DESIGN ONTOLOGY MODELING USING IDEF5

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Md B. Sarder
PhD Candidate and Graduate Teaching Associate
Department of Industrial and Manufacturing Systems Engineering
University of Texas at Arlington,
Box 19017
420 Wolf Hall
Arlington, Texas – 76019, USA
E-mail: bsarder@hotmail.com

Don H. Liles
Professor and Chair
Department of Industrial and Manufacturing Systems Engineering
University of Texas at Arlington,
Box 19017
420 Wolf Hall
Arlington, Texas – 76019, USA

Abstract: Ontologies are being constructed for a growing number of manufacturing, engineering, and scientific domains in order to realize many benefits on a local and/or global scale. An important benefit is the ability to access and reuse a huge number of ontologies in the design and construction of new systems. The nature & use of ontology differs from domain to domain. Ontology of medical vocabularies is certainly different from product and process design ontology in terms of intended use. In this paper we have discussed about ontology modeling tools & techniques, requirements of design ontology, and how IDEF5 fulfills these requirements while building design ontology. IDEF5 is being developed in the belief that it can contribute in a vital way to the realization of global knowledge sharing. The IDEF5 method therefore fulfills an important need by providing a cost-effective mechanism to acquire, store, and maintain scaleable and re-usable design ontologies.

Keywords: Design ontology, Manufacturing enterprises, Product & process design, IDEF5

1. Introduction

An important requirement for world-class Product & process design process is the ability to capture knowledge from multiple disciplines and store it in a form that facilitates re-use, sharing, and extendibility. Taxonomies and glossaries, in and of themselves, will not fully address this requirement. These taxonomies will need to be supplemented so as to circumscribe the meanings and logical properties of the terms as precisely as possible (Benjamin P., 1995). There is a perceived need for ontologies rather than mere taxonomies. Ontologies are becoming increasingly important because they provide the critical semantic foundation for many rapidly expanding fields of knowledge. They are very useful for knowledge reuse, knowledge sharing, and enterprise modeling. In the following sections we have discussed the ontology modeling techniques, the benefits of ontology modeling, design ontology and its characteristics, and how IDEF5 can be used to build design ontology.

2. Ontology Modeling

Ontology modeling is gaining momentum among enterprise engineers. This model helps enterprise engineers to understand the insights of the systems. In an ontology model, descriptors are cataloged (like a data dictionary) and create a model of the domain, if described with those descriptors. Thus, in building an ontology, it must produce three products, which are to catalog the terms, capture the constraints that govern how those terms can be used to make descriptive statements about the domain, and then build a model that when provided with a specific descriptive statement, can generate the "appropriate" additional descriptive statements.

In the context of knowledge sharing, the term ontology means a specification of a conceptualization. That is, an ontology is a description (like a formal specification of a program) of the concepts and relationships that can exist for an agent or a community of agents (P. Benjamin, 1995). This definition is consistent with the usage of ontology as set-of-concept-definitions, but more general. And it is certainly a different sense of the word than its use in philosophy. Ontologies are often equated with taxonomic hierarchies of classes, class definitions and the subsumption relation, but ontologies need not be limited to these forms. Ontologies are also not limited to conservative definitions, that is, definitions in the traditional logic sense that only introduce terminology and do not add any knowledge about the world (Enderton, 1972).

Any domain with a determinate subject matter has its own terminology, a distinctive vocabulary that is used to talk about the characteristic objects and processes that comprise the domain. The nature of a given domain is thus revealed in the language used to talk about it. Clearly, however, the nature of a domain is not revealed in its corresponding vocabulary alone; in addition, one must (i) provide rigorous definitions of the grammar governing the way terms in the vocabulary can be combined to form statements and (ii) clarify the logical connections between such statements. Only when this additional information is available is it possible to understand both the natures of the individuals that exist in the domain and the critical relations they bear to one another. An ontology is a structured representation of this information. More exactly, an ontology is a domain vocabulary together with a set of precise definitions, or axioms, that constrain the meanings of the terms in that vocabulary sufficiently to enable consistent interpretation of statements that use that vocabulary.

2.1. Objective of Ontology modeling

The primary goal of the Ontology Description Capture method is to provide a structured technique, supported by automated tools, by which a domain expert can effectively develop and maintain usable, accurate, domain ontologies. A key to effective integration is the accessibility of rich ontologies characterizing each of the domains addressed by each cluster. For instance, access to a manufacturing ontology that includes constraints on how a given part is manufactured can aid designers in their design of a complex product by giving them insight into the manufacturing implications of their design concepts. Similarly, access to an engineering ontology that includes constraints on how a given part is to function given a particular shape or fit can aid process planners in their development of the appropriate manufacturing processes. A commonly accessible collection of relevant ontologies thus permits more efficient sharing of information arising from various sources within the enterprise.

An enormous problem in the coordination of collaborative team is the diversity of backgrounds the various kinds of team members bring to their respective roles. As a consequence, many members use similar terminology in many different ways with many different connotations. Because of such differences, the information that one member intends to convey to another may in fact become garbled; in the best case, such miscommunications can be responsible for a great deal of lost time and resources. Consequently, it is often necessary in the course of a large project to standardize the relevant vocabulary. The ontology capture method provides a principled method for carrying out this task efficiently and effectively, and maintaining the results of the task in a robust, accessible form.

2.2. Modeling Tools & Techniques

Over the last few decades numerous modeling techniques, used to define requirements for building information systems, processes, activities, ontologies, etc. have emerged with no consistent theoretical foundation underlying their conception or development. Concerned that this situation would result in the development of models that were unable to completely capture important aspects of the real world, WAND and WEBER (Wand and Weber, 1989; Wand and Weber, 1990; Wand and Weber, 1993; Wand and Weber, 1995) developed and refined a set of models based on an ontology defined by BUNGE (Bunge, 1977) for the evaluation of modeling techniques. There has been further work concentrating on the ontological evaluation of process modeling related techniques, see, for example, (Opdahl and Henderson-Sellers, 1999; Soffer et al., 2001) Some of these techniques rely on an object-oriented (OO) paradigm (like UML, OML, OPM). Stanford University research center developed well-known Protégé tool for ontology modeling. This tool is being widely used to build ontology because of its automated sharing information feature.

IDEF models are widely used in the mid 90's for various modeling such as activity modeling, process modeling, information modeling, ontology modeling, etc. Among all of these, activity modeling and process modeling is very familiar. IDEF5 is being developed in the belief that it can contribute in a vital way to the realization of this vision of global knowledge sharing. The IDEF5 method therefore fulfills an important need by providing a cost-effective mechanism to acquire, store, and maintain scaleable and re-usable ontologies (P. Benjamin, 1995). The intended contribution of IDEF5 is a method to guide and assist domain experts and knowledge engineers in the construction of both small and large reusable ontologies. From the above discussion it has been shown that IDEF5 is a powerful tool to build ontology but never got exposure. It is better than Protégé in terms of graphical presentation as well as comprehensiveness.

2.3. Benefits of Ontology Modeling

Ontology modeling provides a wide range of benefits in the area of enterprise engineering. Domain ontology, standardized terminology with precise meanings that are fixed across industries and across international borders, can be access and reuse in the design and construction of new systems. Central products of this effort include the Knowledge Interchange Format (KIF), a text-based logical language for the interchange of knowledge, and Ontolingua, a mechanisms built on KIF for translating knowledge between different representation languages (P. Benjamin, 1995). The UML, Protégé, and IDEF5 methods have been designed with the Knowledge Sharing Effort and its vision closely in mind. Most notably, the IDEF5 elaboration language is the central medium for storing ontology information collected via the

IDEF5 method - uses KIF as its foundation, and is thus wholly compatible with the central tools of the Knowledge Sharing Effort. This is particularly crucial as the concepts behind the effort become even more widely accepted and implemented.

Ontology development provides several benefits to organized enterprises. The benefits of ontology development can be grouped under two headings:

1. Benefits of developing the ontology: The process of ontological analysis is a discovery process that leads to an enhanced understanding of a domain. The insights of ontological analysis are useful for (i) identification of problems (diagnosis), (ii) identification of the problem causes (causal analysis), (iii) identification of alternative solutions (discovery and design), (iv) consensus and team building, and (v) knowledge sharing and reuse.

2. Benefits derived from the products of ontology development: The ontologies that result at the end of an ontology development effort can be used beneficially for (i) information systems development: ontologies provide a blueprint for developing more intelligent and integrated information systems, (ii) systems development: ontologies can be used as reference models for planning, coordinating, and controlling complex product/process development activities, (iii) business process reengineering: ontologies provide clues to identifying focus areas for organizational restructuring and suggest potential high-impact transition paths for restructuring.

3. Product & Process Design Ontology

In modern design environments products are so complex that correct externalized information and knowledge must be readily accessible by the designer. Unlike any other function in the manufacturing enterprise, design is the most important in terms of cost allocation. According to current research about 70% to 80% of a products cost is determined in the design phase (Mike True & Carmine Izzi, 2001). In that case manufacturers have a great risk if the design process is not appropriate. Manufacturing enterprises cannot afford to have a design on wrong information. It is widely believed that design engineers spend up to 47% of their time seeking design information in the design process (Hales, 1987). Given that design can be described as a problem solving process and considering that engineers tend to solve problems based on available knowledge. It is important to ensure that appropriate knowledge is available at the correct time in the process (Lawson 1990; Cross 1994; Hubka 1996; Pahl and Beitz 1996). Knowledge can be made available in two ways, i.e. external (established from the experience of others, existing research and new research) or internal (designers own experience and knowledge established through learning) (Lawson 1990). Both external and internal knowledge can be represented by the design ontology.

An appropriate design representation scheme is a prerequisite for an efficient design system. As the design ontology aims to support the evolutionary process of design reuse, and its representation scheme should be able to capture the information and knowledge involved at all stages of the design process. Much research has been devoted to issues relating to problem clarification, conceptual design and detailed design. Less effort has been made to the embodiment design representation, especially from a computational perspective (Ong & Guo, 2004).

Design ontology could be site specific, practice, or domain in nature. These levels are useful when scoping an ontology-building effort. The first is the site-specific ontology. This describes all of the relevant concepts, terminology, structures, and relationships for a specific industrial site. For example, GM plant in Arlington might create ontology to describe its facilities. The second type of ontology is known as practice ontology. Practice ontologies are models of an entire industry. For example, a group of automobile manufacturing companies might develop an ontology for the automobile industry as defined by the companies. The third type of ontology is the domain ontology. This represents all of the information known about a general domain. For example, one might develop a domain ontology for automobile manufacturing in general that includes new research from universities that has not yet been incorporated by industry.

There is often overlap among the levels of ontologies, and all site specific and practice ontologies are subsets of the domain ontology. Generally the design ontology is a domain specific ontology and can be converted to other according to need. The design ontology must posses some/ all of the following characteristics;

- Accurate and up-to-date information
- Easily sharable & reusable
- Enable to capture future research and lesions learned
- Consistent information
- Visual & structured representation

4. Building Design ontology using IDEF5

As mentioned earlier that IDEF5 is a powerful tool to capture design knowledge and build the design ontology. It is easy to use and step-by-step method. In the IDEF5 method, capturing the content of certain assertions about real-world objects, their properties, and their interrelationships and representing that content in an intuitive and natural form construct ontology. This section describes the IDEF5 ontology description development process. As described earlier, an ontology characterizes what exists: the kinds, their properties, and their interrelationships in a given domain, as revealed in the terminology used by experts in the domain. A complete ontology, then, reveals the fundamental nature of a given domain. The construction of ontology differs from traditional information capture activities in the depth and breadth of the information captured (P. Benjamin, 1995). Thus, an ontology development exercise will go beyond asserting the mere existence of relations in a domain.

4.1. Central concept of IDEF5

The basic concepts in IDEF5 are “Kind” and “Relations”. A kind is an objective category of objects that are bound together by a set of properties shared by all and only the members of the kind. Classes, types, and kinds all indicate some grouping of individuals into categories and roughly equivalent. Properties differ from attributes. An attribute is best thought of as a function, that is, a mapping that takes each member of a given set of individuals to a single specific value. By contrast, a property is intuitively not such a mapping. Rather, they are just characteristics of things, “ways things are,” abstract, general characteristics that individuals share in common. Circles graphically represent kinds with a label in its center. Properties are different in kinds such as essential vs. accidental and defining vs. nondefining. Figure 1 demonstrates the difference of properties.

Go to Directory...

	Defining	Nondefining
Essential	Kind: **Rectangle** Property: *having four sides*	Kind: **Circle** Property: *having no interior angles*
Accidental	Kind: **Cutter** Property: *having a diamond insert*	Kind: **Req'ts document** Property: *being 10 pages in length*

Figure 1. Defining/Nondefining vs. Essential/Accidental Properties (P. Benjamin, 1995)

Relations are the interactions of kinds and instances to each other. IDEF5 supports the description of relationships among kinds, among instances, and among kind and instances. It explicitly supports the relation "subkind-of". The relations in an ontology are typically binary; that is to say, they hold between two entities, as with the relation works-in. IDEF5 allows the characterization of the relation in greater detail. Thus, an IDEF5 model of the higher than relation might declare that this relation has the property of being transitive. Moreover, IDEF5 provides mechanisms for characterizing the nature of transitivity by means of appropriate axioms (i.e., rules and constraints governing the behavior of relations with that property). Axioms are recorded using the IDEF5 elaboration language. Lines graphically represent relations with arrow in the tail or in the front.

4.2. IDEF5 Development Process

Ontology development requires extensive iterations, discussions, reviews, and introspection. Knowledge extraction is usually a discovery process and requires considerable introspection. It requires a process that incorporates both significant expert involvement as well as the dynamics of a group effort. Given the open-ended nature of ontology analyses, it is not prudent to adopt a "cookbook" approach to ontology development (P. Benjamin, 1995). It recommends the use of a general procedure along with a set of useful guidelines. The IDEF5 ontology development process consists of the following five activities.

• *Organize and Define Project* This activity involves establishing the purpose, viewpoint, and context for the ontology development project and assigning roles to the team members.

• *Collect Data* This activity involves acquiring the raw data needed for ontology development.

• *Analyze Data* This activity involves analyzing the data to facilitate ontology extraction.

• *Develop Initial Ontology* This activity involves developing a preliminary ontology from the acquired data.

• *Refine and Validate Ontology* This activity involves refining and validating the ontology to complete the development process.

Although these activities are listed sequentially, there is a significant amount of overlap and iteration between the activities.

4.3. Detail Ontology Capture

The IDEF5 Description Summary Form summarizes the evolving/completed ontology description. It records the purpose, viewpoint, and context and also provides a summary of all the schematics and documents used to record the ontology. The following are the fields of an IDEF5 Description Summary Form (see Figure 2).

IDEF5 Description Summary Form		
Project: Product & Process Design Ontology	Analyst: MD Sarder	Reviewer: Don Liles
Version:	Review Starting Date:	Review completion Date:
Purpose: To develop an ontology of the Product & Process Design domain for manufacturing enterprises.		
Context: The information acquired must be sufficient to plan design activities, specify precedence relationships, and supports world-class design procedures.		
Viewpoint: Collaborative design team.		
List of Documents Source Material Log Source Material Description Source Statement Source Statement Description Term Pool, Relation Pool Term Description Form Proto-Kind Pool Proto-Kind Specification Form Proto-Relation Pool	Proto-Relation Specification Form Proto-Characteristic Pool Form Kind Pool Pool Property Pool Form Attribute Pool Relation Specification Form Classification Schematic Composition Schematic Relation Schematic Kind Specification Form	

Figure 2. IDEF5 Description Summary Form

The Source Material Log is a document that serves as the primary index to all source material collected and utilized in the project. Each piece of source material is sequentially assigned a unique identifying number as the log is filled out (Figure 3). A source material may be a text book, a research article, an enterprise-specific document such as a policy manual or a procedure manual, a set of an interview notes, or direct observation notes.

Source Material Log				
Project: Designing Product/process ontology			Analysts: MD Sarder	
Source material #	Source material name	Collected from	Collected by	Date of Collection
SM # 1	"Operate a Small Integrated Manufacturing Enterprise" by Don Liles, ARRI, 1995	---------	Sarder	12/15/04
SM # 2	"Product Development and Design for Manufacturing" by John W. priest & Jose Sanchez, Marcel Dekker, Inc. New York, 2001	---------	Sarder	04/21/04
SM # 3	"Collaborative Evaluation of Early Design Decisions and Product Manufacturability" by S. D. Kleban et el, Proceedings of the 34th Hawaii International Conference on System Sciences - 2001	----------	Sarder	2/23/05
SM # 4	"Complexity and learning behaviors in product innovation" by Ross Chapman and, Paul Hyland. Technovation 24, 2004	----------	Sarder	6/24/05
SM # 5	"Coordination at different stages of product design process" by Antonio J Bailetti et el, R&D Management 28, 4, 1998	----------	Sarder	9/14/05
…	…	…	…	…

Figure 3. Source Material Log

The Source Material Description Form provides a summary of the source material information. For each source material item referenced in this log, there is a Source Material Description that is used to record more detailed information. The following fields are used in a Source Material Description Form (see Figure 4).

Source Material Description Form
Project: Product & Process Design Ontology
Analysts: MD Sarder
Source material #: SM # 3
Source material name: Collaborative Evaluation of Early Design Decisions and Product Manufacturability" by S. D. Kleban et el, Proceedings of the 34th Hawaii International Conference on System Sciences - 2001
Purpose: To record the relevant source statements that help individuate ontology elements in the product & process design domain.
Comments: This source material concerns early design stage and manufacturing of goods.
Abstract: In manufacturing, the conceptual design and detailed design stages are typically regarded as sequential and distinct. Decisions made in conceptual design are often made with little information as to how they would affect detailed design or manufacturing process specification. Many possibilities and unknowns exist in conceptual design where ideas about product shape and functionality are changing rapidly. Few if any tools exist to aid in this

difficult, amorphous stage in contrast to the many CAD and analysis tools for detailed design where much more is known about the final product. The Materials Process Design Environment (MPDE) is a collaborative problem solving environment (CPSE) that was developed so geographically dispersed designers in both the conceptual and detailed stage can work together and understand the impacts of their design decisions on functionality, cost and manufacturability.
Terms Supported: T#2, T#5, T#12, T#15
Statements supported: SS#3, SS#5

Figure 4. Source Material Description Form

The Source Statement Pool records meaningful statements made by different individuals, as well as statements extracted from source documents during the ontology development effort. Each source statement is given a unique identification number to improve traceability. The following fields are used in a Source Statement Pool (see Figure 5).

Source Statement Pool		
Project: Product & Process Design Ontology		Analysts: MD Sarder
Source Statement #	Source Statement	Supported by
SS#1	Engineering Design activities result in recommended manufacturing specifications that satisfy the customer's functional performance requirements and manufacturing constraints.	MD Sarder
SS#2	Resources may be classified as personnel, computer systems, and facilities.	MD Sarder
…	…	…

Figure 5. Source Statement Pool

Once source statement pools are completed, descriptions of those statements are logged using Source Statement Description Form. The following fields are used in a Source Description Form (Figure 6).

Source Statement Description Form		
Project: Product & Process Design Ontology		Analysts: MD Sarder
Source Statement #: SS#1	Statement #S Evolved To:	Status: *Active / Retired* *Original / Derived*
Source Material #: SM#2	Statement #S Derived From:	

Source Statement: Engineering Design activities result in recommended manufacturing specifications that satisfy the customer's functional performance requirements and manufacturing constraints.	Supported by: MD
Version 1: Engineering design deals with the target specifications that will meet customer's functional requirements.	Supported by: MD
Version 2:	Supported by:
Version 3:	Supported by:
Comments:	

Figure 6. Source Statement Description Form

The meaningful terms relevant to the ontology development project effort are recorded alphabetically in a Term Pool. Terms often evolve to proto-kinds, proto-characteristics, proto-relations, kinds, characteristics, and relations (Figure 7).

Term Pool				
Project: Product & Process Design Ontology			Analysts: MD Sarder	
Term #	Term	Source Statement Reference	Source Material Reference	Support list
Term # 1	Engineering Design	SS#1	SM#2	MS
Term # 2	Resource	SS#2	SM#13	DS, MS
…	…	…	…	…

Figure 7. Term Pool

The Term Pool provides a list of the terms used to derive the ontology. Each term in the Term Pool is described in greater detail using the Term Description Form (see Figure 8).

Term Description Form		
Project: Product & Process Design Ontology		Analysts: MD Sarder
Term #	Term	Description
Term#1	E. Design	Engineering design is process of translating customer requirement into design specifications.
Term#2	Resource	Resources are objects/personnel that are consumed, used, or required to perform activities and tasks. Resources play an enabling role in processes.
…	…	…

Figure 8. Term Description Form

All the above forms are the output of data collection and analysis towards building ontology. Once all forms are completed an initial ontology will be build using the terms pool after finding all kinds and relations. Initial ontology will then be validated and presented as a Schematic and/or elaborative language.

4.4. IDEF5 Ontology Languages

A domain ontology is a detailed characterization of "what there is" in a given application domain. Such characterizations must, of course, be given in some language; hence, languages play an important role in the ontology capture process (P. Benjamin, 1995). More specifically, languages for ontology capture are important for two reasons.

- They provide a medium for capturing and storing knowledge.
- They provide a format for displaying the acquired knowledge.

Representational structures that are rich in expressive power are important for ontology because previously acquired knowledge is often used to guide the process of acquiring additional knowledge. Because it cannot generally be determined a priori what sorts of representational structures will be needed to capture the ontology of a given domain, languages for ontology need to be expressively very rich. The ontology languages must have a synergistic relationship with the ontology development procedure. That is, the languages must support the use of the procedure and the procedure must support the use of the languages. IDEF5 has two languages.

• *The IDEF5 Schematic Language* This language is the graphical component of the IDEF5 languages. It provides visual assistance in the ontology capture process and facilitates communication. There are some symbols used to build the graphical representation of ontology.

Following figure 9 shows a typical IDEF5 schematic diagram for the composition of ballpoint pen. This pictorial diagram presents lot of information regarding components, sequence of operation, types of operations and so on. Such kind of representation is very effective and helpful for the design team to reduce their design time.

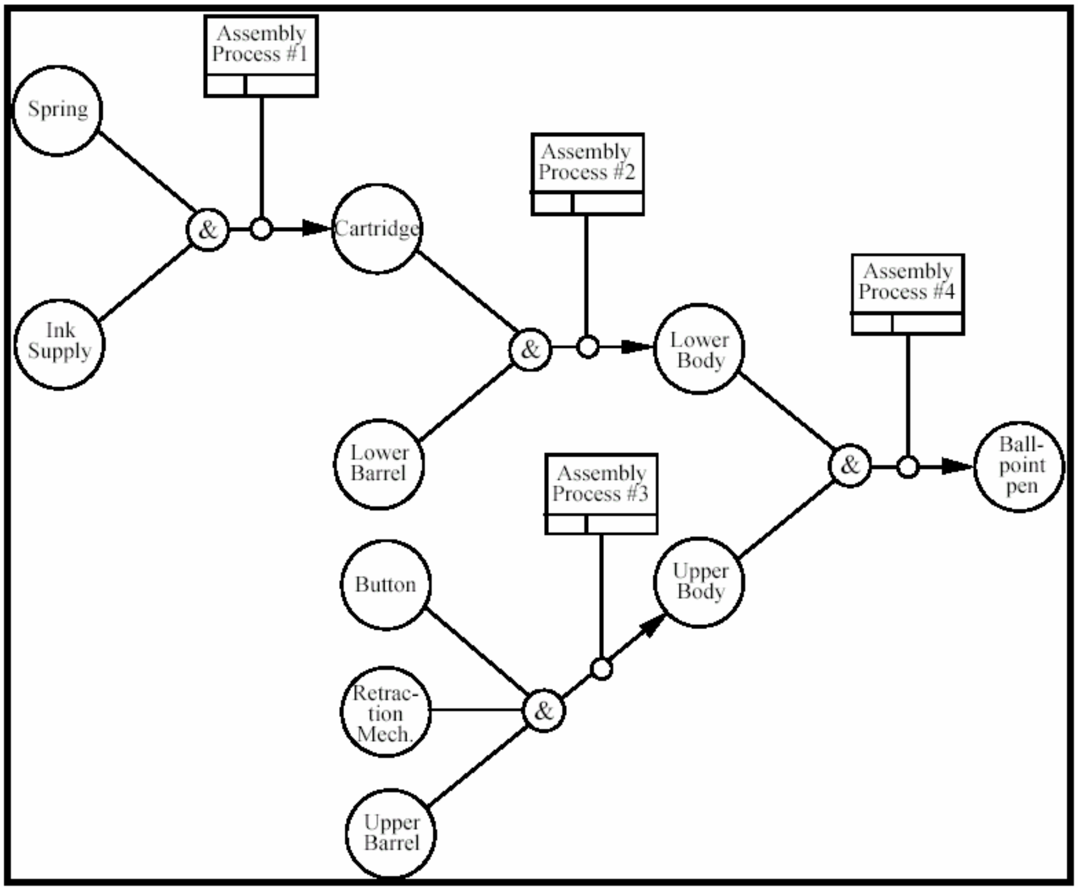

Figure 9. Composition Schematic for the Kind Ballpoint Pen (P. Benjamin, 1995)

• *The IDEF5 Elaboration Language* This language is a structured textual language and has the full power of first-order logic. The two IDEF5 languages complement and supplement each other. The Schematic Language is somewhat restricted in expressive power. However, the graphical structures of this language make it intuitive and easy to use.

5. Conclusion

In recent years a lot of research is going on to develop ontologies. Stanford University Knowledge Systems Laboratory is playing a vital role to develop ontology tools and techniques and sharing related information. Many disciplines now develop standardized ontologies that domain experts can use to share and annotate information in their fields. Design of product and process need such kind of ontology for its own. This research presented a need for such ontology and how to build it by using IDEF5.

6. References

1. Don Liles, (1995), “Operate a small integrated manufacturing enterprise”, The Automation & Robotics Research Institute, University of Texas at Arlington.

2. Gruber, T.R. (1993), “A Translation Approach to Portable Ontology Specification”, Knowledge Acquisition 5: 199-220.

3. Hobbs, J., Croft, W., Davies, T., Edwards, D., and Laws, K., (1987), “The TACITUS Commonsense Knowledge Base”, Artificial Intelligence Research Center, SRI International

4. Hubka, V. (1996). Design Science, Springer-Verlag.

5. Lawson, B. (1990). How Designers Think, 2nd Ed.

6. Menzel, C. P., and Mayer, R. J., (1991), IDEF5 Concept Report, Integrated Information Systems Evolution Environment, United States Air Force AL/HRGA, Wright-Patterson Air Force Base, OH.

7. Mike True & Carmine Izzi (2001), “Collaborative Product Commerce: Creating Value Across the Enterprise, Accenture

8. Opdahl, A. L. and Henderson-Sellers, B., "Evaluating and Improving OO modelling languages using the BWW-model," C. N. G. Dampney (Ed.), Sydney, 1999, pp. 31-38

9. Pahl, G., and W. Beitz, (1996), Engineering design, 2nd Ed. New York, Springer-Verlag.

10. Perakath C. Benjamin, Christopher P. Menzel, Richard J. Mayer, and Natarajan Padmanaban, (1995), “Toward a Method for Acquiring CIM Ontologies”, International Journal of CIM, 8(3), pp 225-235

11. S. K. Ong and D. O. Guo, (2004), “Online design reuse tool for the support of the generation, embodiment and detailed design of products”, International journal of production research, 15 August, vol. 42, no. 16, pp3301–3331

12. Wand, Y. and Weber, R., "On the Deep Structure of Information Systems," Information Systems Journal, (5:3), 1995, pp. 203-223.

13. Wand, Y. and Weber, R., "On the Ontological Expressiveness of Information Systems Analysis and Design Grammars," Journal of Information Systems, (3:4), 1993, pp. 217-237.

14. Wand, Y. and Weber, R., "On the Deep Structure of Information Systems," Information Systems Journal, (5:3), 1995, pp. 203-223.

15. Wand, Y. and Weber, R., "An Ontological Model of an Information System," IEEE Transactions on Software Engineering, (16:11), 1990, pp. 1282-1292.

16. Weber, R., Ontological Foundations of Information Systems, Coopers & Lybrand, Melbourne, 1997.