Semantic web-based supplier discovery system for building a long-term supply chain

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Abstract

As companies move forward to source globally, supply chain management has gained attention more than ever before. In particular, the discovery and selection of capable suppliers has become a prerequisite for a global supply chain operation. Manufacturing e-marketplaces have helped companies quickly and effectively discover new suppliers and/or buyers for their products and services. However, as the requirements and capabilities in isolation, their true meanings may not be uniformly interpreted by each other. The issue of semantics between suppliers and buyers, then, remains an obstacle.

The main objective is to propose a semantic web-based supplier discovery system for building a long-term strategic supply chain. Specifically, 1) a key ontology is developed to represent the supplier's capability information and the buyer's requirements; 2) supplier's potential capability is reasoned; 3) and buyer's requirements are semantically matched with supplier's capability based on a similarity calculation.

In order to build a long-term supply chain, the system receives supplier's capability information composed of manufacturing capability, and non-manufacturing capability. The supplier's non-manufacturing capability is evaluated considering information on the supplier's finances, customers, internal business, and learning and growth, based upon the Balanced Scorecard (BSC), which has been widely used to evaluate companies.

In addition, a prototype for semantic web-based supplier discovery is implemented in order to demonstrate the practicality of the developed system.

Keywords : Collaborative manufacturing; e-Business; Supplier discovery; Supply chain building;

1. Introduction

Rapid globalization of business across emerging markets has changed business competition from a ‘company versus company’ model into a ‘supply chain versus supply chain’ model. A supply chain is defined as a network of participants who procure materials, develop products, and deliver them to customers according to coordinated plans (Goffin, Szwejczewski, and New 1997). As companies move forward to sourcing globally, supply chain management has gained attention more than ever before. In particular, the discovery and selection of capable suppliers has become a prerequisite for global supply chain management. Conventional supplier discovery practices, such as visiting expos, or making phone calls, may not help to find for new suppliers located overseas.

In response, Camarinha-Matos and Cardoso (1999) have implemented an internet based prototype to find and select overseas suppliers as well as domestic suppliers. The prototype stores suppliers’ information from industrial associations, commerce chambers, and websites served by local search engines, and then automatically generates a query to find suppliers. Moreover, manufacturing e-marketplaces have appeared such as Alibaba.com, mfg.com, and ec21.com. These approaches have helped companies quickly and effectively discover new suppliers and/or buyers for their products and services of interest.

Figure 1 shows a supplier discovery scenario, where a buyer attempts to find global suppliers capable of manufacturing a car front bumper mould. Because the requirements and capabilities are described in isolation, their true meanings may not be uniformly interpreted. The issue of semantics between suppliers and buyers could not be solved by the previous methods, so it remains an obstacle.

[Figure 1 near here]
Figure 1 Supplier discovery scenario

In order to overcome this limitation, a number of supplier discovery methods have been introduced, ranging from classic information retrieval methods for text comparison, to more sophisticated semantic-matching-based ones using ontologies (Ameri and Dutta 2008; Cai et al. 2010; Jang et al. 2008; Kulvatunyou, Cho, and Son 2005). These advanced methods have helped to resolve semantic issues between suppliers and buyers. Nevertheless, most aforementioned studies on supplier discovery have considered only manufacturing capability. This simplification is very far from real-world situations. To discover and select suppliers successfully, buyers need to consider multiple perspectives, such as the manufacturing facility and capacity, quality, delivery, and performance history (Dickson 1966; Thanaraksakul and Phruksaphanrat 2009). For this reason, these approaches are not appropriate for building a long-term supply chain, but only for a single trading of specific products (Virolainen 1998).

In response to this shortcoming, the main objective of this paper is to propose a semantic web-based supplier discovery system that considers multiple perspectives to build a long-term supply chain. These perspectives include the Balanced Scorecard (BSC), which has been widely used for evaluating companies, as well as a manufacturing capability perspective (Brewer and Speh 2000; Chiang 2005; Huang and Keskar 2007).

The remainder of this paper is organized as follows. Section 2 explains ontology in the context of manufacturing domain and Web Services followed by the underlying methodologies; Section 3 describes the overall system architecture; and Section 4 presents the approach used for data capturing and ontology building. Ontology-based reasoning and semantic matching are discussed in Section 5 and Section 6, respectively. A case study involving the prototype system is presented in Section 7. The prototype system is implemented to demonstrate its practicality using actual data from the automotive industry for the buyer, and the mould manufacturing industry for the supplier. In Section 8, several implications are discussed. Finally, conclusions are given in the last section.

2. Related Work

2.1. Ontology in the Context of Manufacturing Domain and Web Services

This section outlines some of the applications in which ontology covered the manufacturing domain based on Web Services. An ontology is a ‘formal and explicit specification of a shared conceptualization’ that is used to model a domain of interest, and to support reasoning based on the model (Gruber 1995). Many have proposed to utilize the notion of ontologies in the context of manufacturing domain (Karpowitz et al. 2008; Lee et al. 2009). Likewise, many have also approached modelling manufacturing resources as a web service consisting of three parts: Service Profile for what the manufacturing resources do, Service Model for how the manufacturing resources work, and Service Grounding for how the manufacturing resources are used.

National Institute of Standards and Technology (NIST) developed Process Specification Language (PSL) for description of basic manufacturing and business processes. It aims to overcome interoperability issues in the enterprise processes by integrating processes throughout the manufacturing process life cycle: production planning, workflow management and project management. It is a language to specify all types of manufacturing processes. However, it lacks the specificity to represent manufacturing capabilities required for supplier's capabilities of semantic web-based discovery.

Kulvatunyou, Cho, and Son (2005) extend OWL-S, an ontology developed for semantic representation of Web Services, to include manufacturing operations as well. In this regard, manufacturing operations are defined as a service in Web Services. In their model, manufacturing operations are further represented by defining sub-classes such as *material removal operation* and *hole making*. This augmentation of sub-classes may reduce the overall flexibility of the ontology. Moreover, this ontology assumes that a service profile is a description of the aggregate capability of a shop at its largest. However, supplier discovery requires representing the company's entire manufacturing resources.

MSDL (Manufacturing Service Description Language) is an ontology for the representation of manufacturing services (Ameri and Patil 2012). It is an upper ontology that provides limited basic concepts to address a broad range of objects in the domain of interest. Naturally, an upper ontology has sufficient flexibility and extendibility for further specification. Note that the underlying methodologies used to build and expand from such ontology for implementation are described in the following section.

Meanwhile, an ontology could be used for modelling buyer's requirements in the manufacturing domain (Baldo, Rabelo, and Vallejos 2007, 2008). Baldo, Rabelo, and Vallejos (2007) have presented an ontology-based methodology to identify and select the appropriate evaluation criteria for understanding buyer's requirements. For example, when buyers are looking for evaluation criteria that measure *tasks*, with the objective of *scheduling*, considering the perspective of *responsiveness*, appropriate criteria such as '*average of delay to fulfil tasks*', '*the percentage of tasks completed on time*' are derived from ontology based reasoning. Furthermore, the ontology has been extended to identify the semantic terms such as ‘*defect free*’, ‘*damage free*’ and ‘*without error*’, and consequentially, the performance of criteria identification has been improved (Baldo, Rabelo, and Vallejos 2008). Although these prototypes have enabled buyers to make explicit their requirements and to identify evaluation criteria, they cannot find suppliers by identifying supplier’s capability.

2.2. Ontology Building

Since ontologies are a part of software products, most methodologies are derived from software development methodologies such as the IEEE 1074-1995 or the Unified Process (UP) (De Nicola, Missikoff, and Navigli 2009). Likewise, there are variations in the building methodologies that are created in order to meet the requirements of ad hoc cases.

Chandrasekaran, Josephson, and Benjamins (1999) state that the use of ontologies must be considered in order to select the most appropriate building methodology. In reality, though, one particular methodology alone cannot adequately guarantee the required level of expressivity, so, a mix of application-specific and generic methodologies is typically applied (Staab et al. 2001). In this paper, a number of selected methodologies relevant to the proposed system will be reviewed.

Ontology building methodologies for a specific usage commonly require formal representations for the specific usage: motivation scenarios, use scenarios, competency question lists, and so on. The TOVE project ontology, which covers the domain of business processes and activities modelling, designed a methodology by adopting the use scenarios of the application that utilizes the ontology (Uschold and Gruninger 1996). Use case scenarios are employed in order to identify important concepts and relationships, which are then expanded via generalization and specialization. The

KACTUS project investigated the reuse of knowledge in a complex technical system using an ontology (Schreiber et al. 1994). This knowledge was used as input for the preliminary design of the ontology. What these methodologies have in common is a set of strictly controlled seed concepts that fulfil the required specific usage.

On the other hand, ontologies also need to retain some level of versatility and expandability in order to cover different domains of industry, thus calling for a generic methodology. Uschold and King (1995) derived a skeletal methodology for ontology building based on the experience of building an ontology for enterprise modelling processes. METHONTOLOGY takes a step further in describing the activities involved in the whole lifecycle of an ontology (Cea et al. 1998). What these methodologies have in common is a focus on describing the activities. In this paper, ontologies have been built by applying a mix of the above methodologies. Extensive use case scenarios are written to consider the different ways in which the system may be used by various buyers and suppliers. The system allows for the fulfilment of a specific usage, while also guaranteeing versatility and expandability to other domains.

2.3. Semantic Matching and Similarity

The matching process can be seen as a function f which takes a pair of ontologies in order to match two ontologies. In addition, there are a number of other parameters: (1) an input alignment A, (2) a set of parameters p, e.g., weights or thresholds, (3) a set of oracles and resources r, e.g., domain-specific thesauri, and (4) a returned alignment A' between these ontologies: $A' = f(o, o', A, p, r)$. This can be schematically represented as shown in Figure 2 (Shvaiko and Euzenat 2012).

[Figure 2 near here]

Figure 2 Concept diagram of semantic matching

Semantic matching widely uses a measurement criterion called similarity(Shvaiko and Euzenat 2012). The conceptual representation of similarity can be represented as follows (Markov and Larose 2007):

$$Sim(A,B) = \frac{|A \cap B|}{|A \cup B|} \qquad (1)$$

Essentially, it is the proportion of similar parts in two concepts. There are numerous methods to measure similarity; the ones within the context of semantic matching are reviewed below.

Name-based similarity considers spelling distance as a unit of measurement. For instance, the similarity between ‘art’ and ‘part’ is computed by decomposing the words in the following form : $sim = \frac{|\{a,r,t\}|}{|\{p,a,r,t\}|} = \frac{3}{4}$.

While this is an intuitive measurement measure, it has a clear limitation in not considering semantics. Therefore, name-based similarity is not an adequate measure for semantic matching.

Wu and Palmer (1994) proposed a taxonomy-based similarity calculation, which considers the taxonomical distance and the length between concepts in the taxonomy as a unit of measure:

$$Sim(A,B) = \frac{2dis(C,R)}{dis(A,C) + dis(B,C) + 2dis(C,R)} \qquad (2)$$

where $dis(A,B)$ is the number of arcs between concepts A and B, while C is the least common ancestor, and R is the root ancestor.

While this approach considers the taxonomical characteristics of concepts, the quality of similarity measure is completely dependent on its defined taxonomy. Unfortunately, a well-defined taxonomy is known to be difficult to build.

Vector-based similarity considers conceptual features in the form of vectors. The conceptual features refer to object and data types properties and even more. The similarity is calculated by the formula (Benabderrahmane et al. 2010):

$$Sim(\vec{A},\vec{B}) = \frac{\vec{A}\cdot\vec{B}}{|\vec{A}\cdot\overrightarrow{B}|} \qquad (3)$$

where $\vec{A}$ is a vectored concept.

For example, the similarity between concept 1 and concept 2 is calculated to be $(1,1,0,1)\cdot(1,0,1,1)\times\frac{1}{4}=\frac{1}{2}$, where concept 1 has {property 1, property 2, property 4}, and concept 2 has {property 1, property 3, property 4}. The semantic matching in this paper is based on this vector-based similarity for partial matching, because it is very common that no supplier can satisfy a buyer’s requirements perfectly. This will be elaborated in detail in Section 6.

3. Overall System Architecture

Matching buyer’s requirements with supplier’s capabilities requires semantic matching, because (1) buyer’s requirements are not explicitly described, (2) suppliers use heterogeneous formats and terminologies in their capability description, and (3) buyers and suppliers use different levels of detail in describing their wishes. Therefore, the buyers may not well interpret suppliers' capabilities, and the suppliers may not recognize what the buyers want, either.

A key ontology is built to match semantically. The system includes ontology building, reasoning, and semantic matching. Its brief diagram is shown in Figure 3.

[Figure 3 near here]

Figure 3 Semantic-web based supplier discovery system architecture

Step 1. The collaboration ontology is pre-built in order to be used for reasoning. This ontology is built in the form of Web Ontology Language (OWL), and OWL Rules Language (ORL).

Step 2. Supplier's potential capability is reasoned from classes, properties, reasoning rules, and instances. OWL includes classes and properties, ORL is used for rules, and Resource Description Framework (RDF) for instances. A reasoning tool automates the reasoning process, and it stores the ontology model and its reasoned instances in the 'triple instance store'.

Step 3. Finally, the buyer's requirement is semantically matched with supplier's capability based on similarity calculation. SPARQL (Sparql Protocol And Rdf Query Language) is used for matching.

4. Building the Collaboration Ontology

Buyer's requirements consist of the following sub-requirements: product requirements (that is, '*what to manufacture?*'), and supplier requirements (that is, '*whom to manufacture with?*'). On the other hand, supplier's capability consists of the following sub-capabilities manufacturing capability, and non-manufacturing capability.

4.1. Capturing and Classifying Supplier Capability Information

The system captures supplier capability information composed of manufacturing capability, and non-manufacturing capability. Non-manufacturing capability is evaluated using the criteria for finances, customers, internal business, and learning and growth perspective developed based upon the Balanced Scorecard (BSC), which is widely used for evaluating companies (Brewer and Speh 2000; Chiang 2005; Dickson 1966; Huang and Keskar 2007; Thanaraksakul and Phruksaphanrat 2009). These criteria enable a buyer to select suppliers who are suitable for long-term collaboration.

The manufacturing perspective is related to manufacturing capability, which will be matched with the product requirement of buyer. Manufacturing perspective includes three sub-perspectives: manufacturing facility and capacity, R&D capability, and quality reliability. On the other hand, the other four perspectives from the BSC are used to evaluate non-manufacturing capability, which will be matched with the supplier requirement of the buyer. Table 1 shows the staple criteria classified in terms of the above perspectives, which have been selected and verified by industry experts in terms of their significance and attainability. These criteria will serve as classes in the collaboration ontology.

Table 1 Criteria of each perspective in supplier’s capability
[Table 1 near here]

4.2. Building an Ontology for Supplier’s Capability Information

Since the quality of the semantic matching is directly determined by the richness of the representation, an ontology plays an essential part in this system. The collaboration ontology is built using the formal representation language OWL, the most expressive semantic markup language (McGuinness and Harmelen 2004). Each ontology concept is represented as a class, using owl:Class. An OWL class is characterized by relationship-type properties using owl:ObjectProperty, or by data-type properties using owl:DatatypeProperty. Figure 4 shows the supplier ontology in which classes represent supplier's capability in terms of manufacturing capability and non-manufacturing capability. For example, *tool*, *process*, *part* and *product* classes are used for reasoning regarding manufacturing capability, while *patent*, *location*, and *customer* classes are used for reasoning regarding non-manufacturing capability. In addition, Figure 5 shows a partial OWL code for the supplier ontology in the collaboration ontology.

[Figure 4 near here]

Figure 4 Concept diagram of the supplier ontology

[Figure 5 near here]

Figure 5 Partial OWL code of the supplier ontology

4.3. Capturing and Making Explicit of Buyer's Requirement

Buyer's requirements consist of product requirements (that is, '*what to manufacture?*'), and supplier requirements (that is, '*whom to manufacture with?*'). Table 2 shows explicit meanings of supplier requirements.

Table 2 Explicit meanings of supplier requirements

[Table 2 near here]

4.4. Building an Ontology for Buyer's Requirements

Figure 6 shows the buyer ontology in which classes represent buyer's requirements consisting of product requirements and supplier requirements. For example, *process*, *part*, and *product* classes are used for reasoning regarding product requirements, while *supplier requirement* classes are used for reasoning regarding supplier requirements.

[Figure 6 near here]

Figure 6 Concept diagram of the buyer ontology

5. Reasoning Supplier's Potential Capability

Suppliers may not be fully aware of the buyer's requirements that they can potentially satisfy. Therefore, reasoning supplier's potential capability is essential. In this system, the 'triple instance store' is used to store reasoned supplier's potential capability information.

Figure 7 presents an example concept diagram about how to reason manufacturing capability with the supplier ontology. A car bumper mould is manufactured by milling and drilling. In addition, milling is possible if a supplier has a milling machine, and drilling is possible if a supplier has a high speed drilling machine and a high pressure coolant system. Thus, it could be reasoned that a supplier can manufacture a bumper mould and also can provide milling and drilling process, if a supplier has a milling machine, a high speed drilling machine, and a high pressure coolant system. In addition, Figure 8 represents a partial ORL code for reasoning the manufacturing capability.

[Figure 7 near here]

Figure 7 Concept diagram of reasoning manufacturing capability
[Figure 8 near here]

Figure 8 Partial ORL code of reasoning manufacturing capability

Figure 9 represents a partial ORL code for reasoning the non-manufacturing capability. If the location of supplier is different from that of a known customer, supplier's customer is verified to be a foreign buyer.

[Figure 9 near here]

Figure 9 Partial ORL code of reasoning non-manufacturing capability

6. Semantic Matching of Buyer's Requirements with Supplier's Capability

Semantic matching of buyer's requirements with supplier's capability is required to solve the issue of buyers and suppliers using different levels of detail in their descriptions. In this system, (1) the buyer's product requirements and the supplier's manufacturing capability, and (2) the buyer's supplier requirement and the supplier's non-manufacturing capability are semantically matched.

6.1. Semantic Matching of Product Requirements with Manufacturing Capability

Figure 10 presents an example concept diagram about how to match buyer's product requirements with supplier's manufacturing capability. First, all the manufacturing capabilities of the supplier, such as bumper mould, are reasoned via the described processes. Subsequently, buyer's product requirements are matched with the supplier's manufacturing capability. In this system, the bumper mould instance in the buyer ontology is matched with the front bumper mould instance in the supplier ontology, because they have identical instances.

[Figure 10 near here]

Figure 10 Concept diagram of semantic matching: the buyer's product requirements and the supplier's manufacturing capability

Unfortunately, only rarely can identical instances be expected to appear in both ontologies. Therefore, it is desirable to match buyer's requirements with supplier's capability by suggesting similar alternatives. As a result, it is necessary to match partially based on similarity calculation. The similarity calculation step is conducted as follows: Take a bottom node, and calculate the vector-based similarity. Next, calculate the similarity of its parent node, recursively.

Let us present an illustrative case assuming that necessary reasoning rules exist. Note that the reasoning rule states that the front bumper mould is manufactured by milling and drilling processes and the drilling process is made possible if a supplier either has milling/drilling machine or has both high speed drilling machine and high pressure coolant system. In this case, a buyer wants to manufacture a front bumper mould and a door trim mould. Supplier #1 has a milling/drilling machine and 3D CAD, while supplier #2 has a high speed drilling machine and 3D CAD. Figure 11 presents the above scenario in a concept diagram based on similarity calculation.

[Figure 11 near here]
Figure 11 Concept diagram of semantic matching based on similarity calculation

The similarity calculation procedure for the buyer's product requirement and the supplier's manufacturing capability is outlined below. The steps in the similarity calculation for the manufacturing capability are as follows:

Step 1. Reason all linked instances and properties with similarity calculation. In this case, since supplier #1 has a milling/drilling machine and 3D CAD, supplier #1 can perform the milling process, drilling process, and 3D design. Meanwhile, since supplier #2 has 3D CAD, they can perform 3D design. Supplier #2 only has a high speed drilling machine, so they cannot perform drilling, which requires a high speed drilling machine and high pressure coolant system. In this case, the similarity for drilling can be computed as $(1,1)\cdot(1,0)\times\frac{1}{2}=\frac{1}{2}$.

Step 2. Calculate the vector-based similarity between buyer's requirement and supplier's capability. The buyer's product requirement is composed of {Milling, Drilling, 3D Design}. Supplier #1 has a manufacturing capability of {Milling, Drilling, 3D Design}, so its similarity is calculated as $(1,1,1)\cdot(1,1,1)\times\frac{1}{3}=1$. Meanwhile, since the manufacturing capability of supplier #2 is {None, Half of drilling, 3D design}, its similarity is calculated as $(1,1,1)\cdot(0,\frac{1}{2},1)\times\frac{1}{3}=\frac{1}{2}$.

Step 3. The manufacturing similarity of supplier #1 is concluded as 100%, and that of supplier #2 is 50%.

6.2. Semantic Matching of Supplier Requirements with Non-manufacturing Capability

Figure 12 presents an exemplary concept diagram about how to match buyer's supplier requirements with supplier's non-manufacturing capability information. For example, a buyer wants to work with a 'global company.' This requirement is explicated as shown in Table 1: A supplier can interact in English, has overseas branch offices, has transaction experiences with foreign buyers, and can deliver products abroad. Subsequently, buyer's supplier requirements are matched with the supplier's non-manufacturing capability. In this system, the supplier instance is matched with the global company instance in the buyer ontology, because they have identical properties.

[Figure 12 near here]

Figure 12 Concept diagram of sematic matching: the buyer's supplier requirement and the supplier's non-manufacturing capability

The similarity between the buyer's supplier requirements and the supplier's non-manufacturing capability is also calculated by the vector-based similarity. If a buyer wants to discover a global supplier, the similarity is calculated between the buyer's supplier requirements and supplier's non-manufacturing capability. Table 3 shows a detailed similarity calculation. In this case, supplier #1 is more suitable than supplier #2 with regard to the buyer's supplier requirement of a 'global company'.

Table 3 Similarity calculation between the buyer's supplier requirements and the supplier's non-manufacturing capability
[Table 3 near here]

7. Case Study and Implications

7.1. Case Study

In order to demonstrate the system's practicality, a prototype is developed and tested. Table 4 presents an example of supplier capability information, which is based on the actual data collected from mould manufacturing companies in South Korea. Let us present an illustrative case where the buyer's product requirements are 'automobile bumper' mould and 'door trim mould' and the buyer's supplier requirement is 'global company.'

Table 4 Example of supplier capability information
[Table 4 near here]

In the prototype, Protégé 4.1.0 (Build 239), which is an open source ontology editor, is used to model the collaboration ontology, which is represented in Figure 13.

[Figure 13 near here]

Figure 13 Implementation of the supplier ontology

A typical supplier has the following object properties: '*hasTool*', '*hasProcess*', '*hasProductFocus*', and '*hasIndustryFocus*'. All these object properties have the domain of '*Supplier*' in common. Consequently, the ranges for these object properties are the concepts described in the collaboration ontology. For example, Figure 14 shows a partial RDF code for an instance of the 'Tool' class in the collaboration ontology. Its description denotes that '*MP2618*' is a type of '*5_Axis_milling_machine*', and '*Tool_for_general_use*'. It furthermore denotes that it is manufactured by a company whose name is '*TOSHIBA*', and that it is able to perform the manufacturing processes of '*Milling*', '*Drilling*', and '*Boring*'. These properties imply that '*MP2618*' is inherited from '*5_Axis_milling_machine*', and '*Tool_for_general_use*'. In addition, let us assume that a DMB-U5S, and an HMT-1300N are milling/drilling machine, T-101 is a high speed drilling machine, and WILD FIRE 4.0 is 3D CAD.

[Figure 14 near here]

Figure 14 Partial RDF code for the supplier ontology

Likewise, Figure 15 shows the major concepts, and the object and data properties of '*Buyer.*'

[Figure 15 near here]

Figure 15 Implementation of the buyer ontology

A typical buyer requirement has the following object properties associated with it:

‘*FindsPart’*, and ‘*hasSupplierPreferenceWith*’. Likewise, these object properties share the domain of ‘*Buyer*’ in common, while the ranges are the concepts described in the collaboration ontology. The modular design of the buyer ontology can be applied to handle further buyer requirements from other domains.

In the prototype, *Pro-Reasoner* serves as a reasoning tool to automate the reasoning process, and it stores the ontology model and its instances in the triple store. This automated reasoning tool, *Pro-Reasoner,* is developed by Korea Institute of Science and Technology Information (KISTI). It is based on the Rete algorithm, which is able to reason quickly. It is often used in pattern matching for the implementation of production rule systems (Forgy 1982).

Table 5 shows the values of the implemented reasoning process with calculating similarity. A number of additional properties are added via reasoning, assigned respective values, and stored in the triple store.

Table 5 Values of reasoned properties
[Table 5 near here]

Table 6 shows the similarity between the buyer requirements and supplier’s capability for semantic matching. These are derived from the averages of the manufacturing and non-manufacturing similarities in Table 5. After calculating these similarities, the buyer’s requirements from the buyer ontology are converted into a query in SPARQL, the W3C-recommended language for an RDF query, for semantic matching (Prud’Hommeaux and Seaborne 2008).

Table 6 Similarity between the buyer requirement and supplier’s capability
[Table 6 near here]

Figure 16 shows selected suppliers executed by SPARQL, from the matching result shown in Table 6. After obtaining the calculated similarities for each supplier, the next step is selecting suppliers that exceed the threshold value. In this prototype, the threshold is set as 0.7. As a result, Minkyung Mould, KJ mould, and Alpha Mould are selected. GD mould, which satisfies the product requirement perfectly is not selected, since its similarity for the supplier requirement is less than the threshold. Although GD mould is capable of manufacturing the product, they do not satisfy the supplier requirement.

[Figure 16 near here]

Figure 16 Selected suppliers by SPARQL

Finally, a webpage prototype have been developed. Figure 17 shows the webpage prototype screenshot for receiving the buyer's requirements, which enables the buyer to type in or select their requirements.

[Figure 17 near here]

Figure 17 Webpage prototype screenshot

7.2. Experimental Implications

Most existing ontology-based systems have often been hindered due to the slow reasoning speed of reasoning engines. Likewise, this system in practice may face the same difficulty with increasing numbers of suppliers stored in the system. Therefore, the feasibility was tested via a series of experiments to measure the computational time of reasoning and matching with changes in the number of suppliers. The results are shown in Table 7. Since suppliers are registered in the system beforehand, the system always has sufficient time to reason supplier's potential capability. Therefore, the reasoning time may be regarded as sufficiently fast. Moreover, semantic matching of buyer's requirements with supplier's capability information could be performed less than a second in all cases. It proves the system can be widely used in practice.

Table 7 Computational time for reasoning and matching
[Table 7 near here]

7.3. Managerial Implications

As the system captures manufacturing capability as well as non-manufacturing capability, a long-term strategic supply chain can be built (Chiang 2005). It also reduces the uncertainty in supply chain, since more suppliers are discovered. It is noted that the uncertainties in supply chain can be measured by the means and variances of lead times. Guo and Ganeshan (1995) has proven that more suppliers could reduce means and variances of lead time.

Furthermore, both buyers and suppliers receive benefits via supplier diversification. For buyers, the system helps to leverage suppliers' power, and to reduce procurement cost (Barua, Ravindran, and Whinston 1997). For suppliers, the system helps to create new business opportunities.

8. Conclusion

In this paper, a semantic web-based supplier discovery system is proposed to solve the issue of semantics between suppliers and buyers. The system includes ontology building, reasoning and semantic matching. 1) A key ontology is developed to represent the buyer's requirements and the supplier's capability information; 2) supplier's potential capability is reasoned, since suppliers may not be fully aware of the buyer's requirements that they can potentially satisfy; 3) and buyer's requirements are semantically matched with supplier's capability based on similarity calculation. In addition, a prototype of the system has been implemented to test feasibility. It proves the system can be widely used in practice.

Up until now, supplier discovery methods have only focused on matching product requirements with the supplier's manufacturing capability at a semantic level. As the proposed system extends to considering supplier requirements as well as product requirements, the system facilitates the building of a long-term strategic supply chain. Also, the number of potential suppliers greatly increases since the system helps to discover more suppliers. This supplier diversification allows buyers to leverage suppliers' power and suppliers to create new business opportunities.

In future work, rich ontologies will be developed to reflect industry realities. The United Nations Standard Products and Services Code (UN/SPSC) and the North American Industry Classification System (NAICS) can be fed into the ontologies via automated reasoning. This would not only enrich them in terms of information, but would also enable them to handle other domains with a high degree of accuracy.

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References

Ameri, F., and D. Dutta. 2008. "A Matchmaking Methodology for Supply Chain Deployment in Distributed Manufacturing Environments." *Journal of Computing and Information Science in Engineering 8*(1): 1-9.

Ameri, F., and L. Patil. 2012. "Digital manufacturing market: a semantic web-based framework for agile supply chain deployment." *Journal of Intelligent Manufacturing* 23(5): 1817-1832.

Baldo, F., R. J. Rabelo, and R. V. Vallejos. 2007. “An ontology-based approach for selecting performance indicators for partners suggestion.” In *Establishing the Foundation of Collaborative Networks*, 187-196. Springer US.

Baldo, F., R.J. Rabelo, and R. V. Vallejos. 2008. “Modeling Performance Indicators' Selection Process For Vo Partners' Suggestions.” In *Innovation in manufacturing networks*, 67-76. Springer US.

Barua, A., S. Ravindran, and A. B. Whinston. 1997. “Efficient Selection of Suppliers over the Internet.” *Journal of Management Information Systems 13*(4): 117–137.

Benabderrahmane, S., M. Smail-Tabbone, O. Poch, A. Napoli, and M.-D. Devignes. 2010. “IntelliGO: a new vector-based semantic similarity measure including annotation origin.” *BMC bioinformatics 11*(1): 588.

Brewer, P., and T. Speh. 2000. “Using the balanced scorecard to measure supply chain performance.” *Journal of Business logistics 21*(1): 75–93.

Cai, M., W. Y. Zhang, G. Chen, K. Zhang, and S. T. Li. 2010. “SWMRD: a Semantic Web-based manufacturing resource discovery system for cross-enterprise collaboration.” *International Journal of Production Research 48*(12): 3445–3460.

Camarinha-Matos, L. M., and T. Cardoso. 1999. “Selection of partners for a virtual enterprise.” In *Infrastructures for Virtual Enterprises*, 259-278. Springer US.

Cea, G. A. de, A. Bañón, S. Bateman, S. Bernardos, M. Fernández, A. Gómez-Pérez, E. Nieto, A. Olalla, R. Plaza, and A. Sánchez. 1998. "ONTOGENERATION: Reusing domain and linguistic ontologies for Spanish text generation." In: *Workshop on Applications of Ontologies and Problem Solving Methods, ECAI* (Vol.98, pp.1-10).

Chandrasekaran, B., J. R. Josephson, and V. Benjamins. 1999. “What are ontologies, and why do we need them?” *Intelligent Systems and their Applications 14*(1): 20–26.

Chiang, Z. 2005. “A dynamic decision approach for long-term vendor selection based on AHP and BSC.” In *Advances in Intelligent Computing*, 257-265. Springer Berlin Heidelberg.

De Nicola, A., M. Missikoff, and R. Navigli. 2009. “A software engineering approach to ontology building” *Information systems* 34(2): 258-275.

Dickson, G. W. 1966. “An analysis of vendor selection systems and decisions.” *Journal of Purchasing 2*(1): 5–17.

Forgy, C. L. 1982. “Rete: A fast algorithm for the many pattern/many object pattern match problem.” *Artificial Intelligence 19*(1): 17-37.

Goffin, K., M. Szwejczewski, and C. New. 1997. “Managing suppliers: when fewer can mean more.” *International Journal of Physical Distribution & Logistics Management* 27(7): 422–436.

Gruber, T. R. 1995. “Toward principles for the design of ontologies used for knowledge sharing.” *International Journal of Human Computer Studies* 43(5): 907-928.

Guo, Y., and R. Ganeshan. 1995. “Are More Suppliers Better ?” *The Journal of the Operational Research Society* 46(7): 892–895.

Huang, S. H., and H. Keskar. 2007. “Comprehensive and configurable metrics for supplier selection.” *International Journal of Production Economics 105*(2): 510–523.

Jang, J., B. Jeong, B. Kulvatunyou, J. Chang, and H. Cho. 2008. “Discovering and integrating distributed manufacturing services with semantic manufacturing capability profiles.” *International Journal of Computer Integrated Manufacturing*, 21(6): 631–646.

Karpowitz, D. J., J. J. Cox, J. C. Humpherys, and S. C. Warnick. 2008. “A dynamic workflow framework for mass customization using web service and autonomous agent techniques.” *Journal of Intelligent Manufacturing* 19(5): 537–552.

Kulvatunyou, B., H. Cho, and Y. J. Son. 2005. “A semantic web service framework to support intelligent distributed manufacturing.” *International Journal of Knowledge-based and Intelligent Engineering Systems* 9(2): 107–127.

Lee, M., H. Yoon, H. Shin, and D. G. Lee. 2009. “Intelligent dynamic workflow support for a ubiquitous web service-based manufacturing environment.” *Journal of Intelligent Manufacturing* 20(3): 295–302.

Markov, Z., and D. T. Larose. 2007. *Data mining the Web: uncovering patterns in Web content, structure, and usage*. Wiley-Interscience.

McGuinness, D. L., and F. V. Harmelen. 2004. “OWL web ontology language overview.” *W3C recommendation*, 10.

Prud’Hommeaux, E., and A. Seaborne. 2008. “SPARQL query language for RDF.” *W3C recommendation*, 15.

Schreiber, G., B. Wielinga, R. De Hoog, H. Akkermans, and W. Van de Velde. 1994. “CommonKADS: A comprehensive methodology for KBS development.” *IEEE expert* 9(6): 28–37.

Shvaiko, P., and J. Euzenat. 2012. “Ontology matching: state of the art and future challenges.” *IEEE Transactions on Knowledge and Data Engineering 25*(1): 158–176.

Staab, S., R. Studer, H.-P. Schnurr, and Y. Sure. 2001. “Knowledge processes and ontologies.” *Intelligent Systems, IEEE* 16(1): 26–34.

Thanaraksakul, W., and B. Phruksaphanrat. 2009. “Supplier evaluation framework based on balanced scorecard with integrated corporate social responsibility perspective.” In: *Proceedings of the International MultiConference of Engineers and Computer Scientists*, vol. 2, 5-10.

Uschold, M., and M. Gruninger. 1996. “Ontologies: Principles, methods and applications.” *Knowledge Engineering Review* 11(2): 93–136.

Uschold, M., and M. King. 1995. *Towards a methodology for building ontologies*. Artificial Intelligence Applications Institute, University of Edinburgh.

Virolainen, V. 1998. “A survey of procurement strategy development in industrial companies.” *International Journal of Production Economics* 56-57(1): 677–688.

Wu, Z., and M. Palmer. 1994. “Verbs semantics and lexical selection.” In: *Proceedings of the 32nd annual meeting on Association for Computational Linguistics*, 133-138.

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Table 14 Criteria of each perspective in supplier's capability

MANUFACTURING PERSPECTIVE	
Manufacturing facility and capacity	Tools (Equipments), Available processes, Main products, Main industry, Maximum production capacity
R&D capability	Annual R&D expenditure, Annual investment expense for facilities, Patents, Technological support
Quality reliability	Rate of defective products, Conformance to global standards (e.g., global SQA, 5S), Quality certification
FINANCIAL PERSPECTIVE	
Financial status	Annual profit and growth, Annual revenue and growth, Current assets, Investment assets, Current liabilities
Economic perspective	Currency fluctuation, Tax and customs duties, GDP growth
CUSTOMER PERSPECTIVE	
Communication ability	Department in charge of buyer relations, e-bidding, EDI (Electronic Data Interchange), post-sales service and support
Delivery reliability	Export experience, On-time delivery rate, Average delivery time, Average order-fulfilment lead time
Repair & services	Average time for expediting delivery and transfer process, Average cost for expediting delivery and transfer process
Amount of past business	Customer portfolio, Principal customers
Customer relationships	CRM activities, Available languages, Department in charge of buyer relations
Customer satisfaction	Feedback to customer needs, Market share
Geographical location	Location, Accessibility
Performance history	Awards
INTERNAL BUSINESS PERSPECTIVE	
Environmental awareness processes	Environmental process/program, Environmental policies, Recycling processes
Safety awareness processes	Safety equipment, Safety audits, Safety training
LEARNING AND GROWTH PERSPECTIVE	
Human resources	Organizational structure, Training and education activities
Information systems	Enterprise Resource Planning (ERP) system, Manufacturing Execution System (MES), Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM), Materials Requirement Planning (MRP) system

Table 15 Explicit meanings of supplier requirements

Supplier requirements	Explicit meanings
A global company	A supplier can be interacted in English, has overseas branch offices, has transaction experiences with foreign buyers, and can deliver products abroad
A company with delivery competitiveness	A supplier is located close to airport/port, has various delivery conditions, and has achieved high delivery performance
A company equipped for active responsiveness	A supplier can be interacted with e-bidding/EDI, and can provide post-sales service and support
A company that provides assured quality	A supplier has high market share, has transaction experiences with principal customers, has received certifications by principal customers, has received quality awards
An eco-friendly company	A supplier has environmental processes/programs, has environmental policies, and has received environmental awards/certifications.
A company with a strong focus on human resources	A supplier implements training and education activities, has human resources program, and has received human resources awards.

Table 16 Similarity calculation between the buyer's supplier requirements and the supplier's non-manufacturing capability

Explicit meanings	Supplier #1	Supplier #2	Supplier who has all capabilities
Ability to be interacted in English	O	-	O
Overseas branch offices	O	-	O
Transaction experience with foreign buyers	-	O	O
Ability to deliver products abroad	O	O	O
Similarity	$\frac{(1,1,1,1)\cdot(1,1,0,1)}{4} = \frac{3}{4}$	$\frac{(1,1,1,1)\cdot(0,0,1,1)}{4} = \frac{2}{4}$	$\frac{(1,1,1,1)\cdot(1,1,1,1)}{4} = \frac{4}{4}$

Table 17 Example of supplier capability information

Property \ Suppliers	Minkyung Mould	KJ mould	Rete mould	JTBC mould	Alpha mould	GD mould
isInteractedIn	English	English	English	English	English	English
hasCustomer	Toyota	Mercedes-Benz	Honda	Peugeot	GM	Hyundai
hasBranch	China	Korea	Korea	Malaysia	China	Null
isDeliverAbroadAvaiable	O	O	O	O	O	X
hasTool	DMB-U5S T-101 WILD FIRE 4.0	MP2618 T-101 WILD FIRE 4.0	HMT-1300N	T-101 WILD FIRE 4.0	MP2618 T-101 WILD FIRE 4.0	HMT-1300N WILD FIRE 4.0

Table 18 Values of reasoned properties

Reasoned Properties \ Suppliers	Minkyung Mould	KJ mould	Rete mould	JTBC mould	Alpha mould	GD mould
hasProcess(Milling)	1.0	1.0	1.0	0	1.0	1.0
hasProcess(Drilling)	1.0	0.5	1.0	0.5	0.5	1.0
hasProcess(3DDesign)	1.0	1.0	0	1.0	1.0	1.0
hasEnglishAbility	1.0	1.0	1.0	1.0	1.0	1.0
hasForeignBuyers	1.0	1.0	1.0	1.0	1.0	0
hasOverseaBranches	1.0	0	0	1.0	1.0	0
hasDeliverAbroAbility	1.0	1.0	1.0	1.0	1.0	0

Table 19 Similarity between the buyer requirement and supplier's capability

Reasoned Properties \ Suppliers	Minkyung Mould	KJ mould	Rete mould	JTBC mould	Alpha mould	GD mould
Product requirement (Automobile bumper mould, door trim mould)	1.00	0.83	0.67	0.50	0.83	1.00
Supplier requirement (Global company)	1.00	0.75	0.75	1.00	1.00	0.25

Table 20 Computational time for reasoning and matching

# of suppliers	# of instance triples	Reasoning time(Sec)	Matching Time(Sec)
100	30,566	38.39	<0.1
200	51,239	51.82	<0.1
600	176,090	84.12	<0.1
1,000	290,142	101.12	<0.1

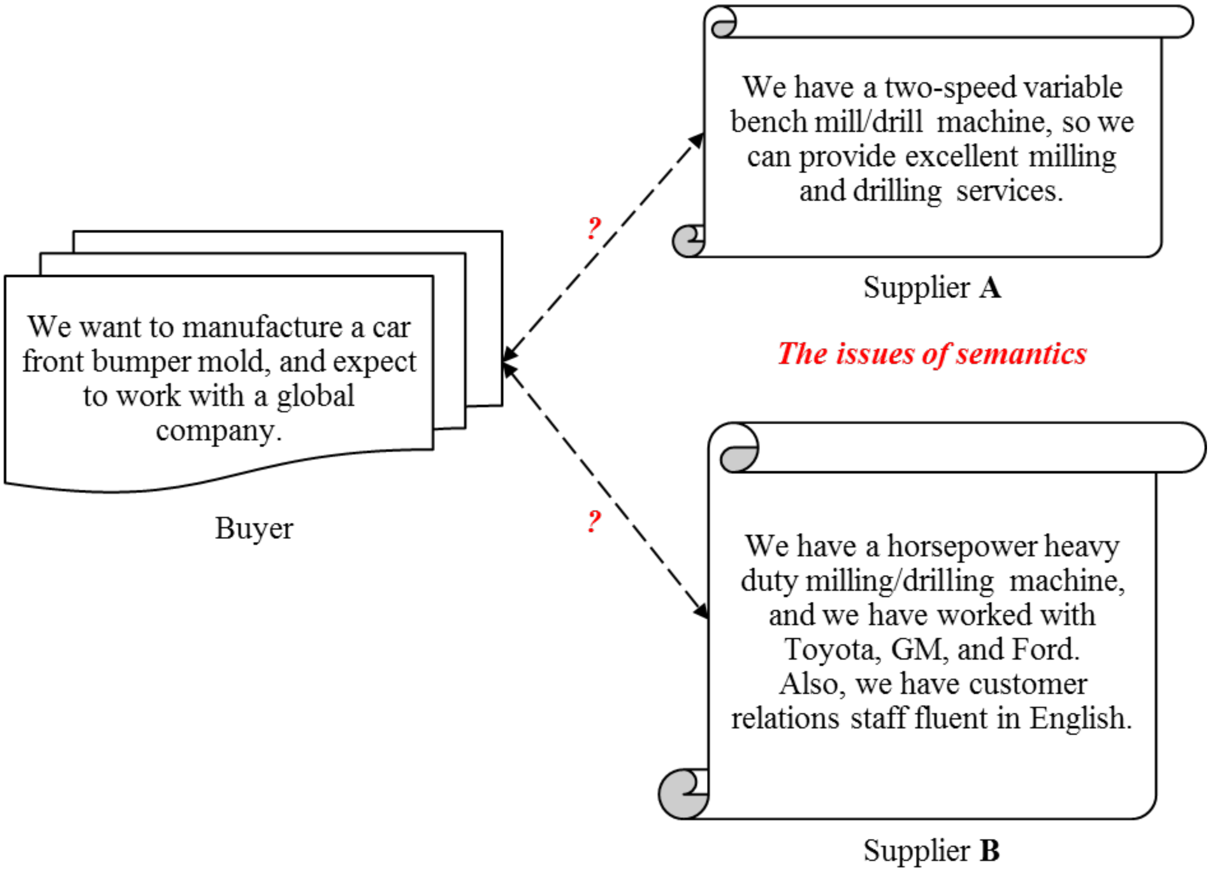

Figure 18 Supplier discovery scenario

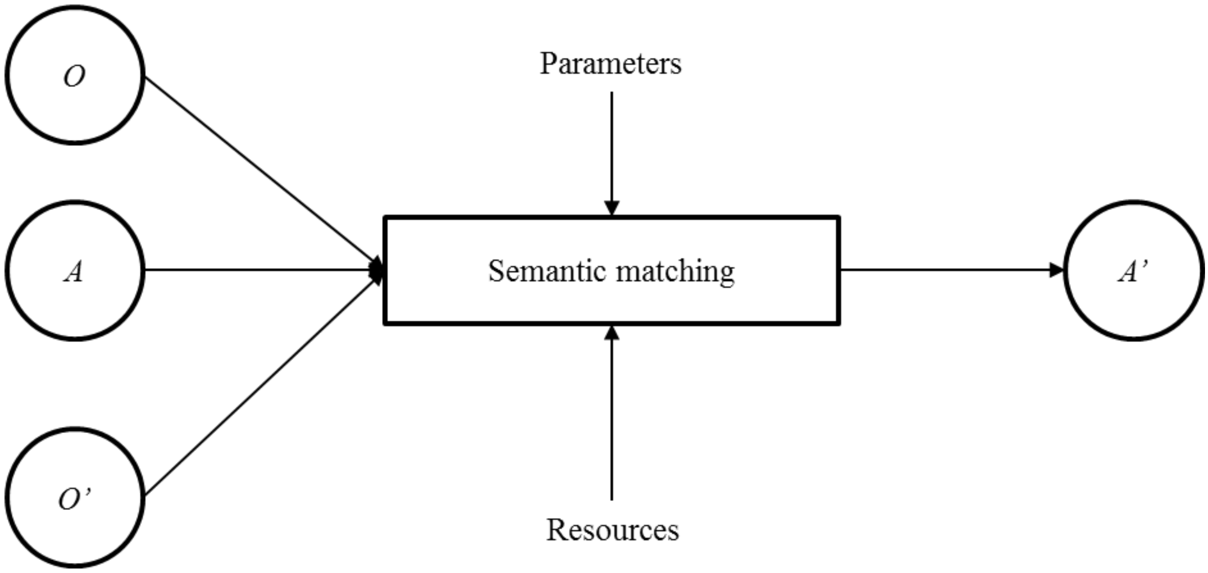

Figure 19 Concept diagram of semantic matching

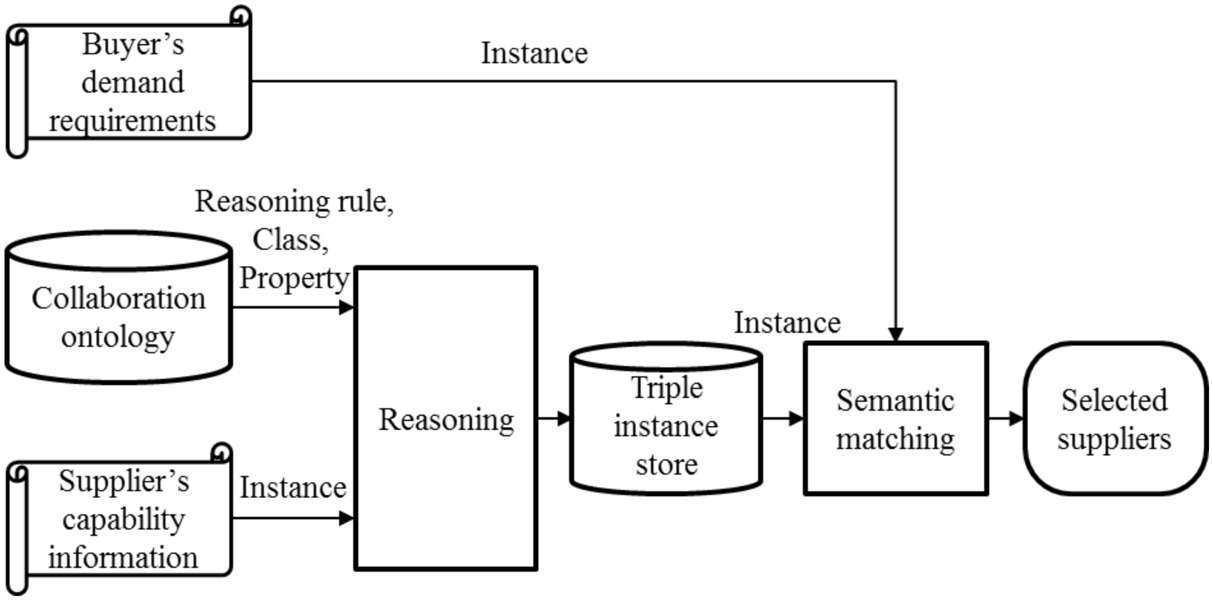

Figure 20 Semantic-web based supplier discovery system architecture

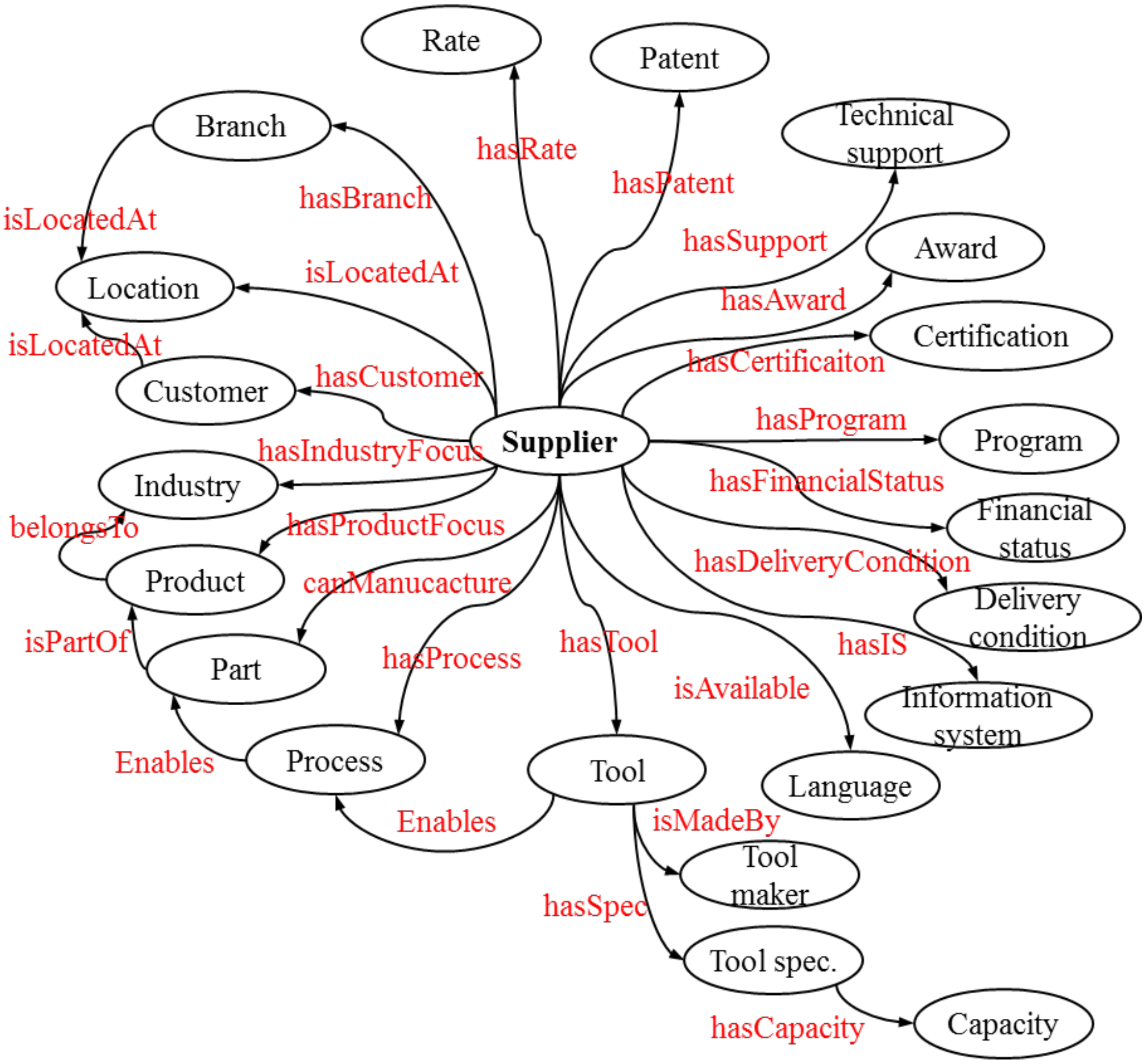

Figure 21 Concept diagram of the supplier ontology

```xml
<?xml version="1.0"?>
<owl:Class rdf:about="http://data.emss.or.kr/id/resource/ToolSpec">
   <rdfs:label xml:lang="en">Tool Spec</rdfs:label></owl:Class>
<owl:Class rdf:about="http://data.emss.or.kr/id/resource/Branch">
   <rdfs:label xml:lang="en">Branch</rdfs:label></owl:Class>
  <owl:Class rdf:about="http://data.emss.or.kr/id/resource/Language">
   <rdfs:label xml:lang="en">Language</rdfs:label></owl:Class>
  <owl:Class rdf:about="http://data.emss.or.kr/id/resource/Product">
   <rdfs:label xml:lang="en">Product</rdfs:label></owl:Class>
  <owl:Class rdf:about="http://data.emss.or.kr/id/resource/Location">
   <rdfs:label xml:lang="en">Location</rdfs:label></owl:Class>
```

Figure 22 Partial OWL code of the supplier ontology

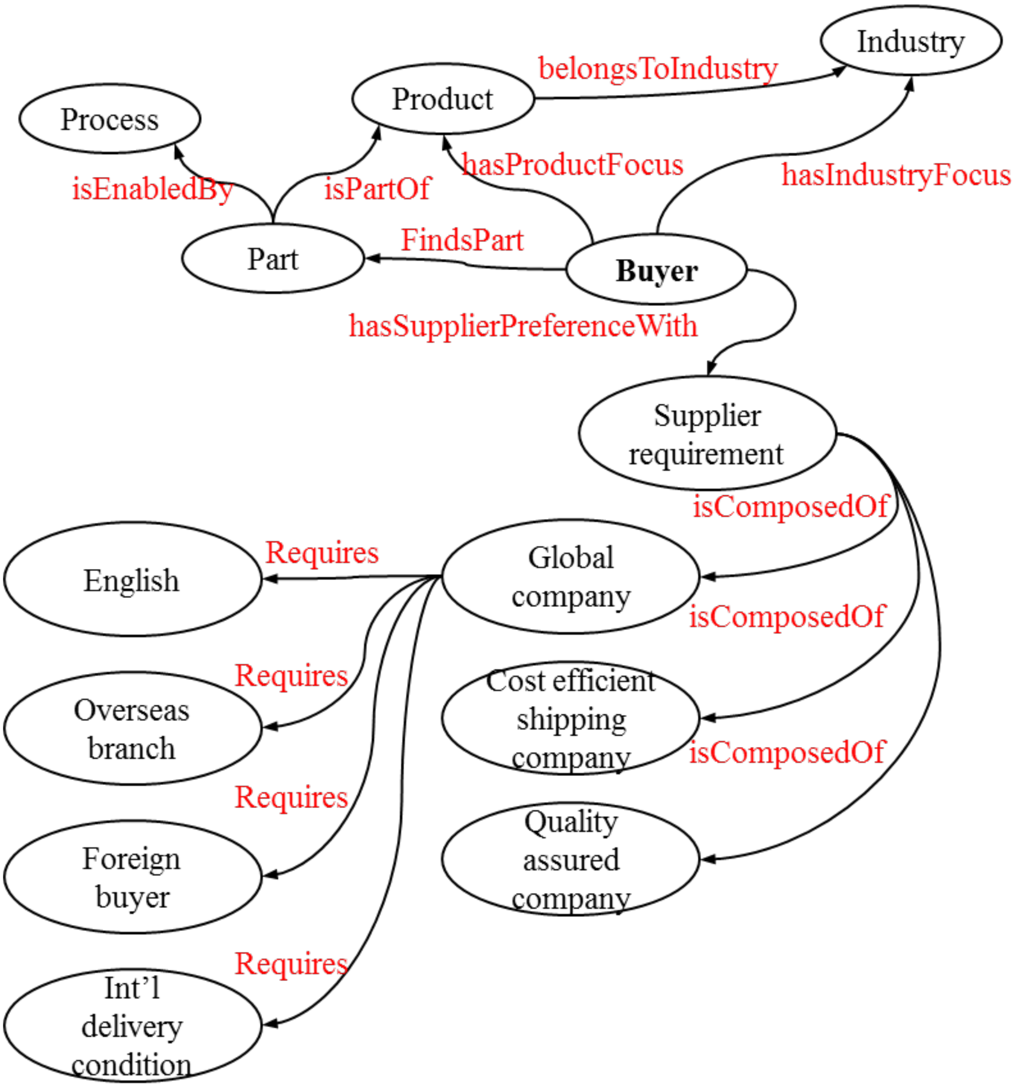

Figure 23 Concept diagram of the buyer ontology

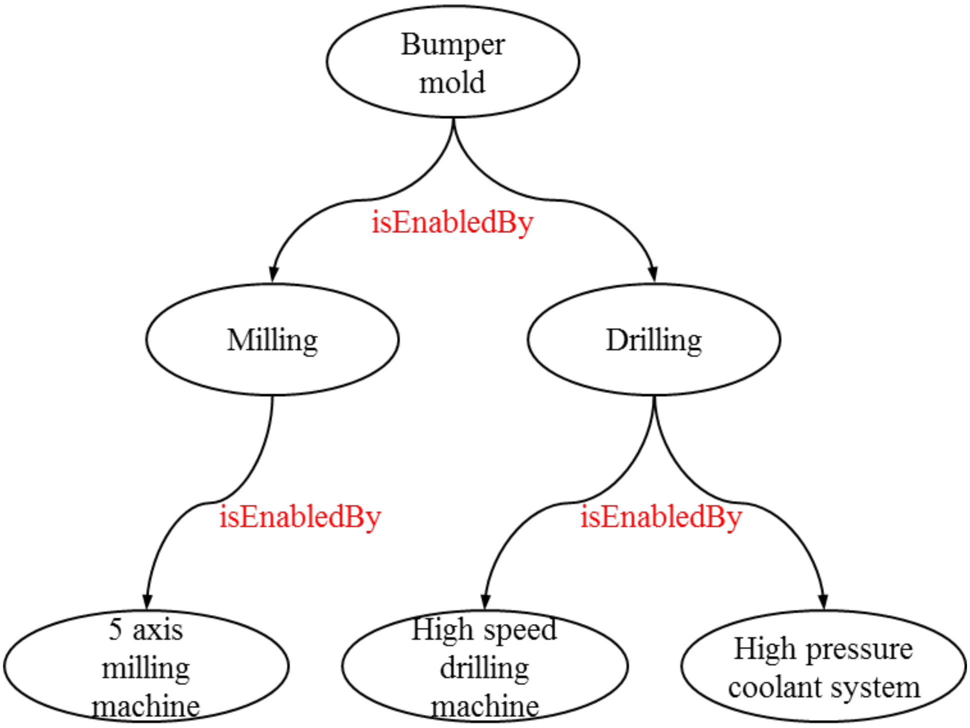

Figure 24 Concept diagram of reasoning manufacturing capability

```
[ (?a rdf:type Supplier) (?a hasTool ?5axisMillingMachine )
-> (?a hasProcess Milling )]
[ (?a rdf:type Supplier) (?a hasTool ?HighSpeedDrillingMachine ) (?a
hasTool ?HighPressureCoolantSystem ) -> (?a hasProcess Drilling )]
[ (?a rdf:type Supplier) (?a hasProcess Milling ) (?a hasProcess Drilling )
-> (?a hasPartBumperMold )]
```

Figure 25 Partial ORL code of reasoning manufacturing capability

```
( ?c isa Supplier ) ( ?c hasCustomer ?r ) (c?isLocatedAt ?p1)
( ?r isLocatedAt ?p2)(?p1 isSame ?p2) -> (?r isForeignBuyer true^^boolean)
```

Figure 26 Partial ORL code of reasoning non-manufacturing capability

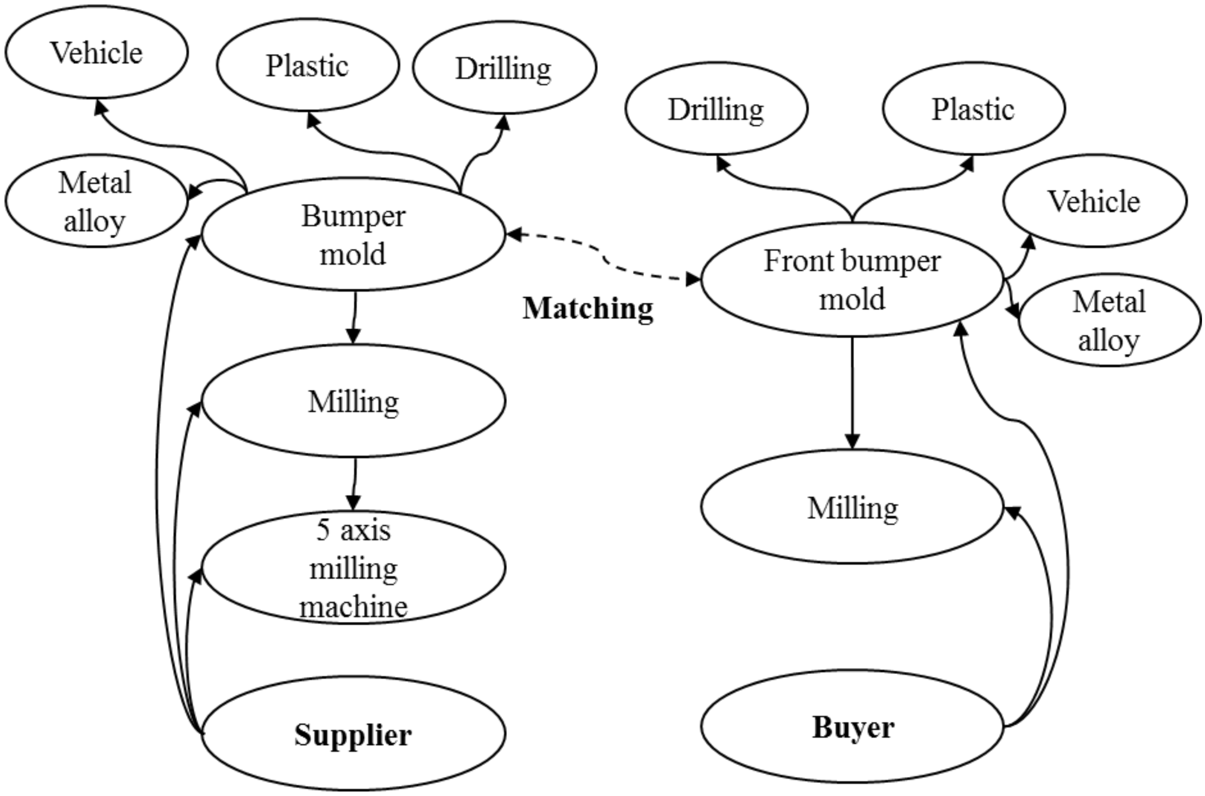

Figure 27 Concept diagram of semantic matching: the buyer’s product requirements and the supplier’s manufacturing capability

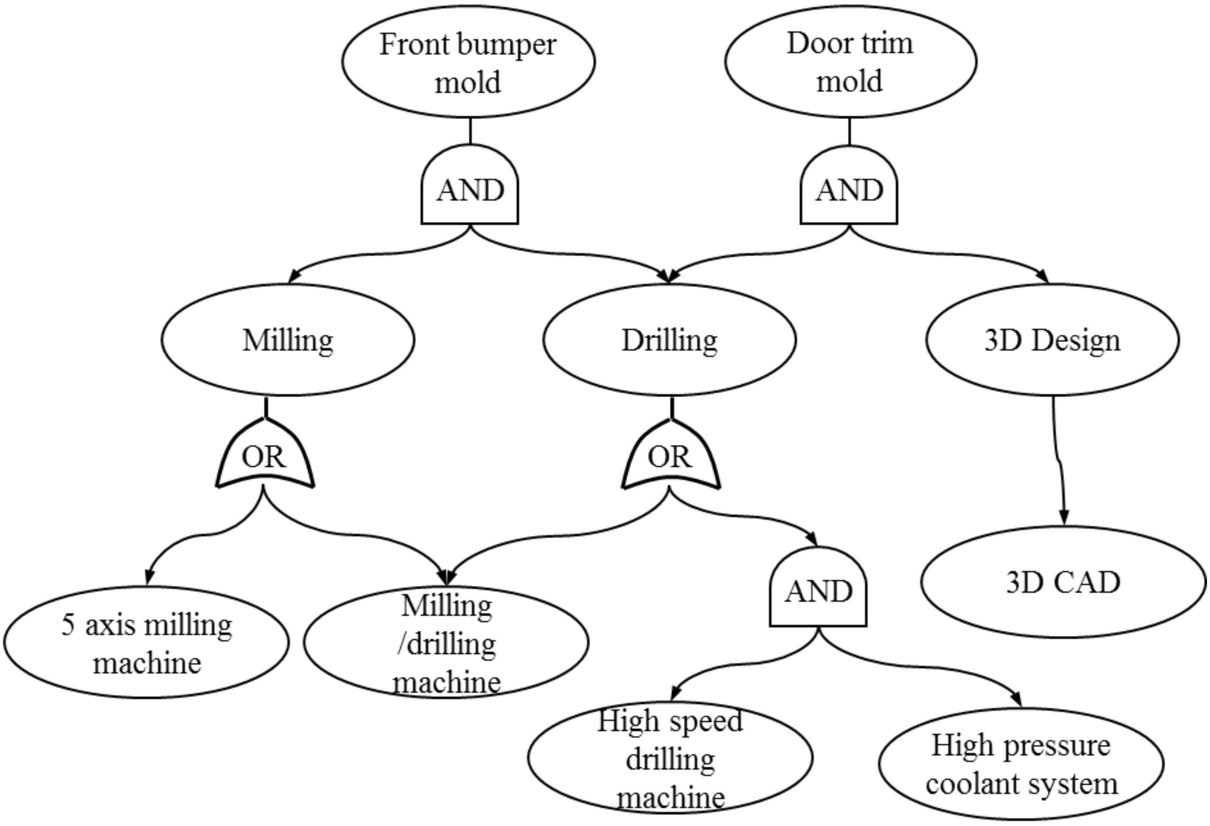

Figure 28 Concept diagram of semantic matching based on similarity calculation

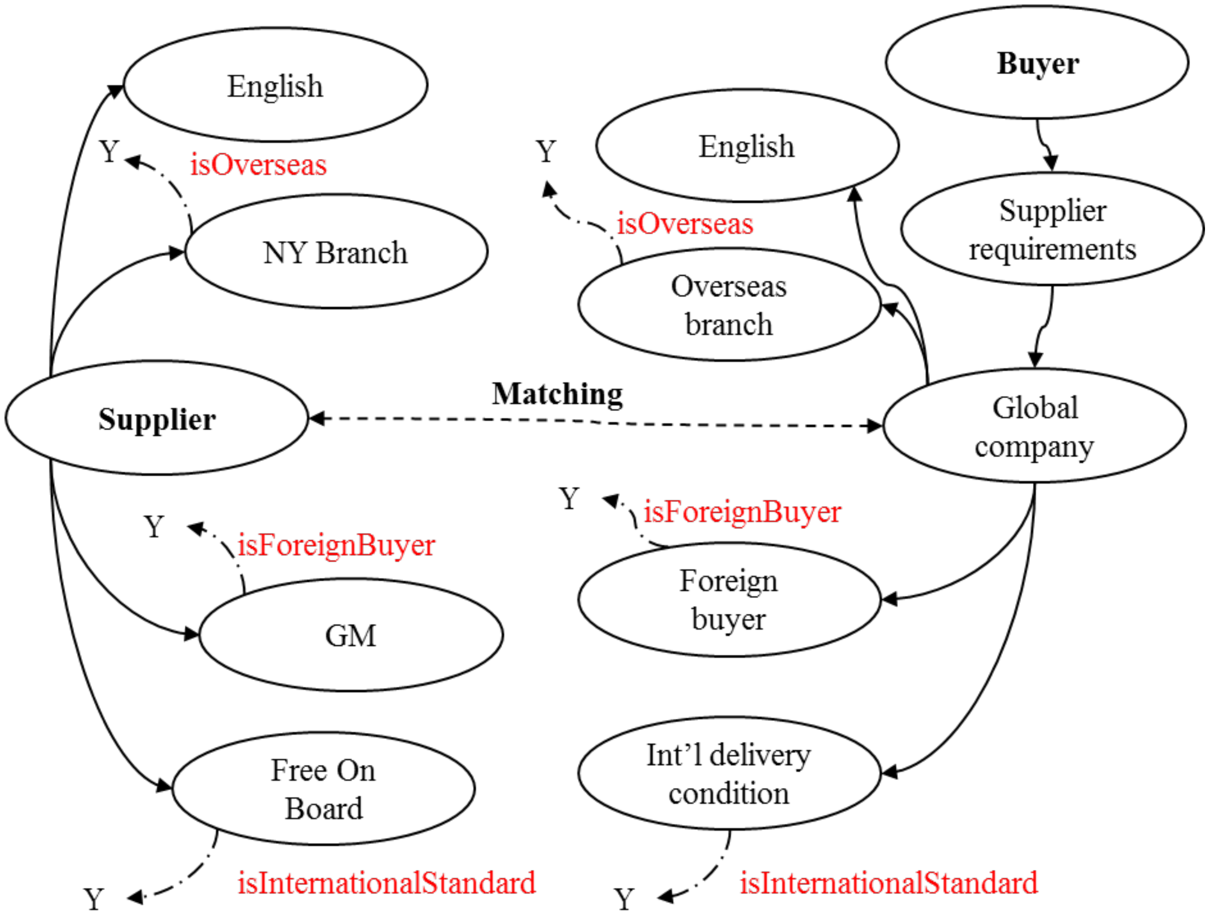

Figure 29 Concept diagram of sematic matching: the buyer's supplier requirement and the supplier's non-manufacturing capability

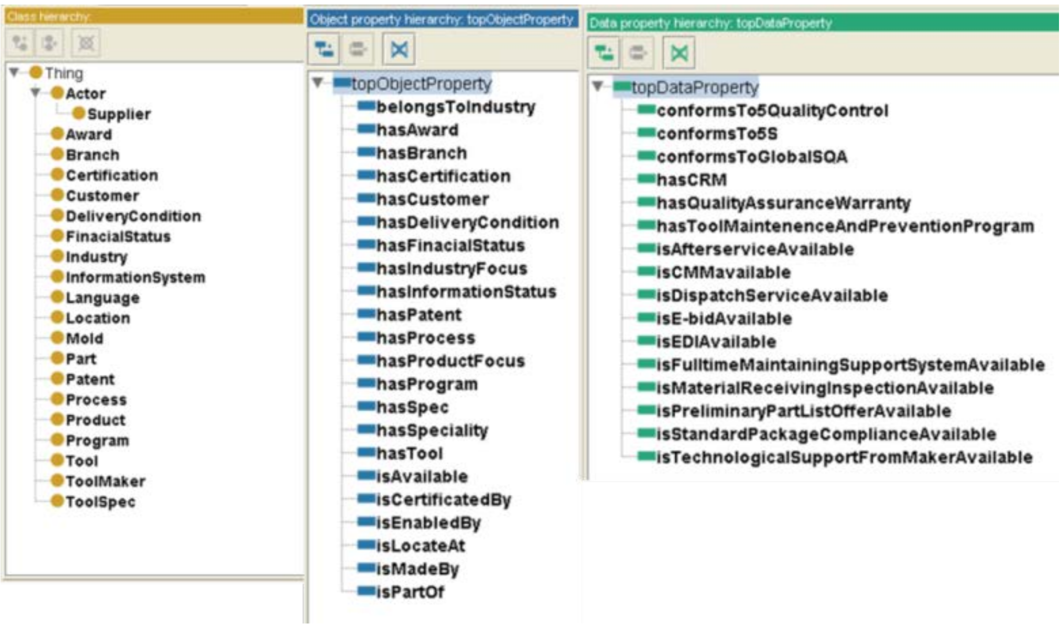

Figure 30 Implementation of the supplier ontology

```
<Tool rdf:about="http://data.emss.or.kr/id/resource/MP2618">
<rdf:type rdf:resource="http://data.emss.or.kr/id/resource/5_Axis_milling_machine"/>
<rdf:type rdf:resource="http://data.emss.or.kr/id/resource/Tool_for_general_use"/>
< isMadeBy rdf:resource="http://data.emss.or.kr/id/resource/TOSHIBA"/>
<Enables rdf:resource="http://data.emss.or.kr/id/resource/Milling"/>
<Enables rdf:resource="http://data.emss.or.kr/id/resource/Drilling"/>
<Enables rdf:resource="http://data.emss.or.kr/id/resource/Boring"/>
</ Tool>
```

Figure 31 Partial RDF code for the supplier ontology

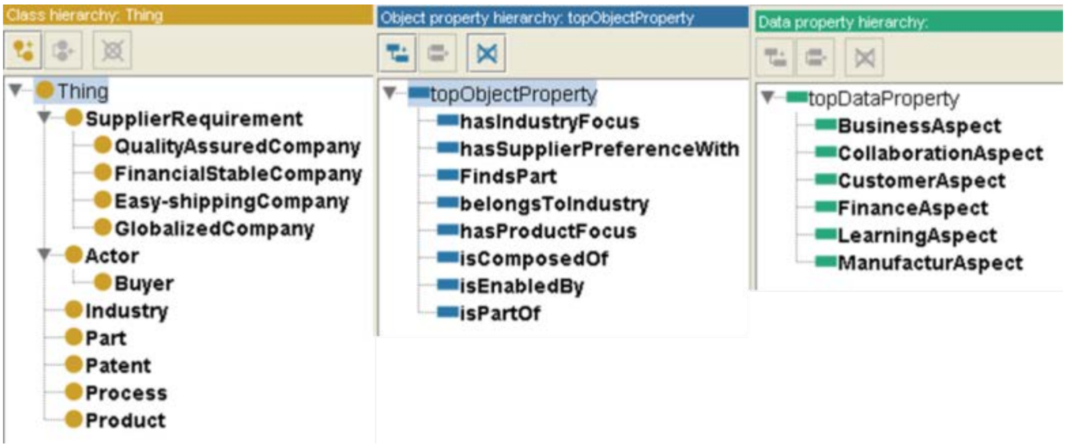

Figure 32 Implementation of the buyer ontology

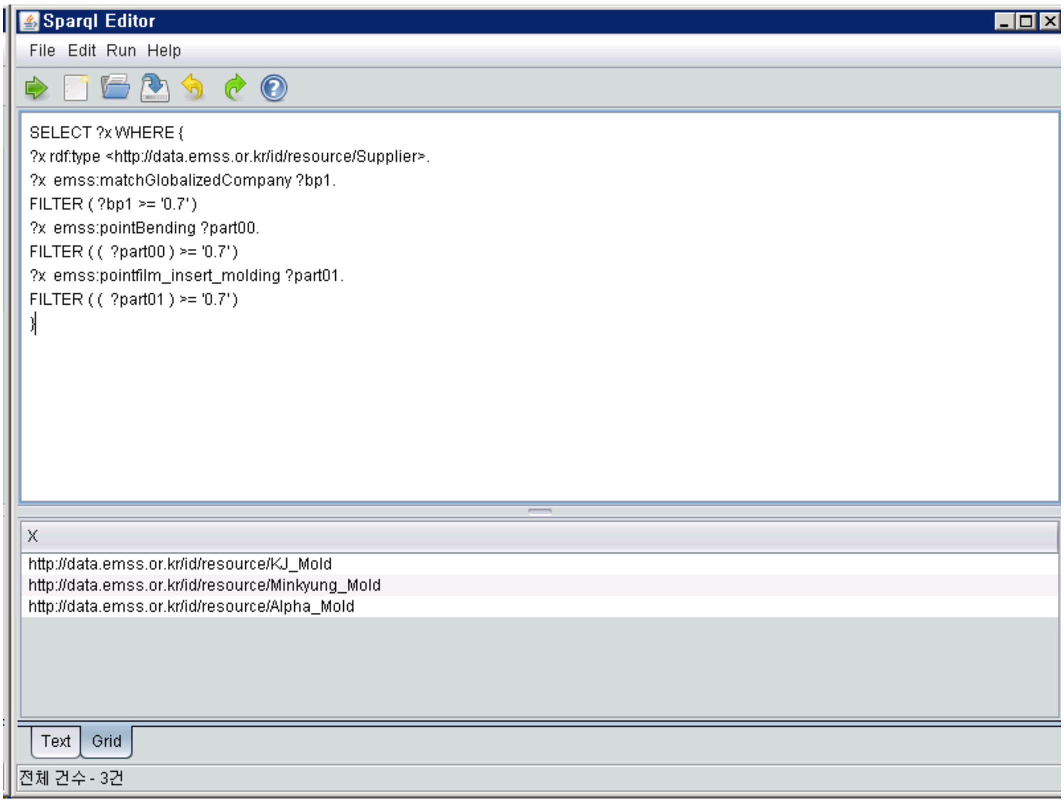

Figure 33 Selected suppliers by SPARQL

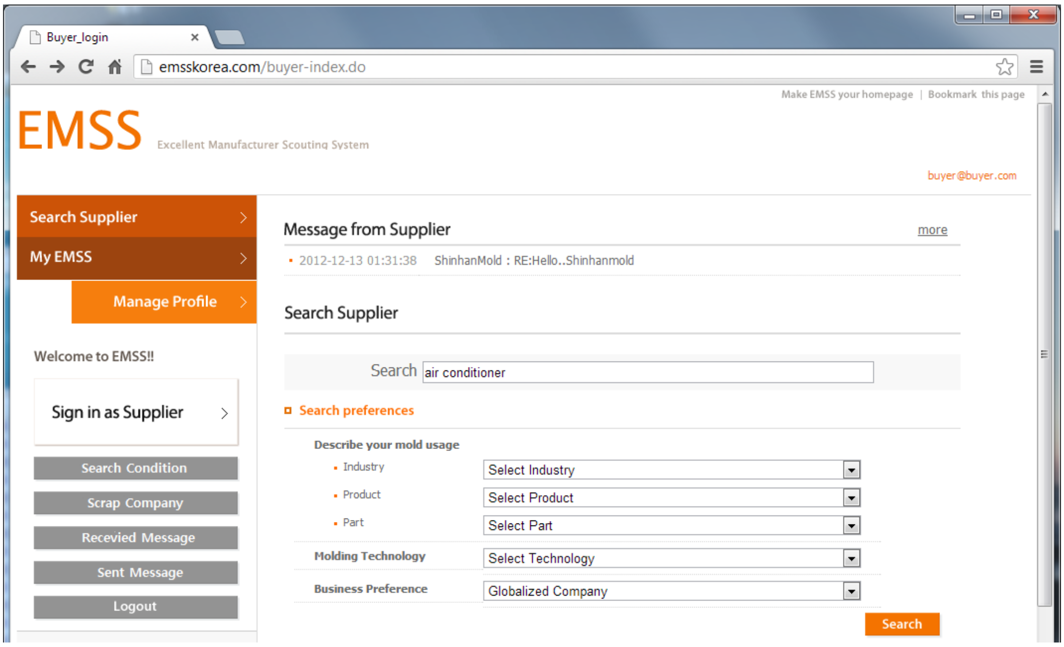

Figure 34 Webpage prototype screenshot