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Ontology Building of Manufacturing Quality Knowledge for Design Decision Support

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Abstract: Manufacturing knowledge on product quality is a kind of typical knowledge for supporting design decisions. In order to clearly identify and understand design decisions and their knowledge needs on manufacturing quality, an ontology of design decisions and manufacturing quality knowledge is developed. The methodology and tool used for the development of the proposed ontology is firstly introduced. The design decisions are organized along with five main design phases ranging from planning and task clarification, conceptual design, embodiment design to detail design. The knowledge needs of different design decisions, especially on the manufacturing quality knowledge, are analyzed through competition questions. Then, the ontology is built in the form of a hierarchical structure through the proposed methodology and ontology editor. Based on the developed ontology, further instances of the classes in the ontology can be filled as detailed knowledge, and can be accumulated for further construction of knowledge base.

Key words: ontology building; manufacturing quality knowledge; design decision; design support; design ontology.

1- Introduction

Engineering design is knowledge intensive process in which large quantities of decisions are involved. Designers request large amounts of knowledge when making decisions. Manufacturing knowledge on product quality is a kind of typical knowledge for supporting design decisions, however, which is not considered and used effective and efficiently through formal feedback from manufacturing to design. In order to support design decisions, the first problem to be solved is to identify design decisions and their needs on manufacturing quality knowledge. One ontological approach is proposed in this work to solve this problem.

An ontology is a formal, explicit specification of a shared conceptualization [G1]. "Conceptualization" refers to an abstract model of phenomena in the world by having identified the relevant concepts of those phenomena. "Explicit" means that the type of concepts used, and the constraints on their use are explicitly defined. "Formal" refers to the fact that the ontology should be machine readable. "Shared" reflects that ontology should capture consensual knowledge accepted by the communities" [G1].

Engineering design researchers are increasingly interested in the development of an ontology for engineering design [AS1]. Engineering design ontology is a hierarchically structured set of terms for describing engineering design domain that can be used as a skeletal foundation for a knowledge base. One particular motivation for developing engineering design ontology is to provide a structured basis for navigating, browsing and searching information through the hierarchical descriptions of the ontology. It can help the collaborative design team by providing accurate design information and guidelines. This is especially useful when designers are not aware of the information available or have difficulty in forming suitable queries.

However, most constructed ontologies focus only on the design activities and design process, and few works consider the manufacturing issues when constructing the design ontology. In this work, an ontology named "Design Decisions and Manufacturing Quality Knowledge (DD-MQK)" is developed for identifying the design decisions and their MQK needs.

The paper is organized as follows: the methodology and editor for the development of the proposed ontology are illustrated in section 2. Then the ontology is developed along with seven major steps in section 3. Section 4 concludes with discussion and further works.

2- Methodology and tool for building ontology

2.1 – Methodology for building "DD-MQK" ontology

In recent years, there are two most widely known methodologies for ontology development, which are presented by Uschold & Gruninger [UG1] and Noy & McGuinness [NM1] respectively. The approach taken by

Noy and McGuinness overlaps with and is influenced by Uschold and Gruninger's work. It provides guideline for the development of a declarative frame-based ontology. The key elements of the methodology are illustrated as follows:

- Step 1: determining the domain and scope of the ontology: Establishing the domain and the scope of the ontology can be assisted by answering the following three competency questions [GF1]: What domain of interest will the ontology cover? For what will the ontology be used? For what types of question will the information in the ontology provide answers?
- Step 2: considering reuse of existing ontologies: There are a growing number of ontology libraries from which can be imported existing ontological structures.
- Step 3: enumerating important terms: This step consists of the two tasks of (a) identification of the key concepts and relationships in the domain of interest and (b) production of unambiguous text definitions for such concepts and relationships.
- Step 4: defining the classes and the class hierarchy: This means placing the selected concepts into some sort of hierarchical organization. Uschold and Gruninger identified three approaches to the development of the class hierarchy: top-down, middle-out, and bottom-up [UG1].
- Step 5: defining the properties of classes-slots: Classes or objects on their own provide only a limited amount of information about a domain, and it is usually insufficient to ensure that the competency questions can be answered.
- Step 6: defining the values (facets) of the properties (slots): Properties in the real world are described by value type, allowed values or perhaps ranges of values, the number of values (the cardinality) and other features that the property has. These are sometimes known as facets.
- Step 7: creating class instances: Creating an individual instance of a class consists of specifying the actual value of each of the properties of a specific instance of the class. When this is done knowledge about the real world can be captured. It is by repeating this process that a knowledge base can be developed, since a knowledge base is a collection of instances of classes of interest for a given task.

The Noy and McGuinness methodology is thought to be the most appropriate one for developing the "DD-MQK" ontology because it has clear logic steps and is very suitable for developing frame-based ontology. Thus, the Noy and McGuinness methodology will be chosen for building of the frame-based ontology "DD-MQK".

2.2 – Ontology editor-Protégé

The Protégé developed by Knowledge Systems Laboratory (KSL) is the most widely used ontology editor tool. Protégé is a free, open-source platform that provides a growing user community with a suite of tools to construct domain models and knowledge-based applications with ontologies. At its core, Protégé implements a rich set of knowledge-modeling structures and actions that support the creation, visualization, and manipulation of ontologies in various representation formats. Protégé can be customized to provide domain-friendly support for creating knowledge models and entering data. Further, Protégé can be extended by way of a plug-in architecture and a Java-based Application Programming Interface (API) for building knowledge-based tools and applications.

The Protégé platform supports two main ways of modeling ontologies: The Protégé-Frames editor and The Protégé-OWL editor. The Protégé-Frames editor enables users to build and populate ontologies that are frame-based. In this model, an ontology consists of a set of classes organized in a subsumption hierarchy to represent a domain's salient concepts, a set of slots associated to classes to describe their properties and relationships, and a set of instances of those classes - individual exemplars of the concepts that hold specific values for their properties.

In this work, the Protégé-Frames editor is chosen as the tool for building DD-MQK ontology. For more information about Protégé, please visit the website of Protégé [P1].

3- Building of "DD-MQK" ontology

Before the investigation and organization of the subject content of engineering design decisions' MQK needs, a conceptual framework of related topics is formulated. The top level of the structure is shown in Figure 1. Three major topics are formulated including decision-maker, design decision, and MQK. Their elaboration and detailed hierarchy will be discussed in following subsections.

According to the methodology, this section illustrated the detailed development of the ontology. For clarity, it should be noted that only part of DD-MQK ontology is used to illustrate the development methodology.

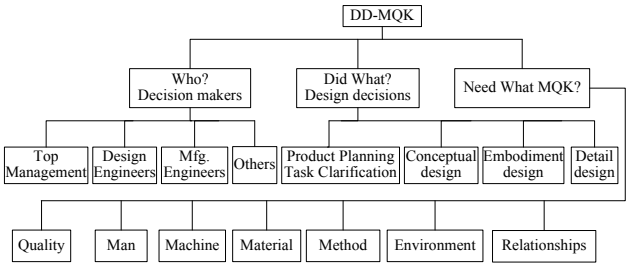

Figure 1: Conceptual framework of DD-MQK ontology.

3.1 – Determining the domain and scope of the ontology

One of the ways to determine the scope of the ontology is to sketch a list of questions that a knowledge base should be able to answer based on the ontology. If we can answer these questions correctly, the ontologies will be developed easily. These questions are referred to as competency questions [GF1]. These questions will serve as the litmus test later: Does the ontology contain enough information to answer these types of questions? Do the answers require a particular level of detail or representation of a particular area? These competency questions are just a sketch and do not need to be exhaustive.

According to the works of Darlington and Culley's work [DC1], crucial to the success of the ontology development is determining the domain and the scope of the ontology. Establishing this can be assisted by answering the following three questions:

- What domain of interest will the ontology cover?

In this case the domain is that of product design decisions

and their MQK needs, the content of which relates to such things as product design decision makers, product design decisions, product manufacturing, and product quality inspection, and the materials of which they consist or upon which they are placed.

- For what will the ontology be used?

The purpose of the DD-MQK ontology is to provide a knowledge context, which can assist the designers in raising and answering all the questions appropriate to completing the design decisions relating to the quality of a designed product. In general, "knowledge context" might be defined as the prevailing conditions, environment or knowledge state by which an interpretation is made of the information.

- For what types of question will the information in the ontology provide answers?

The competency questions are considered to be of immense importance in focusing on what the ontology is to be used for, and providing guidance as to the structure and content of the ontology. The use to which the ontology is to be put is critically important in deciding the level of description for the entities in the conceptual space (that this is the case can be seen from the examples given in Step 4). Competency questions assist in clarifying what the entities are, their natures, and at what level they might best be described. In addition, the competency questions provide a means by which the ontology, and its implementation in some problem-solving method, can be validated, since they can be used to query an application's performance.

In the DD-MQK Ontology, some competency questions can be listed as follows:

About the actors (including designers, manufacturing engineers, managers, etc.):

- To what decisions does the actor (Manufacturing engineers/quality engineers, etc) contribute MQK?
- For what decisions is the actor declared an expert or knowledge base?
- What decisions and sub-decisions does the actor own?
- What is the geographical location of the actor and the knowledge base?

About the design decisions:

- What MQK knowledge is required to make the decisions?
- What information is generated by this decision?
- Who are the decision makers (or stakeholders)?

About the knowledge. Instances of the "knowledge item" class are chunks of knowledge, which may include a technical report, guidelines for using a software tool or advice from an expert on an issue associated with the task.

- What tasks in manufacturing generate this knowledge item?
- For what decisions does this MQK item provide knowledge?
- Where is the knowledge item located?
- What types of the format does the knowledge item exist as?
- In what languages is the knowledge available?

The competency questions need not be exhaustive, merely indicative of the sorts of questions that could require answering by a knowledge base founded on the ontology. However, in order to formulate the questions it is necessary that predictions be made about the use to which the ontology is to be put; it is difficult to see how the competency questions could be derived without having some sort of use in mind [DC1].

3.2 – Considering reuse of existing ontologies

There are a growing number of ontology libraries from which can be imported existing ontological structures, for example, the Ontolingua ontology library or the DAML ontology library. There are also a number of publicly available commercial ontologies (e.g., UNSPSC (www.unspsc.org), RosettaNet (www.rosettanet.org), DMOZ (www.dmoz.org).

However, no source ontologies were judged to be directly useful in contributing to the ontology developed in this study, and this work will assume that no relevant ontologies already exist. So the ontology "DD-MQK" will be constructed from scratch.

3.3 – Enumerating important terms

Having established the scope of an ontology this step constitutes the starting-point for building a new ontology, and consists of the two tasks of (a) identification of the key concepts and relationships in the domain of interest and (b) production of unambiguous text definitions for such concepts and relationships.

It is useful to write down a list of all terms this work would like either to make statements about or to explain to a user. What are the terms this work would like to talk about? What properties do those terms have? What would this work like to say about those terms?

Initially, it is important to get a comprehensive list of terms without worrying about overlap between concepts they represent, relations among the terms, or any properties that the concepts may have, or whether the concepts are classes or slots.

For this step, this work will take all the terms in the engineering design domain, especially from Pahl and Beitz's classic works [PB1]. Some important terms have been emerged naturally through Step 2 in section 3.2. More terms will emerge in following steps.

3.4 – Defining the classes and the class hierarchy

The next two steps-developing the class hierarchy and defining properties of concepts (slots)-are closely intertwined. It is hard to do one of them first and then do the other. Typically, a few definitions of the concepts are created in the hierarchy and then the properties of these concepts are continuous described, and so on. These two steps are also the most important steps in the ontology-design process.

This step consists of placing the selected concepts into some sort of hierarchical organization. Uschold and Gruninger identified three approaches to the development of the class hierarchy: top–down, middle–out, and bottom–up [UG1]. Although no approach is inherently better, the middle–out approach where the ontology is developed from basic categories has been found to be of benefit, not least because it is at this level that the most descriptive concepts in the domain tend to be clustered.

Due to space limit, only the top levels of the classes and the class hierarchy of "DD-MQK" is presented, as shown in figure 2.

Concerning the construction of class and their hierarchy in Protégé, here only some concepts in the conceptual design phase are illustrated for the analysis of the design decisions and their manufacturing quality knowledge needs, and for the

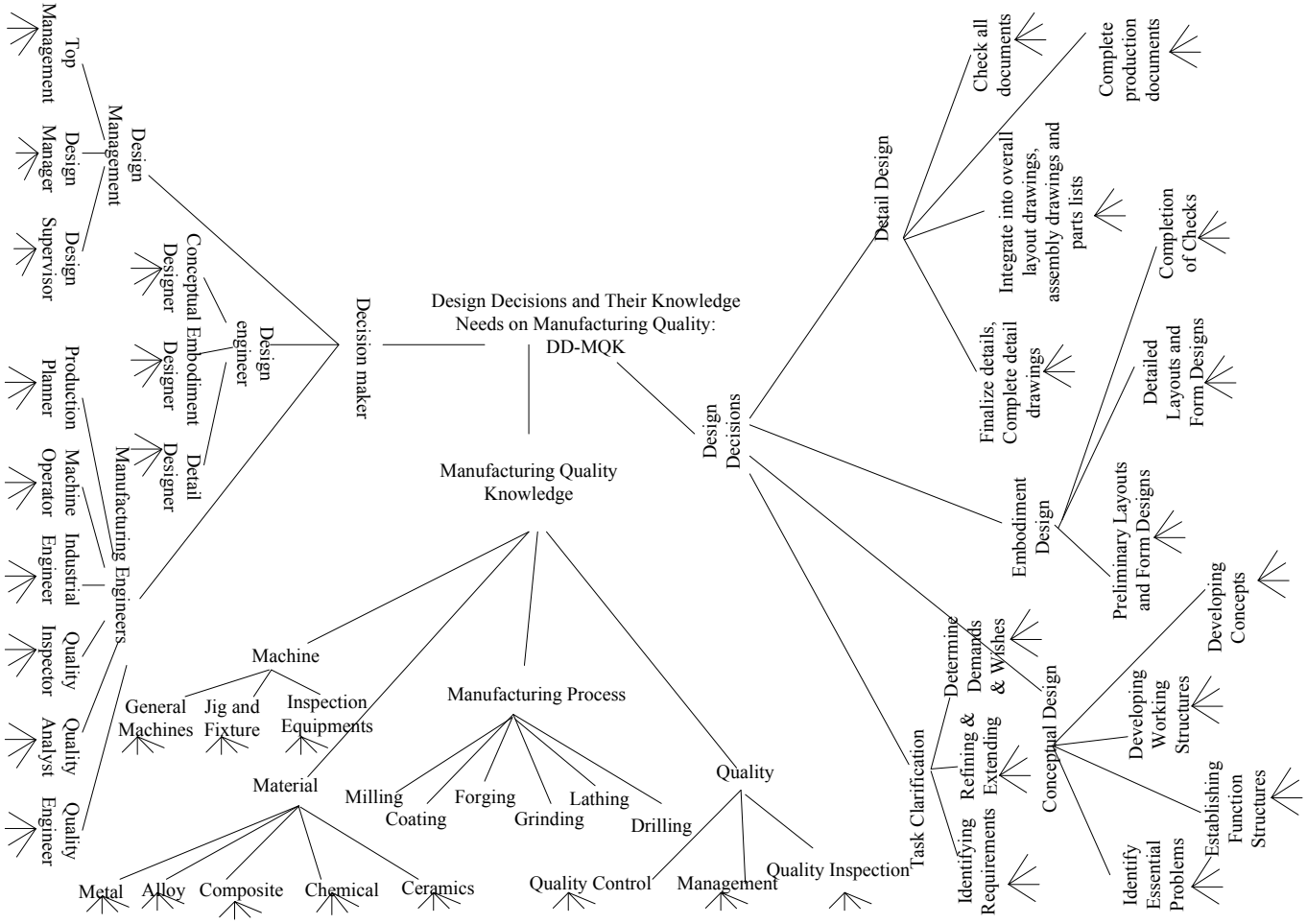

Figure 2: Top levels of DD-MQK class hierarchy.

construction of the part of the ontology. Conceptual design initiated from the requirement list (or design specification). This phase includes four major working steps in which there include different tasks and decisions. The major steps are:

- Abstracting to Identify the Essential Problems, which includes broadening the problem formulation and identifying the essential problems from the Requirements List.
- Establishing Function Structures, which includes identifying overall function, breaking a function down into subfunctions.
- Developing Working Structures, which includes searching for working principles, combining working principles, and selecting working structures.
- Developing Concepts, which includes firming up into principle solution variants, evaluating principle solution variants, and determine principle solution.

Thus, the design decisions classes and class hierarchy are formulated (Figure 3).

Along with the different working steps and the detailed working tasks for implementing working steps, this work can analyze their different manufacturing knowledge needs. As we know, there are many kinds of manufacturing knowledge for support product design decisions.

With reference to the analysis of different quality problems in quality management domain, the problems can be analyzed from four viewpoints such as man, machine, material, method,

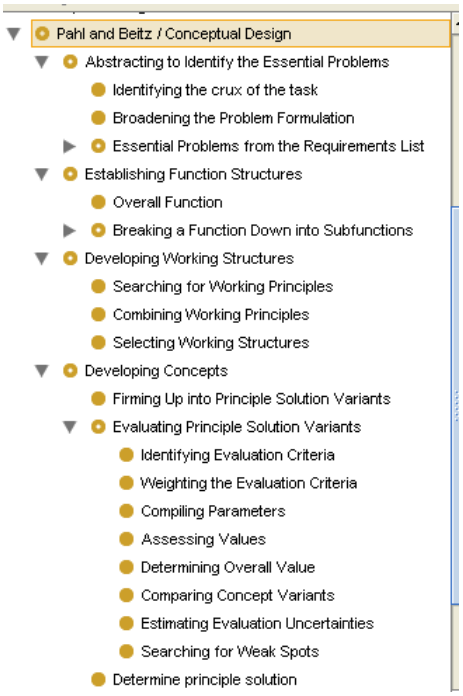

Figure 3: Class and class hierarchy of design decisions in conceptual design.

and environment, often being called as 4M1E. Here this work focus the manufacturing knowledge on the 3M such as material, machine, and methods (in this work we call it manufacturing process). The detailed manufacturing knowledge class and the class hierarchies are shown in Figure 4.

3.5 – Defining the properties of classes-slots

Classes or objects on their own provide only a limited amount of information about a domain, and it is usually insufficient to ensure that the competency questions can be answered. The addition of properties allows the internal structure of the domain to be added to the external – classification – structure. In a hierarchy, the property should be attached to the most general example in a class structure, subordinate classes acquiring the property by inheritance.

There are a number of types of property that can in general be assigned to objects or classes.

- Intrinsic properties, including such things as mass, hardness and melting point.
- Extrinsic properties, including such things as the name of materials or the price.
- Parts, where an object has a decomposable structure. The 'parts' can be physical (e.g. in decomposing an assembly into components) or abstract (e.g. the stages of a process).
- Relational properties. These are relationships between individual members of a class and other objects.

Some of the slots of the classes are shown in figure 5. The class "Identifying Evaluation Criteria" has some slots such as "Name", "Need", and "Derived from", etc.

3.6 – Defining the facets of the properties

Properties in the real world are described by value type, allowed values or perhaps ranges of values, the number of values (the cardinality) and other features that the property has. These are sometimes (as is the case in Protégé 3.3.1 terminology) known as facets.

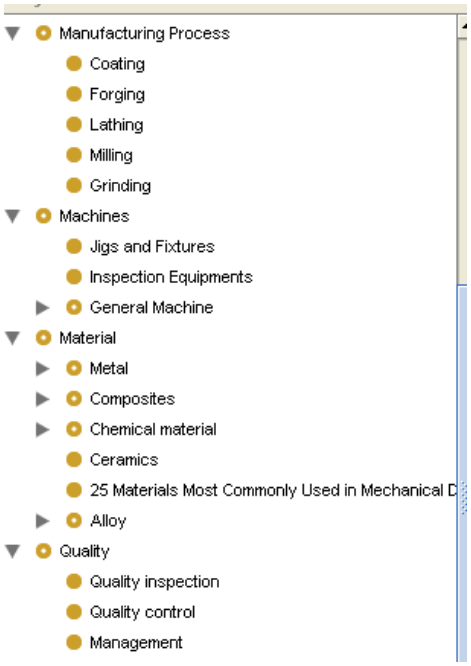

Figure 4: Part of class hierarchy of MQK.

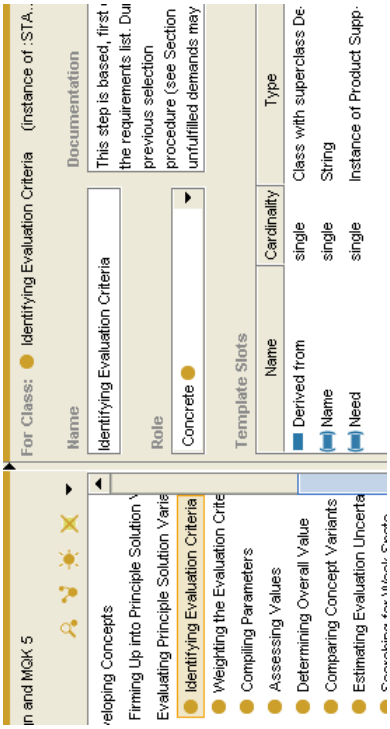

Figure 5: Slots of the class "Identifying Evaluation Criteria".

After defining the slots of the properties of the classes such as design decision and manufacturing knowledge, this step will fill all the corresponding values of the different properties.

As we know, in Protégé 3.3.1 we call values of properties/slots as facets. Due to space limit, here only the definition of one slot "Need" is illustrated. As shown in figure 6, for the slot "Need" of the classes such as different kinds of design decisions, the value type of slot is instances, the allowed class is "Product Support Knowledge" which is the super class of manufacturing knowledge in our project.

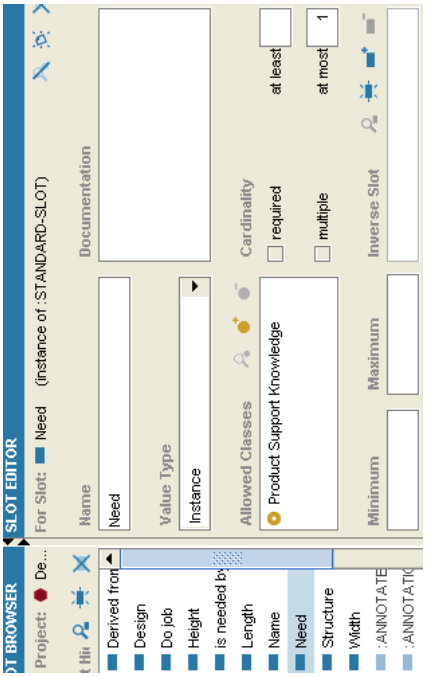

Figure 6: Facets of the slot "Need".

3.7 – Creating class instances

The last step is creating individual instances of classes in the hierarchy. Defining an individual instance of a class requires (1) choosing a class, (2) creating an individual instance of that class, and (3) filling in the slot values.

Creating an individual instance of a class consists of specifying the actual value of each of the properties of a specific instance of the class. When this is done knowledge about the real world can be captured. It is by repeating this process that a knowledge base can be developed, since a knowledge base is a collection of instances of classes of interest for a given task.

4- Conclusions and Future Works

For the purpose of identifying and organizing the manufacturing quality knowledge needs of different product design decisions, this paper build a preliminary ontology which can help us understand specific kinds of manufacturing knowledge that different design decisions need. The common-used methodology is adopted for ontology development. All the design decisions and related manufacturing quality knowledge are identified along with the engineering design process which is adapted from Pahl & Beitz's works. The DD-MQK ontology is constructed by using the ontology editor named Protégé. Based on the DD-MQK ontology, more and more detailed knowledge, for example the knowledge extracted from domain expert or from manufacturing data, can be filled as instances of the classes in the ontology. With long term accumulation, the knowledge in the ontology can be exported and used for further construction of manufacturing quality knowledge base for supporting design decisions, which is the most important part in future works.

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