ONTOLOGY OF MANUFACTURING ENGINEERING

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Abstract

Manufacturing sector in Malaysia is the main driver in the economy. Therefore, most of the universities in Malaysia have Manufacturing Engineering Programs. Actually number of Manufacturing Engineering Programs is higher than Industrial Engineering Programs throughout the country. The related departments in Higher Education Organizations make frequently Benchmarking studies to compare their Manufacturing Engineering Programs with the other universities not only in the country but also in the region. Manufacturing Engineering Department at IIUM has been conducting another major curriculum review to update the program based on the recent changes in Faculty Outcomes for New Accreditation period by taking stakeholders' feedback into account. This paper proposes the use of a data-model based Ontology of Manufacturing for reviewing and changing the Manufacturing Engineering Programs and gives a kind of benchmarking for the new Manufacturing Engineering Program at IIUM.

Keywords: Ontology Engineering, Artificial Intelligence, Manufacturing Engineering, Data Modeling, AI in Education

1. Introduction

Ontology Engineering coming as a result of Knowledge Representation studies in Artificial Intelligence (AI) has been increasingly popular in Education [1]. An ontology is a specification of a conceptualization. The word "ontology" seems to generate a lot of controversy in discussions about AI. It has a long history in philosophy, in which it refers to the subject of existence. It is also often confused with epistemology, which is about knowledge and knowing. In the context of knowledge sharing, The term ontology is used to mean 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. 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 [2]. Ontology has two main features as follows:-

- the conceptualization of a domain, i.e. a choice on a way to describe a domain.
- the specification of this conceptualization, i.e. its formal description.

Semantic Web seems to be the future direction of internet search due to its ability to seek/retrieve knowledge in internet in an automated way. The Semantic Web relies heavily on formal ontologies to structure data for comprehensive and transportable machine understanding. Thus, the proliferation of ontologies factors largely in the Semantic Web's success [3].

The domain ontologies are useful in education since a high amount of learning may be regarded as conceptualization of things which is conducted simply as transfer of materials in many cases in a passive learning format. Hence, the construction of ontologies in education for different learning domains is required. On the other hand, the benchmarking studies for curriculum development processes have been commonly used by many institutions.

Benchmarking of programs with other institutions in country and other countries is a common technique used in educational institutions. Benchmarking documents are also provided in external accountability (accreditation) procedures to third parties as evidence of being in-line with others.

We believe that the Benchmarking with other programs is not enough to comply with the requirements of learners in a specific domain. This paper suggests a technique to compare the program curriculum with ontologies. Manufacturing Ontology is developed as data model and compared with the new suggested program in Manufacturing Department at IIUM.

2. Ontology of Manufacturing

There are various studies in literature to construct Manufacturing system information models such as CIMOSA [4], MOSES [5, 6], FDM [7] and MISSION [8]. They describe the structure and relationships of data and information elements within manufacturing enterprise information systems. However, modeling the manufacturing engineering domain according to the concepts and principles of ontology engineering is quite new. In this study, a data modeling based ontology for manufacturing is suggested. Fig. 1 shows the suggested ontology for a generic enterprise which may be used for manufacturing.

The main entities are six in the Manufacturing enterprise, namely *Purpose, Facility, Actor, Process, Organizational Unit, Object* and *Operations*. Main entities may be used to hold data to non-specific, generic to all manufacturing. Since ontologies only carry general concepts, the other two entities called *Operations* and *Process Involvements* are specific to enterprise. Specially *Operations* entity has two important parameters called *Time* and *Location* which vary vastly as a choice of the particular interest for every manufacturing organization.

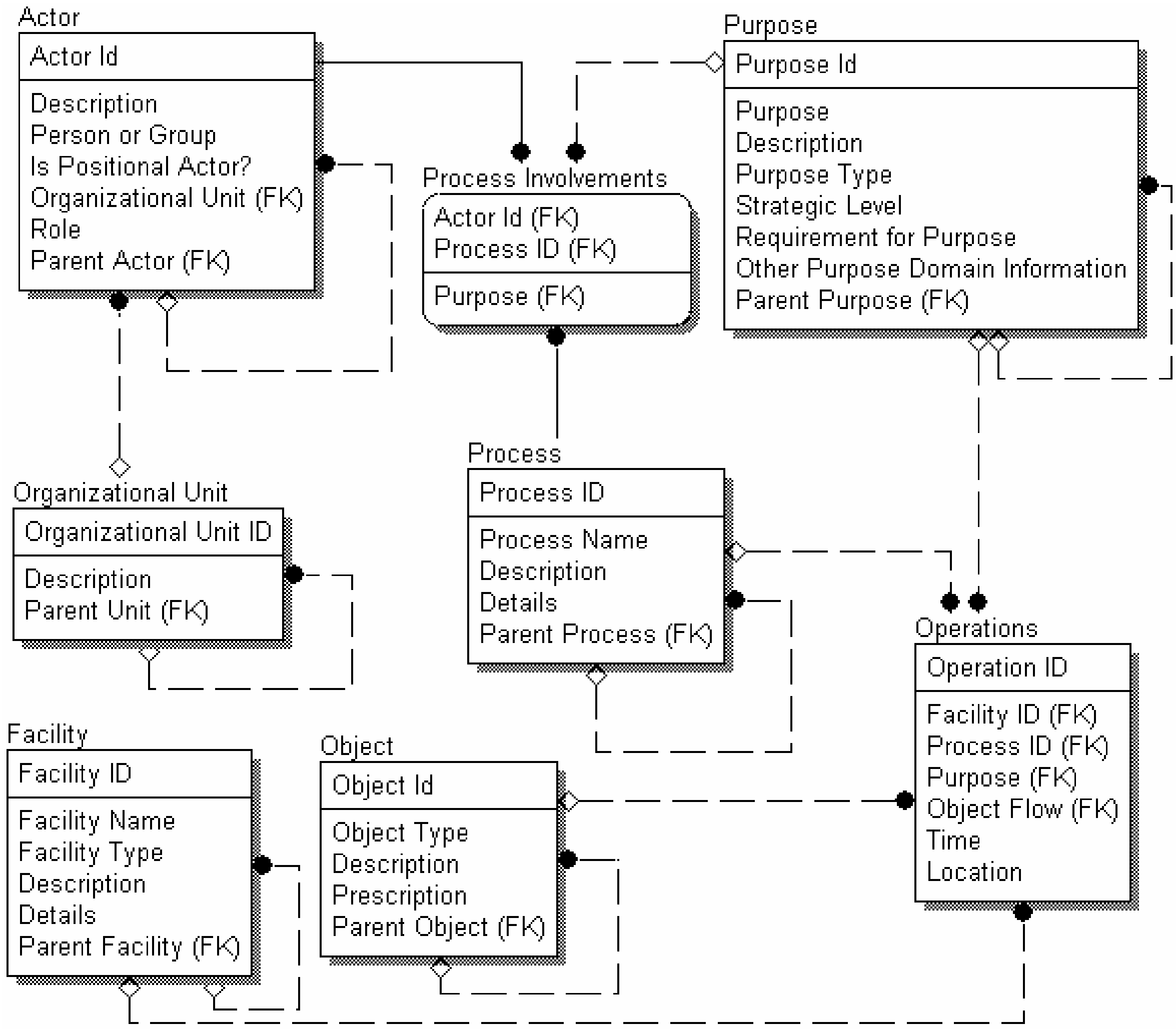

Figure 1. Data Model for Ontology of a Manufacturing Enterprise

A good manufacturing enterprise can effectively and efficiently control its operations on what we call 4Ms which are namely Man, Machines, Methods and Materials. The above entities in the conceptual domain somehow coincide with the 4Ms.

The following briefly describes the entitites in the domain.

Purpose is perhaps the most important entity in domain since it affects the success of *Operations*. *Purpose Type* may be simple a reason, goal or an objective. Purpose may be also be at three different levels namely strategic, tactical and operational levels which may depend on *Process* or *Actor* involved in the *Process Involvement*. *Requirement for Purpose* may be for effectiveness or efficiency. Purposes may be constructed in a hierarchy by using *Parent Purpose* information. *Purpose* may be an objective and even a problem solution in which case several other attributes may be derived such as structural, non-structural solutions etc. Some examples for *Purpose* are Achieving operational efficiency, Setting vision and mission, Ability to use Strategic Management Tools, Identifying/Solving Structured and Un-structured Manufacturing Engineering Problems, Selection of Machine Tools in a certain Manufacturing Process, etc.

Facility is the resources, tools, or other assets to perform the *Operations*. *Facility Type* may be money, energy, labor power, machine tools, etc. Facilities also organized in a hierarchy based on the attribute *Parent Facility* depending on the type of layouts such as Job-shop, Batch or Mass Production. Some examples of *Facility* are Manufacturing Models, Material Handling Systems, Flexible Manufacturing Systems, Cellular Manufacturing, and Machine Tools.

Actor is the one responsible for carrying out the processes. It may a person, a role described in *Organizational Unit*. Every *Actor* whether having a human or a position attribute has a kind of *Job Description*. Every *Actor* has a *Parent Actor* which finally makes up the hierarchy of all Actors. *Actor* may be associated with the organizational roles in *Process Involvements* and has a relation to *Purpose*. Actors have associations in different management levels such as first level, midlevel or top level. Managers, Production Planners, Technicians, Supervisors, and Foremen are examples of *Actor*.

Process is any kind of activity or action to be performed in the manufacturing enterprise. They are the basic descriptions of Operations. Parent Process is similarly defines the hierarchy of all processes. It has connection to *Process Involvement* entity in specific domain. When considering *Process* as an action it may have relation to certain management functions such as planning, organizing, staffing (human aspects of organizing), leading and motivation, and controlling. Financial Process, Product Design Process, Manufacturing Process, Scheduling Process, Inventory Management Process, BOM Process, Turning are all examples to *Process.*

Organizational Unit is simply organizational structure of the enterprise. It may contain information about the whole enterprise itself or specific units under manufacturing department.

Object entity holds concepts about materials and information necessary to perform manufacturing *Operations*. They flow through the *Operations*. Supply-chain information flow, Manufacturing Inputs (Raw Materials), Engineering Drawing of parts to be manufactured are examples to the entity *Object*.

Operation is not a generic concept in manufacturing ontology due to its Time and Location attributes. It is specific to the manufacturing enterprise. When all data entered, the timely operations based on Location and Strategic Level (due to relation to *Purpose*) may be obtained. *Operation* data may be used for data mining purposes. Operations are common examples of first-level production activities.

The above entities are generic and more attributes to each entity may be added later.

3. Database Implementation of the Ontological Model

Since data models are good candidates for transforming the logical models into physical database structures, data modeling approach to construct ontologies presents an effective and efficient way. By even using Computer Aided Software Engineering (CASE) tools, the models may be transformed to physical database designs automatically. Data models are logical representation of the specific ontology developed without having to materialize the design specific information such as data types in a particular database. SQL scripts are convenient way to facilitate the physical design of databases among major Database Management Systems (DBMS). They are used to create/modify the database elements in metada level as well as to insert, delete, update and retrieve data conveniently without depending on a particular DBMS.

The model in Fig. 1 was transferred to Oracle Database Management System by using Structured Query Language (SQL). Fig. 2 shows the SQL language scripts to transfer logical design information to database. This SQL script produces all database elements including the physical tables and relations between the entities.

```
CREATE TABLE Object (
 Object_Id INTEGER NOT NULL,
 Object_Type VARCHAR2(20) NULL,
 Description VARCHAR2(20) NULL,
 Prescription BLOB NULL,
 Parent_Object INTEGER NULL,
 PRIMARY KEY (Object_Id),
 FOREIGN KEY (Parent_Object) REFERENCES Object
);
CREATE TABLE Purpose (
 Purpose_Id INTEGER NOT NULL,
 Purpose VARCHAR2(20) NULL,
 Description BLOB NULL,
 Purpose_Type VARCHAR2(20) NULL,
 Strategic_Level VARCHAR2(20) NULL,
 Requirement_for_Purpose VARCHAR2(20) NULL,
 Other_Purpose_Domain_Informati VARCHAR2(20) NULL,
 Parent_Purpose INTEGER NULL,
 PRIMARY KEY (Purpose_Id),
 FOREIGN KEY (Parent_Purpose) REFERENCES Purpose
);
CREATE TABLE Process (
 Process_ID INTEGER NOT NULL,
 Process_Name VARCHAR2(20) NULL,
 Description BLOB NULL,
 Details BLOB NULL,
 Parent_Process INTEGER NULL,
 PRIMARY KEY (Process_ID),
 FOREIGN KEY (Parent_Process) REFERENCES Process
);
CREATE TABLE Organizational_Unit (
 Organizational_Unit_ID INTEGER NOT NULL,
 Description BLOB NULL,
 Parent_Unit INTEGER NULL,
 PRIMARY KEY (Organizational_Unit_ID),
 FOREIGN KEY (Parent_Unit) REFERENCES Organizational_Unit
);
CREATE TABLE Actor (
 Actor_Id INTEGER NOT NULL,
 Description BLOB NULL,
 Person_or_Group VARCHAR2(20) NULL,
 Is_Positional_Actor_ VARCHAR2(20) NULL,
 Organizational_Unit INTEGER NULL,
 Role VARCHAR2(20) NULL,
 Parent_Actor INTEGER NULL,
 PRIMARY KEY (Actor_Id),
 FOREIGN KEY (Organizational_Unit) REFERENCES
Organizational_Unit,
 FOREIGN KEY (Parent_Actor) REFERENCES Actor
);
CREATE TABLE Process_Involvements (
 Actor_Id INTEGER NOT NULL,
 Process_ID INTEGER NOT NULL,
 Purpose INTEGER NULL,
 PRIMARY KEY (Actor_Id, Process_ID),
 FOREIGN KEY (Purpose) REFERENCES Purpose,
 FOREIGN KEY (Process_ID) REFERENCES Process,
 FOREIGN KEY (Actor_Id) REFERENCES Actor
);
CREATE TABLE Facility (
 Facility_ID INTEGER NOT NULL,
 Facility_Name VARCHAR2(20) NULL,
 Facility_Type VARCHAR2(20) NULL,
 Description BLOB NULL,
 Details BLOB NULL,
 Parent_Facility INTEGER NULL,
 PRIMARY KEY (Facility_ID),
 FOREIGN KEY (Parent_Facility) REFERENCES Facility
);
CREATE TABLE Operations (
 Operation_ID INTEGER NOT NULL,
 Facility_ID INTEGER NOT NULL,
 Process_ID INTEGER NOT NULL,
 Purpose INTEGER NULL,
 Object_Flow INTEGER NULL,
 Time DATE NULL,
 Location VARCHAR2(20) NULL,
 PRIMARY KEY (Operation_ID),
 FOREIGN KEY (Object_Flow) REFERENCES Object,
 FOREIGN KEY (Purpose) REFERENCES Purpose,
 FOREIGN KEY (Process_ID) REFERENCES Process,
 FOREIGN KEY (Facility_ID) REFERENCES Facility
);
```

Figure 2. SQL Code to transfer the Ontological Data Model to Database

4. User Interface Design for the Ontological Model

Entry to database is possible through SQL scripts or using generic tools to support data entries to major Database

Management Systems such as Database Explorer. No specific development tool is needed to provide the main entities with the related data. However, for specific enterprises, a user application is needed. This has two reasons. Firstly, many of the users do not know the SQL language. Secondly, the large number of information required specially for entities *Process Involvement* and *Operations* tables require great amount of data.

Since *Operations* and *Process Involvement* data were not dealt, SQL scripting language was used to enter the required conceptual data to the main tables.

Data is entered into the six main tables corresponding to main entities described before. Fig. 3 shows some of the data entries into database table *Processes* (physical database table corresponding to the entity *Process*).

Processes

Process ID	Process name	Parent Process
1	Financial Process	None
2	Invoicing Process	Financial Process
3	Product Design Process	None
4	New Product Design Process	Product Design Process
5	Customized Product Design	Product Design Process
6	Manufacturing Process	None
7	Fabrication Process	Manufacturing Process
8	BOM Process	Manufacturing Process
9	Manufacturing Information Process	Manufacturing Process
10	Scheduling Process	Manufacturing Process
11	Planning Process	Manufacturing Process
12	Supporting Process	None
13	Purchasing Process	None
14	Production Process	None
15	Inventory Process	Production Process
16	Distribution Process	Production Process

Figure 3. Some Data in Database Corresponding to Ontology Element *Process*

Fig. 4 shows the hierarchy obtained from the data in *Process* entity. Hierarchical trees may be obtained similarly from the entities Actor, Organizational Unit, Facility, Object, and Purpose.

5. Use of Manufacturing Ontologies in Benchmarking Manufacturing Engineering Programs

The Manufacturing Engineering Program at IIUM has been reviewed and updated periodically through a major curriculum review process both under Faculty and Departmental Levels. External constituents such as Engineering Accreditation Council of Malaysia and external examiners continually give the feedback during the review process. In this process, both the contents of the courses and also the assessment schemes have been modified. Marking schemes for all courses having final exams, lab based courses, final year projects, Seminars have been improved and rubrics for allocation of marks have been developed for presentation based assessment systems (projects).

Figure 4. Hierarchy of Some Processes in Ontology Element *Process*

All the courses and their learning topics, and many activities in curriculum are reengineered based on the views of the external parties as well as measurement of internal stakeholders such as students. Some examples regarding the changes after review processes are as follows:-

Tutorial courses having no credit hours in the previous curriculum are now shown as separate courses with their own credit hours without exceeding the total load of agreed credit hours. This is expected to reduce the overloading of the students. Project based learning concepts are being incorporated in various courses, such as the product Design and Development Course, the Work Shop Technology course, Laboratory courses, Machine Tools Technology course, the Production Tooling, and other courses in the form of mini course projects. The above courses and also the industrial Training course, the seminar courses and the Final Year projects are expected to develop in graduates the generic skills such as teamwork, leadership, communication and problem identification. Keeping in view that the management courses are of vital importance to Manufacturing Engineers, these courses have been restructured and now the Manufacturing Engineering department itself is offering the Engineering Management course to all the Engineering Faculty students. Apart from this course the manufacturing engineering students are also taking the ‘Decision Science’ and ‘Introductory Economics courses’ offered by the Faculty of Management Sciences. The program also has included Production Planning Control, Quality Control, Manufacturing Strategy and Quantitative Techniques courses. Benchmarking has played an important role for incorporation of changes in the program.

Benchmarking is an important tool to rank the educational programs in Higher Education Institutions. One can expect to see the development of new bench-marking methodologies and the production of a range of benchmarking studies across the higher education sector.

These studies will help rank universities according to various quality indicators by region, by country and even globally; not only according to teaching and research but across the entire range of knowledge missions [9]. In the quality assurance processes which are now emerging, a much wider range of factors is being considered. Universities will not be able to insist on criteria which reflect their intellectual interests alone rather they will be one actor among several and the challenge for them will be to ensure that their legitimate interests survive the negotiation process.

Benchmarking is mainly the comparison of our Manufacturing Engineering Program with other programs in Malaysia as well as abroad. Under the new curriculum review processes which started in 2008, six manufacturing engineering programs have been benchmarked against our manufacturing engineering program. The six programs have been selected from six different universities namely, Universiti Teknoloji Malaysia (UTM), Boston University (USA), Nottingham University (UK), Loughborough University (UK), Atilim University (Turkey), and University Wisconsin (USA).

Fig. 5 shows a small portion of the benchmarking table for Manufacturing Courses related to design area. The table has in detail the course description, credit hours, lab works, optionality of course etc. The course names are also linked to the related courses in the benchmarking table.

	IIUM	Boston University	UTM	Nottingham University	Loughborough University	Atilim University	University Wisconsin
Areas (EAC)	Course	Course	Course	Course	Course	Course	Course
Area 1 (Design)	Engineering Drawing	Engineering Drawing	Engineering Drawing	Design & Manufacture 1	Computer Aided Design	Engineering Drawing	Engineering Drawing I
	Manufacturing Drawing	Conceptual Design & CAD		Industrial Design		Project 1: Product and Process Design	CAD Problems (Solid Modeling)
	Mechanics of Materials		Mechanics of Solids I Mechanics of Solids II			Mechanics of Solids	Design of Jigs, Fixtures and Tooling
	Design of Machine Components		Components Design			Engineering Design Principles	Capstone Design I: Product/System Design
	Product Design and Development	Product Design & Development	Introduction to Design	Design for Manufacture	Engineering Product Design	Product Design	Capstone Design II: Manufacturing Systems Design
		Design for Manufacturing	Design for Manufacture and Assembly	Rapid Product Development	Design for Assembly Manufacturing		
	Production Tooling	Tooling Design	Tooling for Production			Toooling Design	
		Manufacturing System Design				Manufacturing Systems Design	
			Manufacturing Systems				

Figure 5. Part of Benchmarking Table for comparing 7 Manufacturing Programs (Including IIUM)

Ontologies are suggested herein to benchmark the programs to make sure that all concepts are covered throughout the curriculum. To do benchmarking for all curriculum, first, a matrix called Ontology-to-Course Incident Matrix is created. Then every row of data in six main entities is visited and checked against every course. Fig. 6 illustrates general structure of Ontology-to-Course Incident Matrix for benchmarking data for a Manufacturing Engineering Program against the ontology developed in Section 2. The final row in the matrix contains the average frequency of the ontology element visited in different courses. The matrix is usually too large depending on the number of ontology elements.

	Ontology Data																	
	Purpose			*Facility*			*Actor*			*Process*			*Object*			*Organizational Unit*		
Courses	P_1	…	P_n	F_1	..	F_n	A_1	..	A_n	P_1	..	P_n	O_1	..	O_n	OU_1	..	OU_n
Course 1	H							H									L	
Course 2			M			H	L			H			H			H		
Course 3																		
. .																		
Course n																		

Average	H		M			H	L	H		H			H			H	L	

Fig. 6 Ontology-to-Course Incident Matrix for Benchmarking a Program against Manufacturing Ontology (L=Ontology is covered in the related course in L(ow), M(oderate), or H(igh) amount)

Ontology-to-Course incidence matrix has too many values to illustrate here. Therefore, a small portion of incidence matrix is given in Figure 7 as an example to the Ontology element *Process*.

Ontology Elements									
	Process								
Courses	Financial Process	New Product Design	Inventory Management	Material Removal	Heat Treatment	Production Planning	Welding	Mechanical Assembly	Material Handling
MME2104				H			H	H	
MME2105	M			H	H				
MGT3050	H		H			H			
MME3107	L	H						H	
MME3113	M		M			M			
MME4114	M		H			H			
MME4115	M	M	M			M			H
MME4116	M	H		M				M	
Average	M	H	H	H	H	H	H	H	H

Fig. 7 Small portion of Ontology-to-Course Incidence Matrix for *Process* Domain

6. Conclusion

An ontology has been described herein for manufacturing engineering domain using data modeling approach. The data model and related database design issues have been discussed. The common technique of benchmarking used for comparing the educational programs was also discussed. An alternative benchmarking based on the use of ontology was proposed. The technique may be effectively used to benchmark a manufacturing engineering program to the concepts in manufacturing engineering. It was demonstrated on how to apply the technique to benchmark a program to other programs.

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