Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 00 (2013) 000–000

Procedia Computer Science

www.elsevier.com/locate/procedia

Conference on Systems Engineering Research (CSER'13)
Eds.: C.J.J. Paredis, C. Bishop, D. Bodner, Georgia Institute of Technology, Atlanta, GA, March 19-22, 2013.

Concept Analysis to Enrich Manufacturing Service Capability Models

Junho Shin, Boonserm Kulvatunyou, Yunsu Lee, Nenad Ivezic

100 Bureau Drive, Gaithersburg, MD 20899, USA

Abstract

When an Original Equipment Manufacturer (OEM), which makes a final product for the consumer marketplace by purchasing components from its suppliers, faces unexpected supply network failures and market events, models of suppliers' manufacturing service capabilities can provide information required for efficient recovery of these supply network. Models of manufacturing service capabilities include descriptions of both material processing and manufacturing information processing capabilities of a supplier. Presently, manufacturers and suppliers are challenged in making and streamlining sourcing decisions due to limited, imprecise, or ambiguous semantics associated with these models. This paper identifies issues with existing manufacturing service capability (MSC) models by analyzing several practical use cases found in existing web portals containing supplier capability descriptions. We identify the use of an ontology-based manufacturing service capability model can address the imprecision and ambiguity issues. This paper also proposes an approach based on concept analyses on archetypal data sets as a way to enrich semantics and address the limited semantic issues. Several model extension methods for semantic enrichments are formalized within the approach. We demonstrate the approach on an ontology-based manufacturing service model called manufacturing service description language (MSDL) using data sets including product and service categories, detailed capability descriptions of specific processes, and product-term definitions.

Keywords: Supply network, Use case analysis, Manufacturing service capability, Ontology, Concept analysis proecdures

1. Introduction

Agile manufacturing supplier networks need to respond quickly to unexpected market events and supplier failures. For instance, in the case of an emergency or radical market change, such networks recover and re-establish their normal operation levels by quickly identifying and establishing communication with alternative suppliers. In spite of the existence of many U.S. SME (Small- and Mid-sized Enterprise) manufacturers that can support manufacturing requirements in a timely manner, quick recovery or re-establishment of supplier networks by creating new relations with such SME manufacturers is still challenging. A key reason is the limitation of information systems and infrastructures that support communication of product and process requirements (i.e., manufacturing service capability information – MSC) between customers and suppliers.

Currently, there are many commercial e-sourcing portals in operation that support the establishment of new relations between SME manufacturers and customers, such as ThomasNet[a], MFG.com[b], MacRAE'S BLUE BOOK[c], Global Spec[d], and JobShop.com[e]. However, they enable limited communication of MSC information [1] due to simplistic tools and the issues of the adopted information representation approaches. Manufacturing capability representation mostly relies on the manufacturers' own text-based or semi-structured (e.g., tabular) capability specifications that carry only arbitrary and ambiguous semantics. Moreover, the mapping of manufacturers' capability specifications to the capability models that e-sourcing portals currently utilize typically causes loss of semantics and limited expressiveness when representing manufacturing capability. To overcome these problems, a rich and standardized MSC model associated with a better information representation approach is necessary.

This paper first identifies the problems of current MSC models of e-sourcing portals by analyzing several use cases. The problems are addressed in three aspects: low information fidelity, semantic ambiguity, and semantic modeling conflicts. The paper then proposes an ontology-based approach as a better way to represent MSC information. The benefits of utilizing an ontology for representing MSC information are also described. Finally, concept analysis procedures coupled with model extension methods are presented as a way to enrich the ontology-based MSC model.

2. Use case analysis

E-sourcing portals, also called e-marketplaces, are commerce sites on the public internet that allow large communities of customers and suppliers to initiate sourcing transactions with each other [2]. All currently operating e-sourcing portals for the manufacturing industries addressed in Section 1 use MSC models to enable communications between customers and suppliers. This section investigates the limitations of these models within three e-sourcing portals via use case analyses.

2.1. Use case 1: Deep-hole drilling process

The customer requirement for the first use case is to produce an "Input/output shaft for a vehicle transmission that has a hole with a depth-to-diameter ratio greater than 40:1." The most important constraint in terms of supplier capability is to check if a supplier has the capability of deep-hole drilling or gun drilling with the depth-to-diameter ratio greater than 40. Other constraints, such as material requirements, are ignored for simplicity.

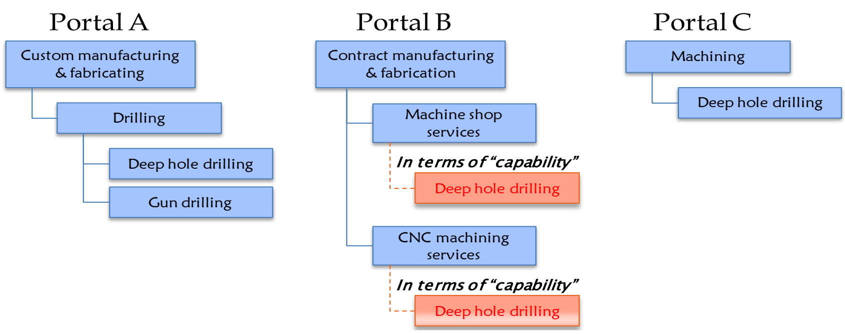

Fig. 1. Product/service categories at three portals associated with the 'Input/output shaft' requirements

Our investigation of the three e-sourcing portals' MSC models indicates that the MSC data captured formally in e-sourcing portals were very limited despite the fact that manufacturing capabilities were described in great detail on

---

[a] http://www.thomasnet.com
[b] http://www.mfg.com
[c] http://www. macraesbluebook.com
[d] http://www.globalspec.com
[e] http://www.jobshop.com

the manufacturers' own websites. Moreover, e-sourcing portals mainly relied on product/service category among the capability data for communication. For such reasons, the main scope of this use case is to analyze a portion of the product/service category that is related to the given product requirement.

Fig. 1 shows portions of product/service categories of three e-sourcing portals that can be used to identify suppliers that meet the given requirement. The solid line in the figure represents the regular hierarchy of categories, while the dotted line represents detailed feature descriptions. The feature is distinguished from the parent/child relationship embedded in the hierarchy as it represents a characteristic of the associated category. For example, in the product/service category of portal B, *Machine shop services* is further classified using features such as *capability*, *number of axes*, and *length capacity*. *Deep-hole drilling* is one of enumerated alternatives for the *capability* feature. Only portal B uses features in addition to product/service categories for classification, while the other two capability models rely solely on product/service categories. Such heavy reliance on product/service categories results in issues in communication between users. The issues are summarized according to the following three aspects: low information fidelity, semantic ambiguity, and semantic modeling conflicts.

- Low information fidelity issues: The current models of three e-sourcing portals do not support communication and supply chain decision-making with depth-to-diameter ratio constraint due to the lack of depth-to-diameter ratio data in their capability specifications. The communication can only be based on a process constraint, i.e., deep-hole drilling or gun drilling; and supply chain decisions made based on such communication may result in the inclusion of many unqualified suppliers. Another example of the low information fidelity issue is the missing definition of *Gun drilling* in portal B and C, which makes it impossible to ensure communication of the gun drilling requirement.
- Semantic ambiguity issues: The hierarchy between *Deep-hole drilling* and *Drilling* indicates no formal relation, even though they seem related in the product/service category of Portal A. As a result, a communication to be submitted to suppliers with some drilling capability will not be submitted to suppliers that are registered only to the *Deep-hole drilling* category. The second example of the semantic ambiguity issue is the sibling relation between *Deep-hole drilling* and *Gun drilling* in the product/service category of portal A. First, *Gun drilling* is a specialization of *Deep-hole drilling* based on established manufacturing knowledge [3]. Moreover, the change of current hierarchy to make *Gun drilling* be a sub-category of *Deep-hole drilling* is not sufficient to fix the issue because of the reason mentioned in the first example. Without a formal relation between the two terms, the communication using the constraint *Gun drilling* and the constraint *Deep-hole drilling* will be mutually exclusive if manufacturers do not include both terms in its capability specification. As the last example, in the product/service category of portal B, it is hard for suppliers/customers to make a distinction of *Deep-hole drilling* capability between one under *Machine shop services* and the other under *CNC machining services*. Despite their similarity, these two terms have no formal relation. Consequently, users face similar ambiguity issues as described in the previous two examples.
- Semantic modeling conflicts issues: *Deep-hole drilling* capability in the category of portal A is defined as a capability to manufacture a hole of which depth-to-diameter ratio is greater than 3. There may be no problem in terms of data accessibility if all suppliers and customers agree upon and share the definition. However, such definition is not standardized and another portal may define its *Deep-hole drilling* as a drilling process where depth-to-diameter ratio is greater than 5. Communication errors can occur in the situations where labels of a term in two systems are the same but carry different semantics.

2.2. Use case 2: EDM (Electrical Discharge Machining) process for injection molds

The customer requirement designed for the second use case is to produce an "Injection mold that has complex geometry and sharp inside corners with a constraint, i.e., tolerance should be equal to or less than 0.025 cm." The requirement is interpreted by human experts into query specifications as follows.

> *The product requires Sinker EDM process rather than traditional CNC machining to effectively deal with complex geometry and sharp inside corners. Tolerance should be equal to or less than 0.025 cm. Service provider's focused product is the injection mold.*

Based on the requirements, terms relevant to *complex geometry*, *Sinker EDM*, *injection mold*, and *mold making* have been identified in product/service categories from the three e-sourcing portals. In addition, manufacturing knowledge was utilized to further identify synonyms such as *Ram EDM* or related industries such as T*ool, die, and mold making*. Fig. 2 shows all the concepts identified in product/service categories from the three e-sourcing portals.

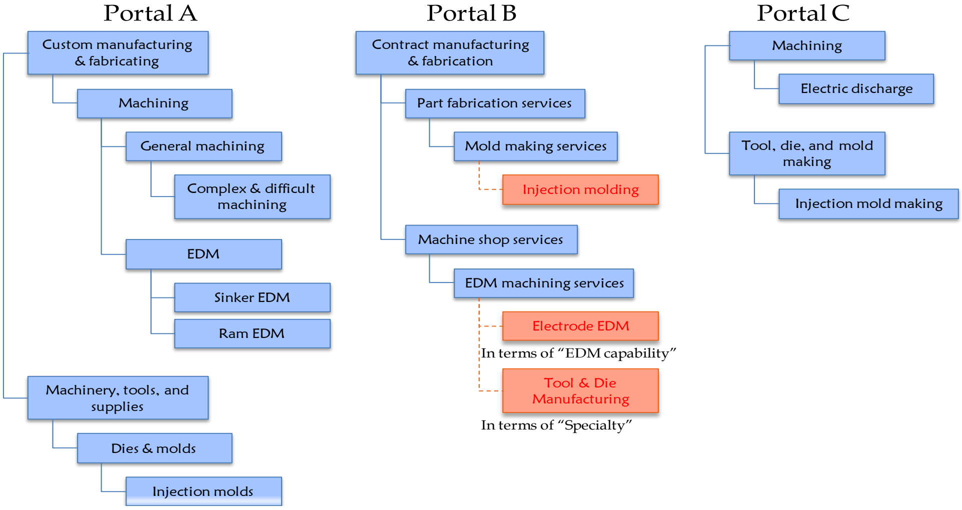

Fig. 2. Product/service categories at three portals associated with *injection mold* requirements

As in the previous use case analysis, issues associated with the MSC models have been identified according to the following three aspects.

- Low information fidelity issues: None of the models allow for formal communication and decision-making related to the tolerance constraint. Tolerance data specified on manufacturers' web sites are missing in e-sourcing portals due to the portals' limited MSC models. Another example is the lack of the term *Sinker EDM* in portals B and C, which makes it impossible to communicate the sinker EDM requirement between customers and suppliers in the portals.
- Semantic ambiguity issues: According to established manufacturing knowledge, *Ram EDM* and *Sinker EDM* refer to the same concept. Therefore, the sinker EDM requirement can be communicated using the term *Ram EDM*. However, *Sinker EDM* and *Ram EDM* in the product/service category of Portal A are represented as siblings of each other and hence the capabilities are mutually exclusive if a manufacturer does not include both terms in its capability specification. The two terms should be regarded as conceptually identical to fix this issue. As another example, *Complex & difficult machining* is ambiguous in its meaning. Some technical descriptions in terms of number of axes, product shape, or tolerance are required to increase the precision of its underlying meaning.
- Semantic modeling conflicts issues: EDM capability is expressed in different terms in product/service categories of three portals such as *EDM* in Portal A, *EDM machining services* in Portal B, and *Electric discharge* in Portal C. These differences cause semantic modelling conflict issues across the portals. Similarly, there are several different terms to represent the injection mold making capability across these models including *Injection molds* in Portal A, *Injection molding* (feature of *Mold making services*) in Portal B, and *Injection mold making* in Portal C. One thing to be noted here is that the meaning of *molding* is totally different from *mold making*. The former represents shaping pliable raw material using a rigid frame, while the latter represents cutting raw material to construct the frame used for molding. However, the contextual semantics of *injection molding* refers to those of *injection mold making* as it inherits from *Mold making services* in Portal C.

3. Ontologies for manufacturing service capability modeling

In this section, we discuss our investigation into the ontological approach to formally represent an MSC model that can resolve the semantic issues discussed in Section 2. An ontology is a "formal, explicit specification of a shared conceptualization" [4]. More technically, an ontology portrays a shared vocabulary and taxonomy, which models a domain with the definition of concepts, their properties, and relations [5]. Therefore, an ontology is a useful tool for sharing conceptual definitions and consequently reducing ambiguity and misunderstanding among users of similar domains. Moreover, while existing MSC models are mostly taxonomy-oriented, the ontology can provide various ways to represent semantics, not only using taxonomy but also using conceptual definitions including relations and properties. The semantics contained in the ontology can also be enriched further by expressing knowledge such as rules, constraints, and axioms. The asserted knowledge not only provides additional semantics but may be utilized by semantic reasoners to infer additional logical facts. Finally, the utilization of OWL (Web Ontology Language) enables the model to be neutral and transferrable to heterogeneous software systems including e-sourcing portals [6].

Several ontological approaches for manufacturing domain representation have been investigated for MSC modeling. Kulvatunyou et al. [7] have a proposed semantic, web-service framework where the capabilities of the manufacturer are defined using DAML (DARPA Agent Markup Language) [8] based on a proposed manufacturing ontology. The ontology captures manufacturers' capability well but is limited due to its heavy reliance on taxonomy of manufacturing processes. Chungoora et al. [9] have presented the ontological approach to formally represent and share manufacturing knowledge in the manufacturing domain, i.e., injection molding. The approach is useful for decision support in engineering design, but it is not optimized for describing capabilities of manufacturers. Lin and Harding [10] have proposed a manufacturing system engineering ontology model to facilitate communication and information exchange among multi-disciplinary engineering design teams. Their focus is rather on sharing knowledge without adhering to standardized terminology, which requires mediation of meta-models across all engineering design teams through semantic matching. In addition, the manufacturing system engineering ontology places more emphasis on representing resources of enterprise and their engineering data, not the capabilities of the enterprise. MASON (MAnufacturing's Semantics ONtology) has been proposed by Lemaignan et al. [11] as a common semantic net in the manufacturing domain. Their draft ontology represented in OWL formally conceptualizes the manufacturing domain using three main concepts: entity, resource, and operation. Although the ontology has a set of initial focus application areas, i.e., cost estimation and multi-agent systems, the ontology still stays abstract and needs to be extended further to describe manufacturing capabilities. Ameri and Dutta [12, 13] have proposed Manufacturing Service Description Language (MSDL) as an ontology for representation of manufacturing services. MSDL provides primitive building blocks to describe manufacturing services provided by manufacturers. We selected and tested MSDL as an ontology-based MSC model in the following analysis since the concepts in MSDL are well suited to represent the capabilities of manufacturing services.

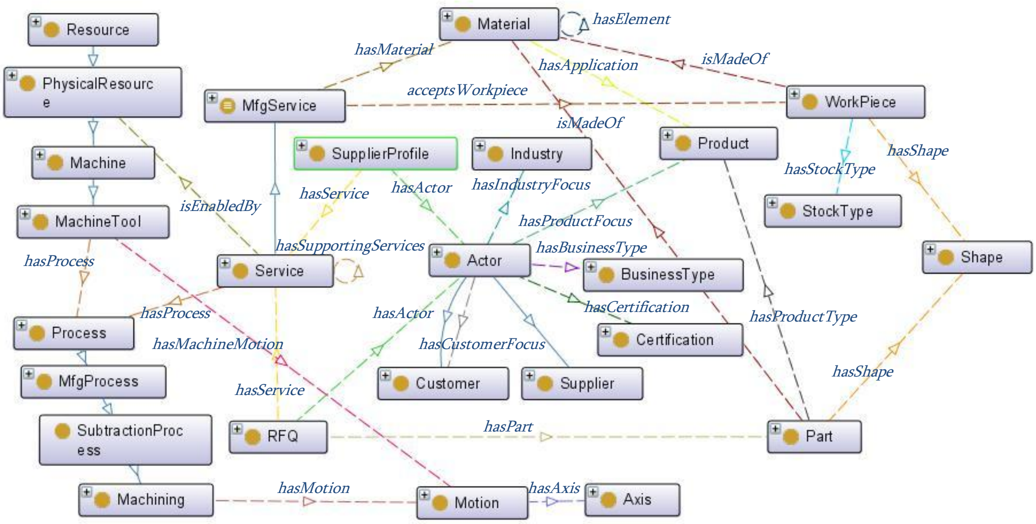

Fig. 3. Core concepts in MSDL

Fig. 3 illustrates MSDL, where each node represents a concept and each arc between nodes represents a relation.

The solid arcs represent inheritance relations between concepts while dotted arcs represent any other semantic relations. Two central concepts to MSDL are *Supplier profile*, which represents a supplier's service description, and *RFQ*, which represents a customer's product requirements. On one hand, both concepts are connected to *Actor*, the abstraction of *Supplier* and *Customer*, to describe a company's basic profiles. For example, *Actor* has relations with *Certification*, *Business Type*, *Industry*, and *Product* in addition to properties such as *Name*, *Address*, and *URL*, that are not exposed in Fig. 3. On the other hand, they are connected to *Service* to describe the services a supplier provides or the services a customer requires. *Service* is further delineated by linking to *Process*, *Physical Resource*, *Material*, and more.

Our investigation into the MSDL as an MSC model concluded that it still lacks richness to resolve all the semantic issues discussed earlier. Methods for enriching the MSDL or more generally an ontology-based MSC model need to be devised. To that end, we describe various ways to enrich an ontology called extension methods and propose practical concept analysis procedures to guide the applications of these methods. The conceptual analyses use several archetypal data sets of e-sourcing portals to arrive at model extensions. The next section provides the details of such extension methods and concept analysis procedures.

4. Concept analysis for MSC model extension

4.1. Extension Methods for ontology-based MSC model

Ontology improvements can be classified into two categories enrichment and refinement. Enrichment is the extension of ontology elements, while refinement includes the resolution of semantic conflicts and the adjustment of ontology design such as structure change and granularity modification [14, 15, 16]. In this paper, we only focus on the enrichment.

The following extension methods for enrichment have been identified.

- e_1: Addition of specialized concepts: New specialized concepts may be added to cover a missing part of an existing taxonomic concept hierarchy or to further conceptualize the domain by taxonomy. For instance, the former corresponds to the situation where the missing part of the current NAICS (North American Industry Classification System)-based industry classification is supplemented by the concepts from other industry classifications. As an example of the latter, a work holder that has no specialized concept in the current MSDL can be expressed by adding the following specialized concepts: fixture, general purpose work holder (e.g., check, clamp, vise), and jig.
- e_2: Addition of root concepts: A new concept that is not subsumed by any existing concepts in an MSC model should be added as a new root concept or a sub-concept coupled with its root concept. For instance, *high volume* and *low volume* that are not conceptualized in the current MSDL should to be added along with their root concept *production volume*. The addition of the new root concept in general helps to group related concepts together and also results in a richer semantics for classification.
- e_3: Addition of properties: The properties can be defined to further describe each concept. For instance, the *Supplier* concept may be further described by the number of employees. For that purpose, a property *hasEmployeeCount* that is directly associated with a number can be added; or depending on the modeling approach and objective, a relation *hasEmployeeQuantity* (also see e_5 below) and a corresponding new concept *EmployeeQuantity* may be added (the *EmployeeQuantity* in turn has properties including the value and the unit).
- e_4: Conceptual definition: By defining a concept using formal logics, one provides more precise semantics and allows logic-based reasoning. For example, the addition of material characteristic definition of *Inconel* can result in a logical inference that it is a kind of *Super alloy* even though there is no direct subsumption relation asserted between *Inconel* and *Super alloy*. This results in a refined taxonomy.
- e_5: Extension of relations between concepts: Extension of relations introduces potentially complex relations between concepts required to represent a real world situation and facilitates descriptions of factual knowledge through natural language-like expressions. For instance, we can build the following expression, "Supplier A – *FocusesOnProductSize* – Small & Medium" by creating a relation *FocusesOnProductSize* between two concepts, *Supplier* and *Product size/dimension*. Following are the extensions of MSDL relations for developing the MSC ontology: *BelongsToIndustry* (Product – Industry), *CanBeManufacturedByControlAxis* (Product shape – Axis), *CanHandleMaterial* (CuttingTool – Material), *FocusesOnProductShape* (Actor – Product shape), *IsMadeOf*

(CuttingTool – Material), *IsSpecializedInIndustry* (Service – Industry), *IsSpecializedInProcess* (Actor – Process), *IsSupportedByControlAxis* **(**Service – Axis), *ProducesProduct* (Service – Product, Actor – Product), *TypicallyProducesProductShape* (Service – Product shape).

4.2. A concept analysis procedure

We propose concept analyses procedures that analyze different types of data sets and guide the applications of the extension methods to enrich an ontology-based MSC model. We focused on data sets popular in e-sourcing portals: Product/service category and detailed capability descriptions for product/process, and term definitions.

- Analysis of product/service category: An MSC model can be extended by examining the product/service categories of e-sourcing portals. The addition of a specialized concept method (e_1) may be used for the model enrichment as all product/service categories are represented as taxonomies (i.e., concept specializations). For MSDL, each term in product/service categories can be mapped to the existing or new concept under the service, process, or product root concepts. However, terms in some product/service categories are mostly compound words, which prohibit the simple 1:1 mapping. For instance, *Ultra precision 5-axis wire EDM services*, a category term in one of the e-sourcing portals, is composed of several meaningful pieces, each of which can be mapped to a concept in MSDL. Consequently, a 1:n mapping or decomposition of a term is necessary for e_1 extension. The concept analysis procedure for product/service categories is designed by considering decomposition of such compound terms. The procedure adds each decomposed term to the MSC model if there is no concept in the model that corresponds to the term. Moreover, the original concept, i.e., the compound term, also can be added to the MSC model as a new concept after its definition is created from decomposed terms. This process can enrich the MSC model and at the same time allow the use of compound terms that are commonly used in e-sourcing portals. According to the proposed procedure, we performed concept analysis for product/service categories of three e-sourcing portals that are associated with machining processes. Six new root concepts – EquipmentControlType, Precision/Tolerance, Production Speed, Production Type, Production Volume, and Size/Dimension – have been added as a consequence of the concept analysis.

```
Select a term T from product/service categories
If the selected term T is a combined word, decompose T into several meaningful chucks p1 .. pn
If not, p1 = T
For each piece pi of term T, identify a root concept in MSC model to which pi belong
    If there is a matching root concept in MSC model
        Identify a matching concept in MSC model under the root concept
        If there is a matching concept, go to the next pi.
        If there is no matching concept, add pi in appropriate position [e1]
        (Other related concepts around pi may need to be added)
    If there is no matching root concept
        Add a new root concept and create a whole taxonomy under the root concept at least to
        the level pi can be included [e2 + e1]
        For the new root concept, add relations with other existing concepts [e5]
    Go to the next pi
Create a conceptual definition of T by combining all p1 .. pn [e4]
```

- Analysis of detailed capability descriptions for product/process: There exist many structured or semi-structured data sets within e-sourcing portals to describe the capabilities in terms of a process or a product. Structured data sets are the ones that have been designed for communication in e-sourcing portals. Some semi-structured data sets that have not been formalized can be regarded as capability descriptions that are commonly used, but not fully agreed upon. The reference to and examination of such data

```
Select a characteristic Ti and its contents C from detailed capability descriptions
Determine if Ti can be added as a property of other concepts
    If possible, add property Ti to the corresponding concept [e3]
    If not,
        If there is a matching root concept in MSC model
            Identify a matching root concept in MSC model
            Add C under the root concept [e1]
        If there is no matching root concept
            Add a new root concept and specialized concepts under the root concept at least to
            the level all the elements of C can be included [e2 + e1]
            For the new root concept, add relations with other existing concepts [e5]
```

sets can be an important direction for an enrichment of an MSC model. An example data set derived from a portal that describes the capabilities of valve product is illustrated in Fig. 4. A row in the data set typically is a capability characteristic of a process or product and its possible values or enumerations. The information gathered from each row can be used to add a new concept or to add a new property or relation according to its data type and application purpose. For example, most of the characteristics in Fig. 4. can be mapped to existing root concepts or be created as new root concepts since their contents, enumerations of the characteristics, are meaningful enough to become stand-alone concepts. Other concepts that have no enumerations or values in general can be designed as a specialized concept of an existing root concept or a property of a concept in the MSC model. The following concept analysis procedure has been defined for analyzing such characteristics of data sets. A total of 11 new root concepts and 123 specialized concepts have been added to MSDL as a consequence of concept analysis of example data sets that describe the capabilities of the CNC machining process and valve product. This addition enabled communication and decision-making related to many constraints such as size/dimension, valve pressure, and valve media (which flow is controlled by valve).

Semi-structured valve descriptions in Portal A

- Max Differential Pressure: 500 PSI
- Pipe Size Inches: ½” to 3”
- Fluid Temperatures: up to 550°F
- Materials: Bronze, 304SS, 316SS, Monel, Alloy 20 and Hastelloy
- End connections: NPT, Flange, Union, Socket Weld, Butt Weld, Pipe Nipples
- Options: Position Switches, Manual Override, Remote Trip with Manual or Automatic Reset and many others
- Capable of handling Dirty / Viscous and Extreamly Corrosive Fluids

Structured valve descriptions in Portal B

- Type: angle, ball, balancing, bellows, …
- Primary material of construction: acetal, aluminum, bronze, …
- Size: less than 0.25”, 0.25”-0.5”, 0.5”-2”, 2”-4”, 4”-
- Number of ports/ways: ≤4, 4-9, 9-13, 13-18, 18-
- Flow (Cv): less than 1, 1-11, 11-67, 67-779, 779-
- Pressure ratings (psi): ≤73, 73-317, 317-1156, …
- Media temperature (F): ≤3, 3-150, 150-297, 297-470, 470-
- Type of actuation: manual/hand, mechanical, electric, pneumatic, …
- Media: Air, Water, Gas, Specialty/Corrosive gases, …

Fig. 4. Example data set describing the capability of valve product

- Analysis of term definition: The documents that have definitions of terms are useful to extend an MSC model, especially using the extension method e_5, conceptual definition. The analyzed documents should not be limited to ones internal to e-sourcing portals but be extended to external references on the web, in books, and standards. The definition of terms in general can be done in various ways such as by a specialization of high-level concept, by the description of properties, or by constraining some properties. Among them, it is essential to discover identifying properties for the definition of terms. The quality of definition is based on how well all the related concepts are classified by the properties and constraints and how well the properties can represent manufacturing capabilities. For example, the definition of a material by its composing atomic elements is useful for classification. On the other hand, identifying physical characteristics such as hardness, strength, thermal conductivity, ductility, and corrosion resistance is useful to describe manufacturing capabilities. The following concept analysis procedure has been defined for analyzing term definitions.

Select a term T of which term definition is ready
Add T as a root concept if it does not exist
Define ‘identifying properties’ $P = P_1, .., P_n$ for T
  For each P_i, determine if P_i can be added as a property of T
  If possible, add property P_i to the corresponding concept T [e_3]
  If not, identify a root concept in MSC model that corresponds to P_i
    If there is a corresponding root concept in MSC model
      Add relation between the root concept and T [e_5]
      Define T by the root concept [e_4]
    If there is no corresponding root concept
      Add a new root concept corresponding to P_i and create its taxonomy necessary to describe T [$e_2 + e_1$]
      For the new root concept, add relation between the concept and T [e_5]

We have performed a concept analysis by referring to a number of web documents and standards such as documents in Wikipedia.org and AISI/SAE that have definitions of stainless steel grades. Identifying properties in stainless steels are the percentages of element contents and physical properties such as corrosion resistance, hardness, and crystalline structure. The definition of *Martensitic precipitation stainless steel* in Fig. 5 is an example of material definition resulting from the analysis. We used Protégé[f] software to run the Pellet[g] reasoner to infer subsumption from material definitions. The left side of Fig. 5 shows the result of generated subsumption hierarchy, which is well-organized rather than flat as is the one in the middle. In particular, conceptual definitions enable the multiple subsumption relationships while only defining and maintaining a simple/linear taxonomic structure of subsumption hierarchy. For example, *Stainless 410 series* is a subsumed by both *Stainless 400 series* and *Martensitic stainless steel* in the inferred hierarchy (left side of Fig. 5), while it is only defined to be subsumed by *Metal* (the middle of Fig. 5).

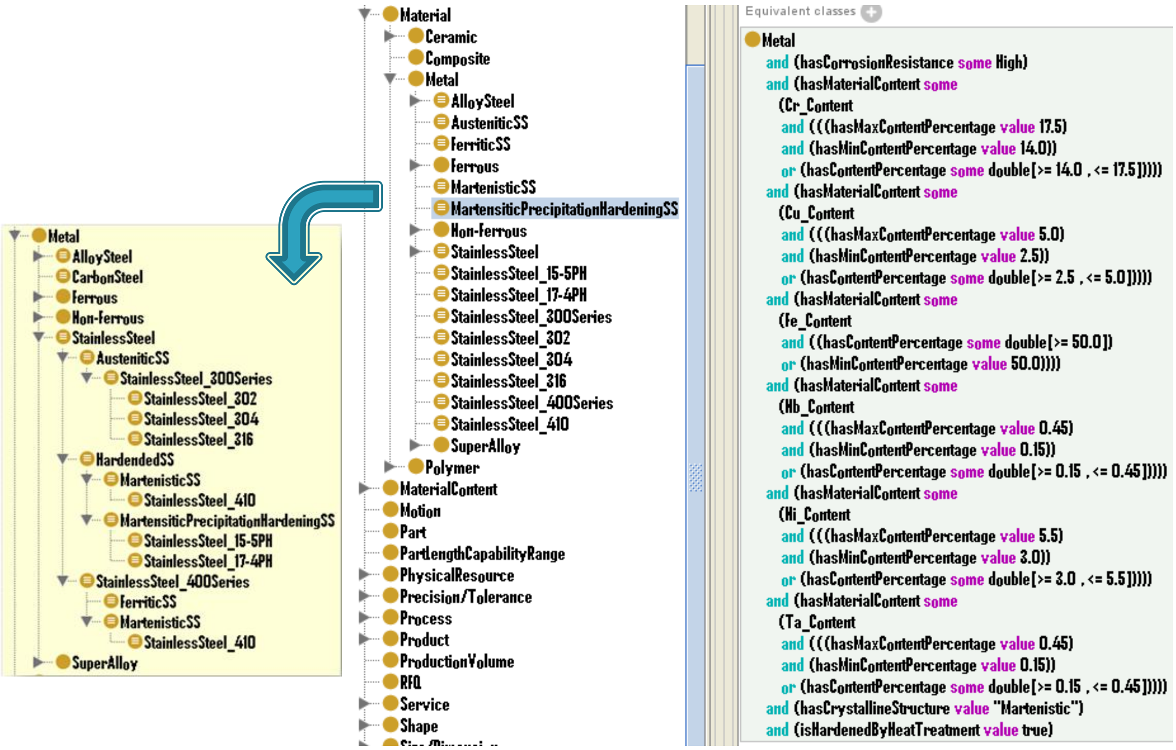

Fig. 5. Definition of *Martensitic precipitation hardening stainless steel*

5. Conclusion

The motivation for the work described in this paper is that the quality of delivered information from existing models of manufacturing service capabilities falls short of expectation due to limited, imprecise, or ambiguous semantics associated with these models. Several use cases have been reviewed to verify if sample capability models from e-sourcing portals can represent capability to support precise representation of manufacturing service capabilities of multiple suppliers. From the use case analysis, it turns out that all legacy capability models had issues that are characterized by low information fidelity, semantic ambiguity, and semantic modeling conflicts.

We have proposed an ontology-based MSC model to address the identified issues caused by limited semantics of manufacturing service capability models. We have investigated several ontology-based approaches that attempted to conceptualize the manufacturing domain for similar purposes and tested one promising approach as an initial ontology-based MSC model. The challenge that remains is that methods for continuous enrichment of the MSC model need to be devised to realistically use ontology-based approach for MSC modeling since an introduction of an ontology with a limited number of concepts does not guarantee anything except the resolution of semantic modeling

[f] protégé.stanford.edu
[g] clarkparsia.com/pellet

conflicts. To that end, we have identified extension methods in the context of concept analysis procedures to support model enrichment by utilizing several archetypical data sets appearing in e-sourcing portals. Through the suggested concept analysis of data sets, i.e., product/service category, detailed capability description for product/process, and term definition, many concepts have been successfully added into the initial MSC model using the formal description logic-based representation.

One of the research issues that needs to be addressed in the future is to decide how to harmonize the new concepts with the existing ontology. This is a challenging problem especially if a new concept requires substantial changes to an existing taxonomy structure. Introduction of multiple subsumption hierarchy for one root concept by conceptual definition may be an alternative approach that needs to be tested with respect to added complexities brought by the introduction of complicated inheritance hierarchies. Along with extensions of the MSC model, other types of enrichment methods such as conflict resolution and abstraction also need to be researched further to optimize the MSC model.

Disclaimer

Certain commercial software products or services are identified in this paper. These products or services were used only for demonstration purposes. This use does not imply approval or endorsement by NIST, nor does it imply these products or services are necessarily the best available for the purpose.

References

1. Ariba, B2B marketplaces in the new economy. (2000). Retrieved from http://www.ariba.com/pdf/B2B_Mkts_white_paper.pdf.

2. M. Grieger, Electronic marketplaces: A literature review and a call for supply chain management research. European Journal of Operational Research. 144. (2003) 280–294.

3. J.G. Bralla, Design for manufacturability handbook. McGraw-Hill. (1999) 4-56.

4. T.R. Gruber. A translation approach to portable ontology specifications. Knowledge Acquisition. Vol. 5 No. 2 (1993) 199–220.

5. F. Arvidsson and A. Flycht-Eriksson, Ontologies I (2008).

6. W3C, OWL Web Ontology Language Overview. Retrieved from http://www.w3.org/TR/owl-features/.

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

8. The DARPA Agent Markup Language Homepage. Retrieved from http://www.daml.org/.

9. N. Chungoora, O. Canciglieri Jr, and R.I.M. Young, Towards Expressive Ontology-Based Approaches to Manufacturing Knowledge Representation and Sharing, International Journal of Computer Integrated Manufacturing. Vol. 23, No. 12, (2010) 1059-1070.

10. H.K. Lin and J.A. Harding, A manufacturing system engineering ontology model on the semantic web for inter-enterprise collaboration. Computers in Industry. Vol. 58 (2007) 428–437.

11. S. Lemaignan, A. Siadat, J.-Y. Dantan, and A. Semenenko, MASON: A Proposal For An Ontology Of Manufacturing Domain. Proceedings of the IEEE Workshop on Distributed Intelligent Systems: Collective Intelligence and Its Applications (DIS'06). (2006) 195-200.

12. F. Ameri and D. Dutta, An upper ontology for manufacturing service description. ASME 2006 (IDETC/CIE2006). (2006) 651-661.

13. F. Ameri and D. Dutta, A matchmaking methodology for supply chain deployment in distributed manufacturing environments. Journal of Computing and Information Science in Engineering. Vol. 8. No. 1 (2008) 011002.

14. A.G. Valarakos, G. Paliouras, V. Karkaletsis, and G. Vouros, Enhancing Ontological Knowledge Through Ontology Population and Enrichment. Engineering Knowledge in the age of the Semantic Web. Vol. 3257 (2004) 144-156.

15. D.D. Kehagias, I. Papadimitriou, J. Hois, D. Tzovaras, J. Bateman, A Methodological Approach for Ontology Evaluation and Refinement. ASK-IT International Conference. (2008).

16. G. Flouris, D. Manakanatas, H. Kondylakis, D. Plexousakis, and G. Antoniou, Ontology change: Classification and Survey. The Knowledge Engineering Review, Vol. 23. No. 2 (2008) 117-152.