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Manufacturing Capability Inference and Supplier Classification Based on a Formal Thesaurus

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Abstract. Standard representation of manufacturing capability information is a necessity for efficient configuration of loosely-coupled supply chains. ManuTerms is a formal thesaurus that provides a set of standard vocabulary that can be used for description of manufacturing capabilities. In this paper, a method is proposed for supplier characterization and classification guided by ManuTerms. The tools developed in this work use the capability narrative of manufacturing suppliers as the input and extract key concepts that refer to certain aspects of manufacturing capabilities in order to characterize and classify manufacturing suppliers. Through an experimental study, the supplier classification method was validated with respect to the level of agreement with human judgment.

Keywords: supply chain interoperability, manufacturing capability, thesaurus, supplier characterization.

1 Introduction

Effective configuration and operation of distributed supply chains highly depends on the ability to meaningfully exchange engineering information among the supply chain members. The main body of research in supply chain information interoperability has been focused on information exchange among the supply chain participants *after* the supply chain is configured [1]. However, information interoperability in *pre-configuration stages* is equally important as it improves the quality of communication among suppliers when searching for appropriate manufacturing counterparts [2]. A significant portion of the information exchanged and consumed during the supply chain pre-configuration stages is related to the *manufacturing capabilities* that different suppliers can offer. Manufacturing capability of a supplier refers to the aggregate abilities, skills, and expertise a supplier can provide to the customers enabled by its internal and external resources. The existing models for manufacturing capability representation are often proprietary and unstructured or semi-structured without well-defined semantics. This has resulted in information loss and information ambiguity in supply chain communications. In order to streamline information exchange in the

early stages of supply chain lifecycle, it is imperative to develop standard models for manufacturing capability representation with uniform and explicit semantics agreeable among larger supplier communities. If the representation can be formalized, then it also enables active participation of machine agents in autonomous supply chain configuration process. One promising approach for addressing the interoperability issue is the use of formal ontologies that encode explicit capability knowledge. In fact, several research projects have used ontological approach for dealing with information interoperability in manufacturing supply chains [1, 3, 4]. One of the key challenges in developing ontologies is *knowledge acquisition* especially when dealing with a vast and complex domain such as manufacturing. There are multiple sources of knowledge that can be utilized for collecting manufacturing engineering knowledge including domain experts, engineering handbooks, and web portals. The online profiles of manufacturing suppliers, in particular, contain a wealth of information pertaining to the capabilities of suppliers. In their webpages, manufacturing companies typically provide different types of information such as their primary and secondary services, the materials they can process, the processes they are expert in, and the types of products or geometries they typically produce. The terms that suppliers use in their capability narratives are essentially the basic building blocks of the capability knowledge model. Therefore, by systematically analyzing supplier profiles and organizing the key terms, it is possible to arrive at a conceptual model that can be incrementally evolved into more complex and axiomatic ontologies.

In a previous research, a thesaurus was developed based on the terms collected from the online profiles of manufacturing suppliers [5] . This paper describes how the developed thesaurus can be used for inferring new knowledge about manufacturing capabilities of suppliers and also classifying and clustering suppliers based on the information patterns that appear in their online profiles. Through inferring new knowledge about the capabilities of manufacturing suppliers, the intelligence of autonomous supplier discovery solutions will be enhanced. Automated characterization and clustering of suppliers is particularly helpful in web-based scenarios in which the supply pool is fairly large and searching and screening process becomes a labor-intensive task.

2 Manufacturing Capability Thesaurus

ManuTerms, a formal thesaurus for manufacturing terms, was developed with the objective of collecting the key terms, or concepts, used in manufacturing capability representations [5]. The collected concepts constitute the conceptual model that serve as the steppingstone for more formal ontologies such as MSDL [6]. The online profiles of manufacturing suppliers, mainly in contract machining sector, were used as the main resources when developing ManuTerms. Simple Knowledge Organization System (SKOS)[1] is used for syntactic and semantic representation in ManuTerms.

[1] http://www.w3.org/TR/skos-reference/

SKOS is a formal language for thesaurus representation and is built upon Resource Description Framework (RDF) and RDFS and enables publication of controlled vocabularies on the Semantic Web as an RDF graph. SKOS core vocabulary is a set of RDF properties and RDFS classes. Each term in SKOS has a *preferred* label and one or more *alternative* labels. *Broader*, *narrower*, and *related* are the semantic relations used in any SKOS thesaurus. Also, each SKOS concept can have a definition provided in natural language. ManuTerms currently has more than 2100 concepts that are organized in eighteen categories such as processes, materials, and machinery. Approximately, 2800 alternative terms have been identified for those concepts.

3 Capability Inference

A formal SKOS thesaurus such as ManuTerms, together with its associated document indexing and concept extraction tools, can enable different types of statistical analysis and data mining that will lead to generation of new knowledge and insight about the population under study. In particular, since ManuTerms was initially developed to organize the vocabulary adopted by manufacturing suppliers for describing their capabilities, it can be used for discovering useful patterns and statistics in a sample of supplier profiles. For example, one can learn about the advertising behavior of suppliers in different domains such as precision machining or electrical discharge machining through analyzing the type and the frequency of concepts used in the supplier profiles. This in turn can lead to development of more intelligent supplier search algorithms that customize their search logics based on the search context. A sample of 50 suppliers from different service categories including machining, casting, and assembly was formed for the purpose of this study. The selected suppliers each had a website in which the core capabilities and services were described in natural language (English) with at least 200 words.

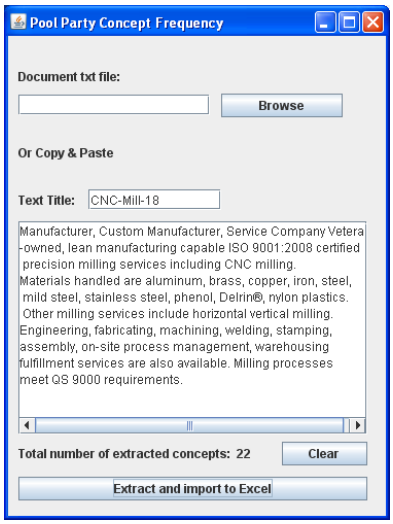

Fig. 1: The GUI of the concept extractor program

In order to rapidly analyze a large sample and improve the statistical significance of the results, a Java-based concept extraction program was developed for automatically extracting ManuTerms concepts from the imported text. **Error! Reference source not found.** shows the user interface of the concept extraction program. The extractor tool exports the identified concepts for each supplier to an Excel worksheet for further analysis. Fig. 2 shows the ManuTerms concepts extracted from the profile of one of the suppliers of CNC milling services and sorted

according to the concept score. The concept extractor tool indexes a profile by a concept if the preferred or alternative labels corresponding to the concept appear in the profile. Concept score is calculated based on *frequency* and *location* of its corresponding terms in the capability narrative. The location score assigns more weight to the terms that appear earlier in the text. Some of the high-score concepts extracted for the supplier narrative shown in Fig. 2 are `Milling`, `Custom Manufacturing Service`, `Precision Machining`, `Steel`, and `Aluminum`. Therefore, just by studying the ranked list of returned concepts, one can conclude that this supplier most likely provides precision machining services for steel and aluminum parts. It can also be inferred that this supplier provides assembly and stamping services as secondary services since these concepts are among the top twenty concepts returned by the extractor but not ranked high in the list.

Manufacturer, Custom Manufacturer, Service Company Veteran-owned, lean manufacturing capable ISO 9001:2008 certified precision milling services including CNC milling. Materials handled are aluminum, brass, copper, iron, steel, mild steel, stainless steel, phenol, Delrin®, nylon plastics. Other milling services include horizontal vertical milling. Engineering, fabricating, machining, welding, stamping, assembly, on-site process management, warehousing fulfillment services are also available. Milling processes meet QS 9000 requirements.

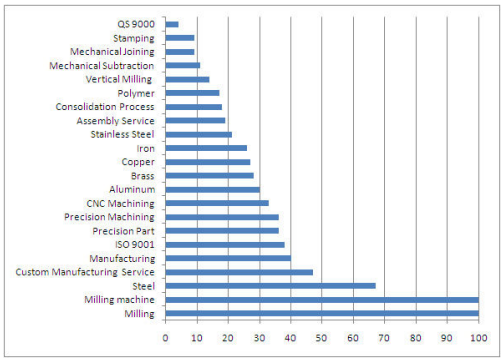

Fig. 2: The capability narrative of a sample supplier along with the listing of the concepts extracted from this profile.

In the studied sample of 50 suppliers, 24 suppliers had `Precision Machining` in their top five lists. However, only two of twenty two suppliers provided `stamping` processes. Therefore, one can conclude that these two data points are outliers and do not provide a strong evidence for the hypothesis that " *providers of precision machining services usually provide stamping service as well*". Table 1 shows some of the discovered patterns of service provision based on the concepts extracted from the studied sample.

Table 1 : The discovered patterns based on a sample of 50 suppliers.

Pattern / finding	**Occurrence percentage**
Providers of `Micromachining` services serve `Medical` industry.	67%
Providers of `Swiss Machining` services are capable of `High Volume` production.	53%
Providers of `CNC machining` services provide `CAD/CAM` services as well.	71%

Providers of `Casting` services provide `Heat Treating` services as well.	75%

4 Supplier Classification

Concept extraction results in *semantic tagging* of supplier profiles by ManuTerms concepts. Semantic tagging and annotation is particularly helpful for automated search and retrieval of suppliers. Machine agents can use the extracted concept cloud in order to characterize and categorize manufacturing suppliers based on their asserted and inferred capabilities, thus generating more precise search results. Supplier characterization is the first step in forming specialized supplier families. As an example, a particular search agent may define an arbitrary family if suppliers called *high-tech suppliers* representing the suppliers that possess 5-axis micromachining capabilities supported by CMM and CAM services. An array of ManuTerms concepts such as `5-Axis Machining`, `CMM Service`, `CAM Service`, and `Micromachining Service` can be defined as the concepts that qualify a supplier as a high-tech supplier. A semantic query over the annotated profiles can be executed to identify the "high-tech" suppliers within the search space depending on the presence of one or more of the *qualifying concepts* in each profile. Through employment of scoring and normalization measures, it is possible to quantify the strength by which a supplier belongs to a particular family. For the purpose of experimentation, six categories of suppliers, together with their qualifying concepts, were defined as shown in Table 2.

Table 2: Example supplier categories together with their description and qualifying concepts

Category Title	Description	Qualifier concepts
Small-part suppliers	Suppliers who are capable of producing small parts.	`Swiss Machine, Screw Machine, Chucking Machine, Small Part, Precision Small Part, Swiss Machining, Screw Machine Part`
Large-part suppliers	Suppliers who are capable of producing large parts.	`Large Part, Medium-to-large Part, Large Machining Job, Vertical Boring, Vertical Boring Machine, Trunkey component, Trunkey Manufacturing`
Aerospace suppliers	Supplier who serve aerospace industry.	`Aerospace Industry, Aircraft, Spacecraft, Aircraft Manufacturing, Aerospace Alloy, Aerospace Part`
Precision suppliers	Supplier who provide precision manufacturing services.	`Precision Small Part, CNC Precision Turning, Precision Machining,`

		Precision Measuring Instrument
Complex-parts suppliers	Supplier who provide manufacturing services for complex parts	Complex Part, Complex Geometry, 5-Axis Machining
High-tech suppliers	Supplier who provide high-end manufacturing services and possess modern manufacturing and inspection equipment.	5-Axis Machining, CMM Service, CAM Service, Micromachining

Twenty suppliers were selected for the classification experiment based on the 6 categories described in Table 2. The concepts extracted automatically for each supplier were analyzed to come up with a numeric value for the membership strength with respect to each category. The membership strength is calculated using the following equation:

$$MS_{ij} = \frac{SQC_{ij}}{QC_j} \qquad (1)$$

Where MS_{ij} is the membership strength of the supplier i with respect to the category j, SQC_{ij} is the sum of the number of qualifier concepts for j^{th} category extracted from the profile of the i^{th} supplier, and QC_j is the number of qualifier concepts for the j^{th} category. For example, there are seven qualifier concepts for the *small parts su*pplier category. Then if three of these concepts appear directly or indirectly in the profile of particular supplier, the membership strength of this supplier to small parts supplier category is 3/7=0. 42.

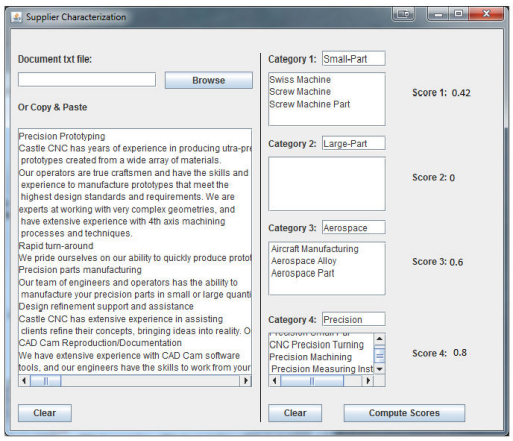

Fig. 3: The screenshot of the supplier characterization tool

A Java-based tool, called supplier characterization tool, was developed for calculation of membership strength based on the capability narrative of the supplier as shown in Fig. 3 . It should be noted that semantic equivalence (i.e., alternative label) is taken into account when calculating MSij.

The supplier classification tool receives the capability narrative of the supplier as the input and calculates the membership strength along different categories. To this end, the tool interacts with an API of a thesaurus builder software tool, Pool Party Extractor (PPX), to obtain a list of concepts extracted from the narrative of the suppliers. The particular supplier shown in this figure is mainly categorized as a "precision supplier" since about 80% of the qualifying concepts related to precision suppliers incurred in the profile of this supplier. This finding was compared against human expert's judgment that was asked to assign membership strength values for different categories after studying the narrative of the supplier. Validation based on expert's judgment was conducted for all sampled suppliers. One interesting observation in the supplier characterization experiment was that most of the suppliers that were strongly characterized as "small-part suppliers", ranked high with respect to precision and complexity measures as well. That is, an intelligent learning algorithm may be developed in the future to use such information to infer capability.

Another experiment was conducted to compare and contrast the capability descriptions collected from the e-sourcing portals and the capability descriptions available in the websites of suppliers. The null hypothesis was that suppliers describe the same capabilities in an e-sourcing portal and in the company's website. For this experiment, the same sample of suppliers used in the characterization experiment was studied. A particular e-sourcing portal widely used in the contract manufacturing industry was selected for this study. After quantitative analysis of the commonalities and differences of the returned sets, it was observed that, for the majority of the studied suppliers, the set of concepts extracted from the portal profile is considerably different from the concept set extracted from the supplier's website. This discrepancy is mainly attributed to the predefined template and keywords imposed by the portals for capability description that provide suppliers with a limited set of options for describing their capabilities. In general, because of the flexibility that suppliers have when describing their capabilities in the company website, the information content of the text extracted from the suppliers' websites is higher compared to e-sourcing portals. This finding is in favor of the distributed sourcing solutions that consume the capability data generated in a decentralized fashion. In a distributed sourcing scenario, ManuTerms can serve as a neutralizing middle agent that converts the contents of heterogeneous profiles collected from the Web into uniform capability models that share a common vocabulary.

5 Conclusions

This paper presented novel approaches for capability inference and supplier classification based on ManuTerms. Classification of suppliers is beneficial in the early stages of supply chain configuration as it narrows down a larger pool of suppliers to a smaller subset composed of suppliers that are relevant to particular search scenarios. The proposed classification technique was evaluated experimentally to verify its agreement with human judgment. More sophisticated search techniques based on axiomatic ontologies such as MSDL can be conducted on the returned subset in order

to arrive at a more fine-tuned search results. The advantage of using a formal thesaurus is that it can be used for automatically converting heterogeneous capability narratives into homogenous conceptual models composed of standard capability terms. One of the future tasks in this research is to use ManuTerms as an intermediary model for Ontology-based Information Extraction (OBIE) from web-based profiles of manufacturing suppliers.

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