imperative for them, in order to adapt to the dynamically changing market requirements. This paper introduces a web-based semantic ontological framework designed for collaborative agent-based manufacturing eco-systems. The proposed framework and its core components enable the information modeling of the manufacturing services and the supply chain concepts. A Collaborative Manufacturing Services Ontology able to describe both manufacturing domain and e-commerce domain is offered alongside with an Application Programming Interface for the effortless manipulation of the ontological resources. Furthermore, a Rule-based Matchmaking engine able to match requesters with possible suppliers, and to evaluate offers from suppliers based on different requesters' criteria and preferences is provided.

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1. INTRODUCTION

By the last decade, the collaborative manufacturing marketplaces and eco-systems are a continuous increasing trend. Their growing popularity is due to a series of advantages and opportunities of these eco-systems. The on-line marketplaces enable the elimination of mediators, reduce the marketing costs, provide low or zero cost of entrance and allow opportunities for overseas sales. Unlike the traditional consumer-focused marketplaces, the manufacturing-focused eco-systems attract customers searching for machining and manufacturing services, raw materials and supporting services to manufacturing such as transportation or waste management services. The description and representation of industrial services and resources alongside with the description of supply and demand domain means is complicated as the manufacturing services are complex and vendor specific. In order to achieve connectivity among participants and provide efficient transaction mechanisms a collaborative manufacturing eco-system should be able to model the heterogeneous descriptions of services, products and resources.

In this paper we introduce a semantic framework easily integrated in agent-based manufacturing ecosystems. The proposed framework offer interoperability to the eco-system by providing the modeling of manufacturing resources and services and the modeling of supply chain means as well using a proposed ontology. It also enables the ontology manipulation by the agents and provides matchmaking mechanisms in both agent level and offers level.

The key innovative aspects introduced by the proposed framework are summarized below:

(1) A common knowledge base which compared to existing ontologies is able to support automated transactions in manufacturing eco-systems by representing the manufacturing services and resources and the participants' requests and offers as well. The eco-system participants are able to modify effortlessly the common knowledge base.
(2) An effective two-level matchmaking mechanism. In first level the matchmaking engine enables the matching of eco-system participants based on its services and services' capabilities related to a request. At second level it provides the evaluation of the providing offers based on requester's classified preferences and criteria.
(3) The semantic framework is easily integrated in agent-based collaborative eco-systems as it is web-based and offers its services using well-known communication protocols and data formats. It is designed to provide a generic solution for manufacturing agent marketplaces by allowing agents to use its services without care about the semantic infrastructure.

The paper is structured as follows. Following the Introduction, a related works review is presented. The proposed semantic framework architecture and its components' de-

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scription are analyzed in section 3. Section 4 provides a brief description of a use case of the proposed semantic framework. Finally, the conclusions and future work are drawn at section 5.

2. RELATED WORKS

There are several existing frameworks related to manufacturing semantic representation and matchmaking. However, the related research mainly presents complete agent-based systems which offers this kind of services and not only a semantic framework for agent-based eco-systems. The selected related works are presented by the perspective of semantic representation and matchmaking.

A LARKS(Language for Advertisement and Request for Knowledge Sharing) Sycara et al. (1999) based matchmaking engine was used in `RETSINA`[1] (Reusable Task Structured-based Intelligent Network Agents) infrastructure. The multi-agent infrastructure was developed by the Carnegie Mellon University in Pittsburgh, USA and contained a matchmaking engine relies on service matching based in LARKS which express advertisements and requests using the same language. The matchmaking engine contains five different filters: key-word-based matching, profile comparison matching, similarity matching, rule-based signature matching and constraint matching. Nevertheless, the RETSINA/LARKS matchmaking framework lacks of features matching. It is not focused on manufacturing domain and LARKS needs a manufacturing domain ontology which should be compatible with LARKS to be used as the content. Only then it is able to perform matching. However, due to the general nature of RETSINA/LARKS matchmaking engine, it is unable to capitalize on the advantages of the representation of the manufacturing specific services, tools and resources.

InfoSleuth Nodine et al. (2000) by MCC Inc., Texas, USA is an agent-based system performs different level information management activities. Broker agents exist in the set of various agents were offered by InfoSleuth, which provide syntactic and semantic matchmaking between services' providers and requesters. A specific "infosleuth ontology" was used by agents in order to describe requests and advertisements. The broker agents use textual comparisons for syntactic matchmaking of advertisements and queries. In the case of semantic matchmaking, it applies SQL queries and then constraint matchmaking to queries' output in order to eliminate useless results based on formal descriptions of requests and advertisements' capabilities. However, the used ontology is not able to represent manufacturing services and resources, thus the broker agent's matchmaking engine is unable to perform a matchmaking process which covers the requirements of manufacturing collaborative eco-systems.

Digital Manufacturing Market Ameri and Patil (2012) is a multi-agent web-based framework contains a manufacturing services ontology and a matchmaking mechanism which match a consumer's requirements with suppliers' manufacturing capabilities. MSDL Ameri and Dutta (2006) stands for Manufacturing service description language is the ontology used in this multi-agent framework. MSDL is a manufacturing domain ontology which is able to represent and connect services and resources describing manufacturing capabilities in four levels of abstraction: supply and demand level, machine level, shop-floor level and process level. The requests and advertisements by the agents are expressed using the MSDL as a common vocabulary. Then a middle agent in order to find possible suppliers for a requested process performs both taxonomy-based and features-based matchmaking exploiting the efficient manufacturing processes' representation in MSDL. A ranked list with possible suppliers is returned to the requester agent. The Digital Manufacturing Market approach is the closest one with the presented framework as it uses a common manufacturing ontology and performs semantic matching based on the services descriptions related to this ontology. Besides the differences in matchmaking logic for service and agent level matchmaking which will be presented in this paper, the Digital Manufacturing Market solution is not uses e-commerce concepts in order to extend the matchmaking process in an offer level in which the evaluation of the matching offers can be executed based in different qualitative and quantitative criteria.

Metadata and Ontologies Semantic Matching SE or `FITMAN-SeMa`[2] is a component of `FIWARE for Industry`[3] aims to solve interoperability problems in the collaboration of business processes. It performs effective semantic matching by using various algorithms. Moreover, FITMAN-SeMa provides storing and retrieving functionalities for ontologies and triplets. Unlike the aforementioned related approaches, the FITMAN-SeMa is an installable software which matches concepts between two different ontologies. This approach may enable the collaboration and the possible matching of two different sources however, it is not a manufacturing agent-based eco-system dedicated solution. FITMAN-SeMa introduces a solution which is not based in a central ontology in order to achieve a higher level of interoperability, but it is not able to extract conclusions from manufacturing domain in order to perform an efficient matchmaking of agents and services.

In conclusion of the related works analysis, it is perceived that the existing solutions are not exclusively designed for the manufacturing domain and lacks the necessary concepts for this domain's representation. Besides this, other approaches are completely related to this domain and lacks of the expressibility to represent e-commerce means which are important for the description of the online marketplaces. In order to cope with these shortcomings a semantic framework for collaborative manufacturing marketplaces is introduced.

3. SEMANTIC FRAMEWORK FOR COLLABORATIVE MANUFACTURING ECO-SYSTEMS

3.1 Architecture Overview

As depicted in the Fig. 1, the proposed Semantic Framework for Collaborative Manufacturing Eco-systems composed by three main components. The Ontology Store

[1] RETSINA https://www.cs.cmu.edu/ softagents/retsina.html

[2] FITMAN-SeMa http://www.fiware4industry.com/?portfolio=metadata-and-ontologies-semantic-matching-sema

[3] FIWARE for Industry http://www.fiware4industry.com/

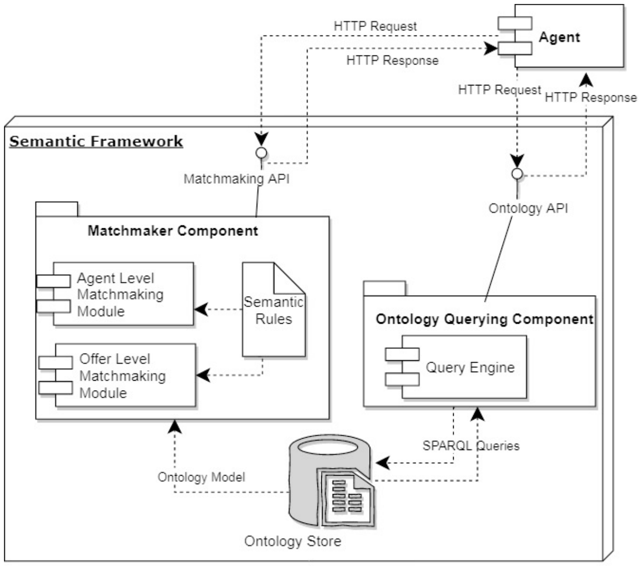

Fig. 1. High level architecture overview

containing the Collaborative Manufacturing Services Ontology, the Ontology Query Engine component and the Matchmaker component. This chapter provides an analysis for these components.

3.2 Collaborative Manufacturing Services Ontology

A collaborative manufacturing eco-system needs a knowledge base in order to support flexible specification and execution of manufacturing collaboration schemes. The knowledge base should enable the description of supply and demand entities participating in the eco-system as well as the description of manufacturing services capabilities and resources for the participating entities. In order to cover these needs a Collaborative Manufacturing Services Ontology is designed and implemented.

The introduced Collaborative Manufacturing Services Ontology is built upon well-known ontologies of both manufacturing and e-commerce domains. Manufacturing service description language or MSDL Ameri and Dutta (2006) was mentioned in section 2, is a manufacturing domain ontology which connects manufacturing services with supply and demand concepts.The structure of this ontology consists the basic idea and the skeleton for the structure of the proposed ontology.As the MSDL core ontology contains only the basic classes for the manufacturing domain's description another one manufacturing domain ontology has been selected to be imported. MAnufacturings Semantics ONtology or MASON was introduced by Lemaignan et al. (2006). It aims to draft a common semantic net in the manufacturing domain by semantically connect concepts such as manufacturing operations, tools, machines, materials, building resources, human resources etc. Most of these concepts are adopted by the proposed ontology. In order to describe the supply and demand entities in more details than the MSDL did, concepts from `GoodRelations Language` [4] are used in Collaborative Manufacturing Services Ontology. GoodRelations Language is a standarized

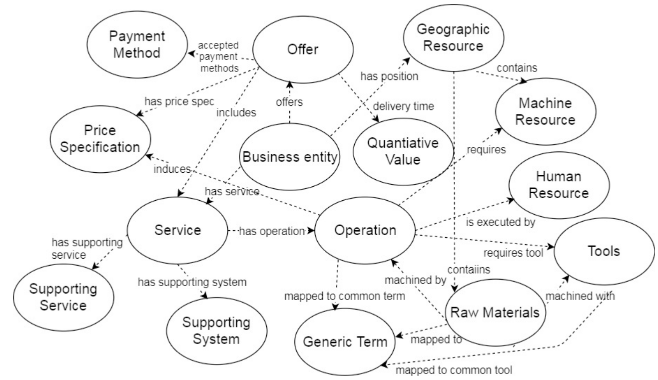

Fig. 2. Basic concepts and properties representation

vocabulary which is suitable to describe almost any kind of e-commerce transactions. It provides the description of concepts such as companies, offers, services/products, prices, store locations and delivery time.

As mentioned in the previous paragraph, the Collaborative Manufacturing Services Ontology imports concepts from various existing ontological resources. The most suited methodology approach in order to built the proposed ontology considered the NeOn Methodology Suárez-Figueroa et al. (2012) as it provides different pathways/scenarios to develop ontologies. The scenario related to reusing, merging, and re-engineering ontological resources covers the case that developers not only choose and merge ontological resources but they also re-engineer them. The processes were described in this scenario were followed in the implementation phase of the Collaborative Manufacturing Services Ontology. The ontology is implemented in `OWL` [5] and its core concepts (see Fig. 2) are presented below:

- *Business entity* class and its sub-classes represent an eco-system's agent who has a service (e.g. manufacturing service) and provides or seeks offers.
- *Offer* class represents a public announcement of a business entity that provides or seeks a certain product or service. This is the key concept for the description of offers and requests of business entities which are involved into the eco-system.
- *Service* class and its sub-classes conceptualize all processes related to a product in an abstract level. The services include operations which are related with resources. It is the general concept of what service is offered by a business entity.
- *Supporting Service and Supporting System* classes and their sub-classes represent services and systems as well which are related to the basic ones and support them. They are actually from a different domain than the business entity's main services and systems but they are useful for the companys activities and processes.
- *Generic Term* class defines common operations, materials and tools. This class will enable the use of same terms for the similar concepts. The vendor-specific concepts will be mapped with corresponding terms of the common Generic Term class instances in order to enable the matchmaking.

[4] GoodRelations Language http://www.heppnetz.de/ontologies/goodrelations/v1.html

[5] OWL https://www.w3.org/TR/owl-ref/

- *Operation* class and its sub-classes represent the processes of a service. Especially the manufacturing processes.The operations are connected with machines, tools and raw materials.
- *Price specification* and *Payment method* classes are related to prices and payments which are core means for transactions' description in a marketplace. The first one specifies the price of a unit, the additional delivery costs and the additional costs related to a payment method. The second one, describes the available procedures for transferring the requested amount for a purchase.
- *Raw material* class and its sub-classes describe materials such as metals which are machined by specific manufacturing processes and tools.
- *Resource* class and its sub-classes represent the total set of linked resources of a business entity. This class enables the description of resources such as buildings, sites, human resources, truck resources, machines and tools which are connected with manufacturing processes and company's activities in general.
- *Quantitative value* class and its sub-classes are used as numerical intervals that represent the range of certain properties. Their individuals are mainly used as the range of other classes object properties related to quantity measurements.

3.3 Ontology Querying Component

The Ontology Querying Component is designed in order to enable the access of eco-system agents into the common knowledge base. By using this component every agent is able to store, update, retrieve and delete information effortlessly from the central Ontology Store.

The implementation of the Ontology Querying Component is in Java and its supported interfaces are available to agents through RESTful web-services. Every agent sends its request to read, store or delete data from the common store using HTTP protocol. The request is described in JSON format in the case a request body exists. The Query Engine which is built on the `Jena API` [6] transforms the request in a `SPARQL` [7] query. Then the query is applied to the Ontology Store. All the queries are constructed based on the terms of Collaborative Manufacturing Services Ontology as the Ontology Store contains only individuals which are described by this ontology's concepts. The Ontology Store is implemented as a permanent triple store which is initialized with the proposed ontology and after that, contains individuals of business entities, and their manufacturing resources and processes. The Ontology Store is built by agents' store requests (POST requests). The stored knowledge becomes available to an agent after its request (GET request), as an HTTP response described in JSON format.

3.4 Matchmaker

The Matchmaker component aims to match possible buyers and suppliers based on the knowledge which is stored at the eco-system's Ontology Store. The component's functionality is strongly correlated with the Collaborative Manufacturing Services Ontology. The Matchmaker infers new knowledge and performs effective matchmaking by applying rules at the knowledge store which is defined by the proposed ontology. It supports semantic matchmaking in the terms of manufacturing capabilities, in order to find the best possible supplier to fulfill a request for a service, raw materials or products involved in the supply chain. Furthermore, different decision criteria for supplier's selection according to several qualitative and quantitative factors such as cost, time, distance, due date, quality, price, and past performance are considered by the matchmaking engine.

The implementation of the Matchmaker component is in Java and it is built on Jena API as the aforementioned presented Ontology Querying component. The matchmaking services are offered through RESTful web-services using HTTP protocol. An agent's request (POST request) is described in JSON format. Based on the request, the matchmaking engine applies a set of Jena rules in the ontology model which is loaded from the Ontology Store, in order to infer new knowledge and perform matchmaking. The Matchmaker responses to the requester agent, using HTTP protocol, in JSON data format.

The introduced matchmaking module offers to eco-system's agents, a two level matchmaking functionality:

(1) *Agent level* matchmaking: In this case an agent sends to the Matchmaker a request for a service or product. Then, the Matchmaker applies a set of semantic rules to the ontology. The matchmaking for a specific service is mainly performed by using the Generic term catalog class of the proposed ontology. The Matchmaker sends as a response to the requester agent a list containing the possible suppliers. If the request describes more requirements except the requested service, the matchmaking module is able to evaluate these requirements in order to achieve a better matching result. For example, if the request specifies a quantity of a product and a minimum eco-system rating for the possible supplier, the matchmaker excludes the providers who did not met these criteria. Finally, it returns to the agent a list containing only the suppliers agents which offer the requested service and fulfill the requested criteria.
(2) *Offer level* matchmaking: In collaborative manufacturing is very common for a company to send a request for offers to its suppliers in order to select the best one based on some criteria. This process can be automated in an agent-based eco-system with the Offer level functionality of the proposed Matchmaker. After the Agent level matchmaking was described above, the requester agent has a list with the possible suppliers. Then, the requester can ask from supplier agents to send their offers which correspond to its request. As soon as, the requester agent receives the biding offers, sends a request for a service alongside with a list of offers to the Matchmaker for evaluation. The offers are translated as instances of the class Offer from the proposed ontology. After that, a set of semantic Jena rules is applied in order to match the request with the best available offer based on some predefined criteria of the requester agent. The

[6] Jena API http://jena.apache.org/index.html
[7] SPARQL https://www.w3.org/TR/rdf-sparql-query/

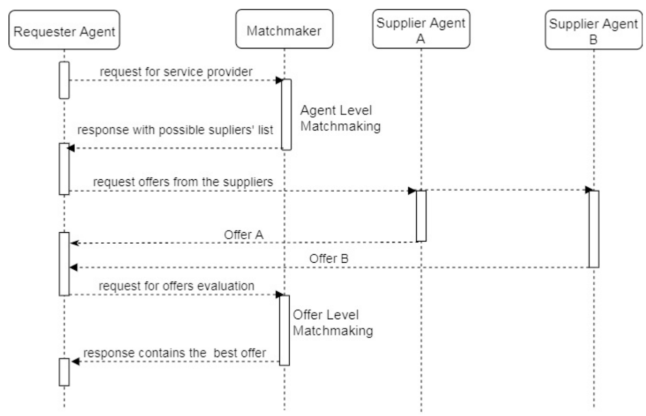

Fig. 3. Information flow

rules are constructed in a generic way, in order to provide different evaluation results if they are applied to the same offers but in a different sequence based on requesters' ranked preferences. For example, for a set of identical offers a requester who wants quick delivery over the price, will get a different result by the Matchmaker than a requester who has the price as the top priority. After the matchmaking process, the best matching offer and the corresponding supplier agent are returned to the requester agent.

Fig 3. presents the information flow between the agents of a collaborative manufacturing eco-system and the proposed Matchmaker component.

4. USE CASE EXAMPLE

In order to explain better the proposed framework, a simple use case scenario is introduced in this section. The scenario describes the case in which a manufacturer wants a scrap metal collection service from the waste management companies participating in the collaborative eco-system.

Table 1. Eco-system's participants

	Company A	Company B	Company C	Company D
ID	agent-A-ID	agent-B-ID	agent-C-ID	agent-D-ID
Service	Waste Mngmt	Scrap Mngmt	Polishing Service	Waste Service
Operation	op-code-1	op-code-1	op-code-2	op-code-1
Rating	5	5	3	2

As depicted in the Table 1, except the requester company other four companies exist at the collaborative manufacturing ecosystem. For reasons of simplicity, we use an example with only four companies with few properties in order to present some simple matchmaking rules which explain better the proposed framework's matchmaking functionality.

Using the terms of Collaborative Manufacturing Ontology the Company A is expressed as follows:

```
CompanyA is-a BusinessEntity
CompanyA hasMarketplaceID "agent-A-ID"
CompanyA hasRating 5
CompanyA hasService WasteMngmt
WasteMngmt hasOperation ScrapCollectionProcess
ScrapCollectionProcces mappedToCommonTerm op-code-1
```

All the companies are described in similar way with the Company A individual and they are stored to the Ontology Store. The services and operations of the companies contain more properties related to manufacturing resources and processes but they are not presented here, as they are out of the scope of this example. The Ontology Querying component was used in order to create and save the individuals to the Ontology Store by applying a set of insert type SPARQL queries. In the case that the requester company wants a scrap metal collection service from the eco-system, the corresponding agent sends a request to the Matchmaker. For the purposes of the current case study, the request contains: the requester ID, the operation code of the requested process based on the common terms catalog and a requirement for a minimum eco-system rating score equals to 3. As soon as, the Matchmaker receives the request, applies a set of semantic rules to the stored ontology. For this scenario the rules that affect the matchmaking results are the following:

```
[matchBusinessEntities:
  (?y rdf:type BusinessEntity)
  (?y seeksOffer ?Offery)
  (?Offery includes ?Servicey)
  (?Servicey seeksOperation ?Operationy)
  (?x rdf:type BusinessEntity)
  (?x hasService ?Servicex)
  (?Servicex hasOperation ?Operationx)
  (?Operationx mappedToCommonTerm ?Operationy)
  ->
  (?y matchesWith ?x)
]
```

By applying the previous rule, the Matchmaker match the requester company with companies A, B and D based on the requested service. Nevertheless, the requester had set a requirement for a minimum rating equal to 3. The following rule was applied in order to match the requester only with the companies which fulfill the rating requirement by removing from the matching list the one with rating less than 3.

```
[matchRequestFulfilment:
  (?x rdf:type BusinessEntity)
  (?x seeksOffer ?Offerx)
  (?Offerx hasMinRating ?minRating)
  (?x matchesWith ?y)
  (?y hasRating ?ratingy)
  lessThan(?ratingy, ?minRating)
  ->
  drop(3)
]
```

The result of the previous rule's appliance is that the matching companies are A and B. The matching companies' IDs returned as a response to the requester agent.

The requester agent receives the Agent level matchmaking result and then is able to ask from matching agents for offers. As soon as, it receives the offers, the requester sends its request alongside with the received offers to the matchmaker for an Offer level matchmaking in order to match the request with the best available offer. Table 2 represents the available offers from companies A and B. For the purposes of this example the offers contains only price and delivery lead time. Besides the request

Table 2. Available offers

	Company A	Company B
ID	offer-A-ID	offer-B-ID
Price	500	400
delivery time	2 days	3 days

and the offers, the requester agent is able to send to the

Matchmaker a set of ranked preferences. In the example case, the requester prefers first of all the highest rating company to fulfill its request. After that the requester prefers the best price over the delivery lead time. In order to fulfill these preferences the matchmaker first detect the best rating value and then removes from the matching list the companies which not have this rating value:

```
[matchRequestToBestOfferByRating:
  (?x rdf:type BusinessEntity)
  (?x seeksOffer ?Offerx)
  (?Offerx hasBestRating ?bestAvailableRating)
  (?Offerx bestMatchingOffer ?Offery)
  (?y rdf:type BusinessEntity)
  (?y offers ?Offery)
  (?y hasRating ?ratingy)
  notEqual(?ratingy, ?bestAvailableRating)
  ->
  drop(3)
]
```

The above rule will not affect the matchmaking output as both companies have the same rating inside the collaborative eco-system. Based on preferences a second rule was applied related to price evaluation. First the best available price has been detected and added to the request's description. Therein-after the following rule is executed:

```
[matchRequestToBestOfferByPrice:
  (?x rdf:type BusinessEntity)
  (?x seeksOffer ?Offerx)
  (?Offerx hasPriceSpecification ?PriceSpecx)
  (?PriceSpecx hasCurrencyValue ?Valuex)
  (?Offerx bestMatchingOffer ?Offery)
  (?Offery hasPriceSpecification ?PriceSpecy)
  (?PriceSpecy hasCurrencyValue ?Valuey)
  notEqual(?Valuey, ?Valuex)
  ->
  drop(4)
]
```

After the above rule's execution the Company A is removed from matching list. As a result, the offer from Company B is the best available. A third rule related to delivery lead time will not affect the final result. Finally, the Offer level matchmaking process will return as a result the Company B and its offer, with the corresponding IDs. If both offers had the same price then a third rule similar to the previous one but related with delivery lead time will choose Company A offer as the best available. Moreover, in the case that the requester prefers delivery time over the price the two rules will be applied in reverse sequence. The Matchmaker is available to provide different results by changing the order of the rules be applied based on requester's preferences, without the need to change the rules' structure. The original set of rules are wider and more complex in order to cope with the requirements of larger collaborative eco-systems with more detailed offers but for purposes of simplicity and comprehensibility the previous basic example were chosen to be presented.

5. CONCLUSION AND FUTURE WORK

The modeling of manufacturing resources and processes alongside with the automation of the supply chain operations have significant potential to aspects such as cost reduction and transactions improvement in collaborative eco-systems. Targeting the limitations that the heterogeneous representations of manufacturing and supply chain domains apply on the eco-systems transactions, a semantic framework for collaborative manufacturing agent-based eco-systems is introduced. In this framework, a Collaborative Manufacturing Services Ontology is proposed. The ontology provides a common vocabulary for the representation of eco-systems' participants in terms of manufacturing services, capabilities, resources and supply chain processes as well. Besides the interoperability that is offered through the proposed semantic framework and its included ontology, the easy access and manipulation of the knowledge store are also ensured. Finally, by the addition of a semantic matchmaking engine, the semantic framework enables the automated discovery of possible suppliers for a service based on manufacturing terms, and the effective evaluation of offers based on supply chain means. The preliminary results of the framework's usage highlights the benefits of the information modeling and the inference of new knowledge based on this information, for collaborative manufacturing eco-systems. Further research will be conducted and the proposed ontology will be enriched in order to be able to represent more complex manufacturing services and collaborative schemes. The set of the semantic rules will be extended as well, in order to exploit the new knowledge that is offered through the enriched ontology.

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