Proceedings of DET2007
4th International Conference on Digital Enterprise Technology
Bath, United Kingdom
19-21 September 2007

SPECIFYING A MANUFACTURING KNOWLEDGE REUSE FRAMEWORK

David Baxter
Cranfield University
d.baxter@cranfield.ac.uk

Rajkumar Roy
Cranfield University
r.roy@cranfield.ac.uk

James Gao
Greenwich University
j.gao@gre.ac.uk

ABSTRACT

This paper presents the first part of a design life cycle knowledge reuse framework: manufacturing knowledge reuse for design. The results of a manufacturing knowledge capture and classification exercise are presented. The research methodology applies the critical incident technique for the interviews. Interview notes were analysed using qualitative content analysis, identifying themes through coding. The interview content from which themes are identified are then analysed to identify the knowledge content. Both the themes and the knowledge content are cross referenced to any identify differences according to knowledge applied by role. A knowledge structure and ontology framework is proposed to support the storage and reuse of knowledge relating to manufacturing in the design process.

KEYWORDS

Manufacturing knowledge, design knowledge reuse, knowledge framework

1. INTRODUCTION TO MANUFACTURING KNOWLEDGE REPRESENTATION

Various manufacturing knowledge representation techniques exist, including: process representation, including simulation and process modelling; enterprise modelling; supply chain modelling; information modelling; and product feature level modelling.

Manufacturing knowledge can also be embedded in knowledge based systems, and applied to design support. Valentincic and Brissaud (2005) demonstrate an expert system that analyses product geometry to reveal critical features from the manufacturing perspective in a toolmaking application. Kumara et al. (2006) demonstrate a low cost knowledge based system to assess manufacturability of sheet metal parts, using AutoCAD. Their system analyses the product design features against a set of production rules. Another common implementation of knowledge based systems in manufacturing is process planning. Shakeri (2004) demonstrates operation sequencing and tool selection in a CAM system. Sharma and Gao (2002) demonstrate a manufacturing evaluation tool that provides product cost, manufacturing time and resources, based on a process planning system.

As manufacturing knowledge becomes either more complex or less specific (i.e. transmissions or sheet metal parts), the level of support offered tends to reduce from full automation to partial automation or simply engineer support. Howard and Lewis (2006) propose a support tool for assessment of a range of material / process combinations during early design. Their tool can generate comparison reports, including process suitability and economics metrics (costs, roughness, quality, etc). Whilst their method is advanced, in the sense that it performs feature recognition and manufacturability analysis, because it offers a broader range of functions the level of automation is lower. Cochrane proposes a method to integrate manufacturing knowledge using a shared ontology, describing manufacturing processes using PSL. The intention is that any given facility can be described using the proposed framework, however at this stage only a limited number of processes have been included (Cochrane et al, 2005).

Manufacturing models have been proposed (Molina and Bell, 1999), in which resources (machines, tools, operators, etc.), manufacturing processes (machining processes, assembly, etc.) and manufacturing strategies are represented. Costa and Young (2001) propose an information model to support variant and adaptive design. The model allows relationships to be created between product functions and design solutions. It also enables manufacturing methods to be linked. These information models show the structure of the manufacturing enterprise and its relationship to the product rather than the structure of the knowledge applied during the engineering design process. Molina and Bell (2002) developed a CAE framework to support the specification, development and integration of simultaneous engineering systems. The reference model is comprehensive, describing the components and requirements of each simultaneous engineering activity (as defined by their underlying methodology) from an 'enterprise model' perspective.

2. DESIGN AND MANUFACTURING KNOWLEDGE FRAMEWORKS

There is a blurred line between 'manufacturing' and 'design' knowledge representation. Several methods that incorporate both design and manufacture (Rodriguez and Al-Ashaab, 2004, Rodriguez and Al-Ashaab, 2007, Kosanke, 1995), and some aim to link the two (Liu and Young, 2004, Costa and Young, 2001).

Young et al (2007) describe an information and knowledge framework including a manufacturing capability model and a product model. The framework can be applied to support the various decisions taken during the design life cycle. Their model of manufacturing is organised according to the physical resources: a facility is comprised of resource, process and knowledge, and a facility is-a (enterprise, factory, shop, cell, station). This model is illustrated in figure 1.

Detailed CAE reference models, comprehensive engineering design methodologies, and advanced CAE tools are available in literature. Intelligent manufacturing is also the focus of current research, making flexible manufacturing systems that integrate more readily with increasingly intelligent design systems (Molina et al, 2005). A feature of both intelligent design and intelligent manufacturing systems is the high cost and effort of implementation. Less complex methods may be applied in the interim period where full automation and optimisation is not available. There also remains a need to support manufacturing process selection and manufacturability analysis on an organisation specific basis.

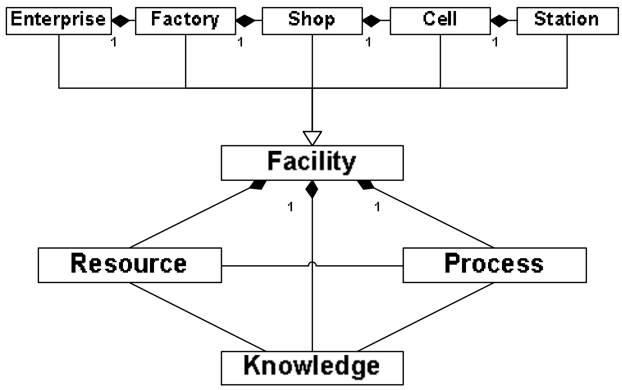

Figure 1: Manufacturing capability model

This research aims to identify specific manufacturing knowledge needs based on knowledge that is applied during the product development process. This will assist in developing an appropriate knowledge support method.

The following section describes the research methodology and process. The analysis method and results will then be described, followed by a proposal for a manufacturing knowledge framework based on the themes identified.

3. RESEARCH METHODOLOGY AND PROCESS

The knowledge capture method was as follows: participants were given a primer document describing the aim of the exercise, the research purpose and the knowledge capture method. The aim was stated as "The aim of the manufacturing knowledge capture exercise is to develop an initial framework describing manufacturing knowledge types." The critical incident technique was applied. It was described in the primer document: the participants should describe a situation from a current or recent project where they have encountered difficulty or overcome obstacles to come up with a solution. We would like to see what manufacturing knowledge designers need, or are missing, and what design knowledge manufacturing engineers need, or are missing. Through describing a critical task, knowledge that was required and applied during that task can be identified. The task should represent something which is important; a core knowledge component. This exercise should allow us to describe the knowledge requirement through modelling knowledge types.

Four people were interviewed as part of this exercise. The system of interest was defined (a major assembly of a specific product type). The question applied during the interview was "From your experience, think of the most recent situation in which you either observed or experienced something that impressed you as an outstanding example of effective (specify situation)." A number of descriptive questions were also asked, including: what was the situation; how experienced are you; exactly what did you do; why was the behaviour particularly effective / ineffective. Notes were taken during the interviews. The notes were typed up and analysed using NVivo qualitative analysis software.

4. RESULTS AND ANALYSIS

The reason for using NVivo was to assist in coding the participant responses. The coding took place in an inductive fashion. A limitation of this study is that the coding process was not validated; no other researcher or participant was asked to perform a similar process. As such, the themes identified could be argued to show some bias due to their identification by only one researcher. The notes from each interview were assessed to identify the knowledge categories applied during the activities described by the participants.

Table 1: knowledge types identified

Category	Occurrences
Manufacturing knowledge	29
Design manufacture interface	29
NPD integrated team	10
Tolerance analysis	6
Supplier quality assessment	5
Supplier liaison	4

Table 1 shows the knowledge types identified from the initial coding, after refinement and collation. The frequency of occurrences shows that the design manufacture interface was equally significant as manufacturing knowledge, and therefore should be the subject of further study. The phrases identified as 'manufacturing knowledge' were again analysed in order to classify the knowledge types in more detail. The results are shown in Table 2. The phrases were also assessed to determine the specific knowledge content: each phrase initially identified as 'manufacturing knowledge' was assessed to discover the category, or content, of that knowledge. The results are shown in table 3.

Table 2: manufacturing knowledge, second coding

Category	Occurrences
Manufacturing capability	23
Manufacturing problem	11
Manufacturing Impact	9
Method of manufacturing	9
New Manufacturing Method	6
Data - Knowledge storage	6

Table 3: knowledge content analysis from phrases identified as 'manufacturing knowledge'

Category	Occurrences
Tolerances	10
New methods	4
Variability	4
Early design	3
Cycle time	2
Datum	2
Dimensioning	2
People	2
Previous projects	2
Product performance	2
Tooling	2
Complex shapes	1
Cutting data	1
NC program	1
New feature	1
Tool library	1

The participants that took part in the interviews came from three roles: manufacturing engineer, manufacturing analyst and quality engineer. The manufacturing engineers work with on a range of tasks, including supporting the specification of producible products in collaborative conceptual design teams, writing NC code, and analysing manufacturing capability data in production and commissioning projects. The manufacturing analyst works with design and manufacturing to assess the impact of process capability on specified design tolerances. The quality engineer is responsible for identifying and solving production quality problems for both internal and supplier based issues. Each role has the potential to make an impact on a new design, and each role is directly interested in manufacturing capability. The frequency of occurrence (of mentioning a knowledge type) was compared against the people interviewed to identify any patterns in knowledge types applied by role. The results are shown in table 4.

Table 4: analysis of knowledge types by role

	Manufacturing Analyst	Manufacturing Engineer 2	Manufacturing Engineer 1	Quality Engineer
Manufacturing knowledge	2	11	15	1
Design manufacture interface	6	9	10	4
NPD integrated team	5	5	0	0
Tolerance Analysis	5	1	0	0
Supplier quality assessment	0	1	1	3
Supplier liaison	0	4	0	0
Manufacturing capability	4	8	9	2
Manufacturing problem	2	1	1	7
Method of manufacturing	0	7	2	0
Manufacturing Impact	0	4	5	0
New Manufacturing Method	0	5	1	0
Data - Knowledge storage	4	0	2	0

Key features of this analysis include:

- Manufacturing knowledge is predominantly applied by manufacturing engineers
- Design manufacture interface is important to each role, however it is most relevant to manufacturing engineers
- Manufacturing capability is most relevant to manufacturing engineers.
- Manufacturing problems are identified in the quality role.
- Manufacturing impact is limited to the manufacturing engineers, as is method of manufacture.
- Supplier liaison is perhaps misleading, due to the example used. Quality also liaise with suppliers.

The manufacturing knowledge content identified in table 3 was also analysed by role. The results are shown in table 5.

Table 5: manufacturing knowledge content by role

	Manufacturing Analyst	Manufacturing Engineer 2	Manufacturing Engineer 1	Quality Engineer
Tolerances	6	3	1	0
New methods	0	4	0	0
Variability	2	0	1	1
Early design	2	1	0	0
Cycle time	0	0	2	0
Datum	0	1	1	0
Dimensioning	0	0	2	0
Previous projects	0	1	1	0
Product performance	2	0	0	0
Tooling	0	1	1	0
Awkward shapes	0	0	1	0
Cutting data	0	0	1	0
NC program	0	1	0	0
New feature	0	0	1	0
Tool library	0	0	1	0

Much of the specific manufacturing knowledge content is applied solely by the manufacturing engineers. This leads to some interesting factors: the manufacturing engineers are not only the main users, but the main providers of much of the manufacturing knowledge in terms of the design-manufacture interface. They form an important interface between design and manufacturing. In terms of developing a knowledge repository to provide designers with some preliminary manufacturing knowledge to reduce the number of iterations necessary for a producible product, the manufacturing engineers would be critical for providing and verifying that knowledge.

Further comments are made, which relate to the success factors and situations described by the participants. It is a major advantage if design and manufacturing engineers are able to communicate face to face, particularly in conceptual design. This face to face contact enables each group to develop an understanding of the issues and constraints of the other groups, within the particular context of the project. It is a further advantage if they are collocated with manufacturing, since this same process can take place between manufacturing engineers and shop floor personnel

5. PROPOSED KNOWLEDGE FRAMEWORK

Critical knowledge categories in the manufacturing area (by frequency, from table 2) include: **method**, **capability**, **tolerances**, **problems**, and **impact**

An analysis of these categories shows that several of them relate directly to a specific manufacturing process: a given *method* consists of *capability* and *problems*. *Capability* consists of *cycle time* and *tolerances*. Manufacturing *impact* is an indication of how the selected manufacturing *method* impacts on the design. This is not a direct relationship; rather it is the result of a knowledge intensive analysis process. Tolerance analysis is another knowledge intensive process that identifies product tolerance stack-up, likely process yields and product conformance. This knowledge-intensive process relates to *tolerances*.

Figure 1 shows the proposed structure for a manufacturing knowledge framework. It is based on objects and inheritance: the link types include composition and dependency. A composition link is shown by a diamond, and indicates that an object (child) is part of a composite (parent) object. In Figure 1, the capability object is part of the manufacturing method object. Or, the manufacturing method object 'is-comprised-of' 'capability' and 'problems'. The other link type is dependency, shown by the dotted line with the open arrowhead. A dependency relationship simply indicates that changes to the source element (i.e. manufacturing method) can cause changes in the target element (i.e. manufacturing impact). The intention of the dependency link type is to show that there is a complex relationship between the two objects that is influenced by the source object.

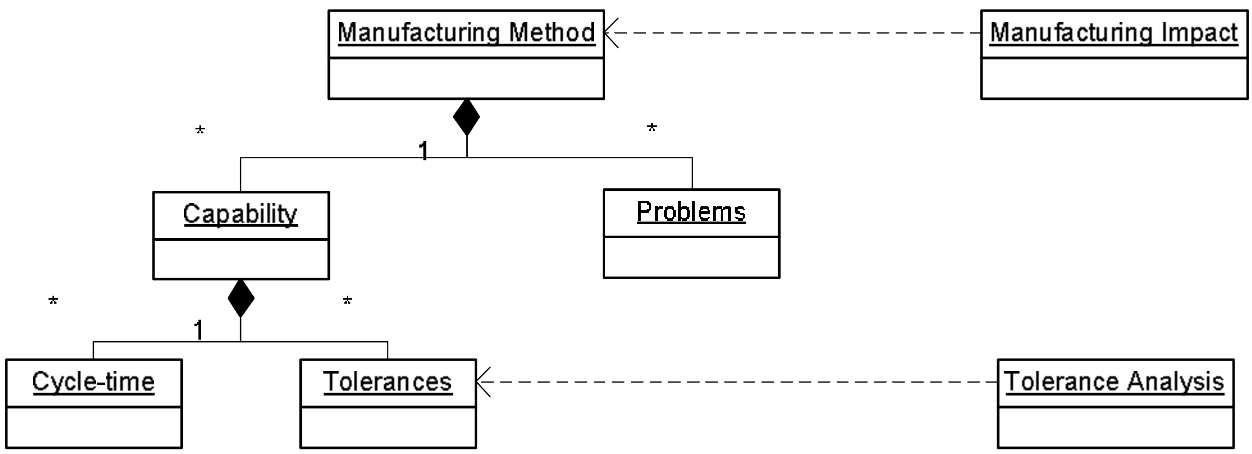

Figure 2: Proposed knowledge framework structure

This model differs to that presented by Young et al (2007). Theirs shows a relationship between a physical facility and its available resources, processes and knowledge. This model shows relationships between a given manufacturing method and its associated capabilities and problems. Their model is developed with a view to describing any process, and so it is built from a more complete conceptual standpoint. This one has been developed as the result of data captured in industry according to knowledge applied during manufacturing related tasks. It therefore reflects a more specific view of the manufacturing operation. This model would provide a means to store and organise manufacturing data according to specific manufacturing methods.

Capability data is identified by the manufacturing engineers, through analysis of historical process data or equipment specifications. Problems are identified by the quality engineer, through liaising with manufacturing. Tolerance analysis is carried out by manufacturing engineers and the manufacturing analyst. Manufacturing impact is contributed to by manufacturing engineers and the manufacturing analyst: the resulting impact on a design of a particular manufacturing method requires input from designers. Manufacturing impact assessment is a complex process which requires an integrated team with some understanding of each other's domain. Identifying the design knowledge applied during this process will form part of the planned future work in this research project. Understanding the source of the knowledge alongside a knowledge structure supports the application of a methodology to capture and reuse that knowledge. Knowledge contributors have been identified, in order to support the knowledge users: in this case, the designers.

The knowledge structure shown in figure 1 will form the basis of a knowledge support system implementation. An ontology describing manufacturing methods will be created. The 'Manufacturing method' object will have child (composite) objects 'capability' and 'problems'. The capability object will have child objects 'cycle time' and 'tolerances'. The cycle time and tolerances will be described initially in terms of a specific product component or feature. Using component or feature specific capability makes the system simpler to implement (feature recognition is not necessary, simply pick from a list) but less flexible (only existing features and components that have been entered into the system can be assessed). The problems object will relate to a particular manufacturing method, with slots for machine identity, component and feature. The ontology framework is shown in figure 3. The classes can be seen in the left hand column: manufacturing method, capability, cycle time, tolerances, etc.

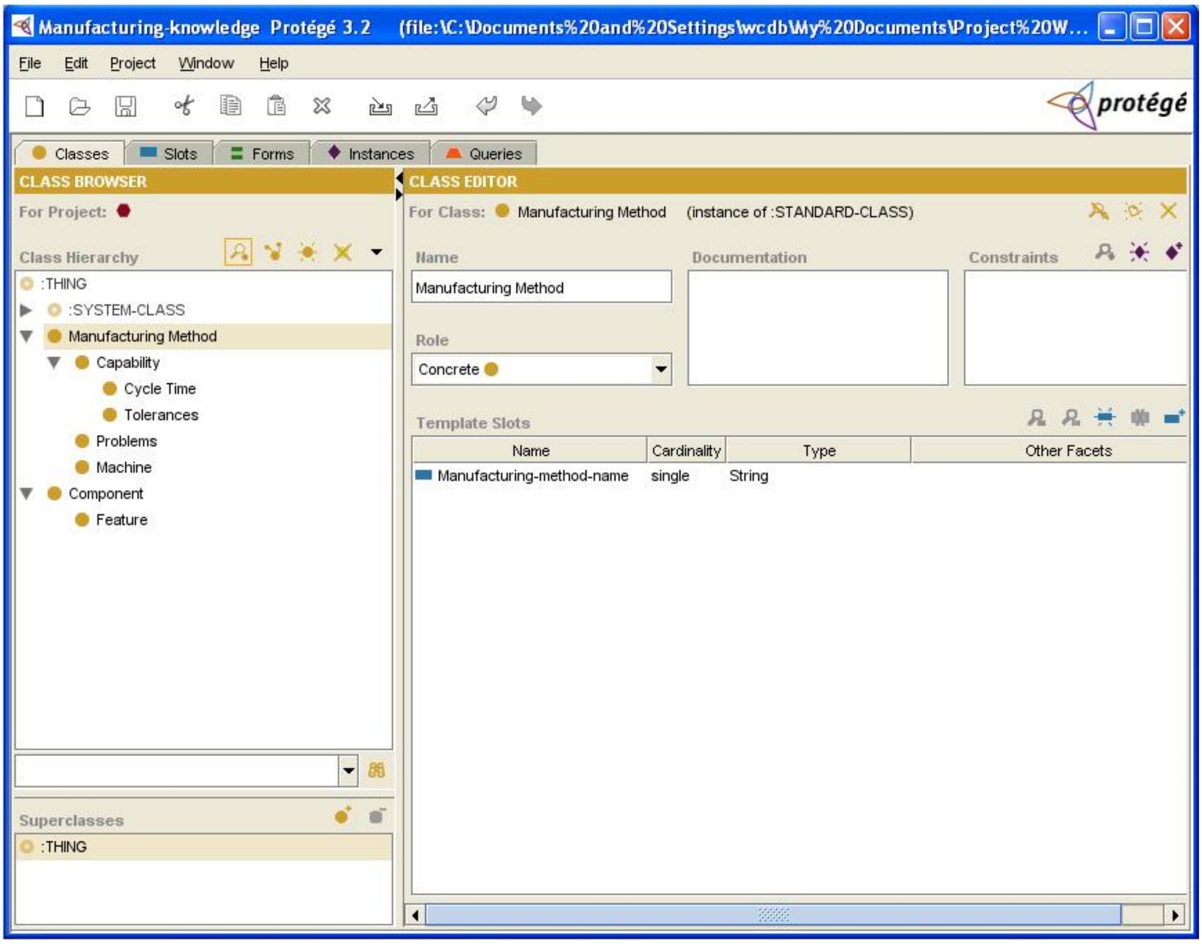

Figure 3: Protégé screenshot showing ontology framework

Of the manufacturing knowledge types identified, this approach will enable structured storage of knowledge relating to tolerances knowledge, but not new methods. Variability will be addressed by the tolerances knowledge. Early design will be addressed to some extent, however meetings between manufacturing engineers and concept designers should still take place. Cycle time will be partially addressed: some machine specific data can be stored using this system, however cycle time data will only be available for previous components and features. Datum and dimensioning are design issues which will not be addressed by this framework. Previous projects is a broad concept, and will not be fully addressed. Product performance is an interesting issue, since it is closely but indirectly related to manufacturing methods and capability. The intention of the framework is to support analysis of product performance by providing specific component or feature data to the design team. Tooling will be included as part of the manufacturing methods: alongside a 'machine' slot, a 'tooling' slot will be created. Awkward shapes refers to the initial judgement an engineer makes regarding the manufacturability of a given part. Some parts may appear at first glance to be unsuitable for a given method of manufacture, yet further analysis shows that they are manufacturable. This system will not support such analysis. Cutting data, NC programming, and new features will not be supported. A tool library will be developed in the future as part of the manufacturing methods object.

6. CONCLUSION AND FURTHER WORK

The knowledge content identified is limited to high precision mechanical assemblies. However, it is hoped that this study offers some insight into an appropriate manufacturing knowledge framework.

Other limitations of the proposed model exist in two areas: generality and situation bias. In terms of generality, the model needs to be examined from the perspective of other manufacturing organisations. This represents the next phase of this research project. In terms of situation bias, working on the basis of an 'as-is' scenario will not necessarily result in a conceptually complete model. As such, the model needs further development from both the industrial and conceptual perspectives.

Further work is also required to identify and classify manufacturing knowledge applied by designers, and design knowledge applied by designers and manufacturing engineers. Through this exercise, a knowledge map will be created that shows what knowledge is required by a particular role. Extending this through design process modelling will enable the identified knowledge requirements to be mapped to a particular design task. Those knowledge requirements which can be represented by an existing method in a computer based system can then be provided to the person carrying out the task. Those knowledge requirements which need expertise based analysis will be carried out in the current fashion – through a combination of manual methods and knowledge based analysis tools. The purpose of the knowledge modelling is to provide the design team with some knowledge of those domains which have a potential design impact, and thereby reduce the number of iterations necessary to specify a producible product.

ACKNOWLEDGMENTS

The authors would like to acknowledge the support of BOC Edwards in this research. The project was jointly funded by the EPSRC through Cranfield IMRC.

REFERENCES

Cochrane, S.D., Case, K., Young, R.I., Harding, J.A. and Dani, S. "Knowledge Sharing Between Design and Manufacture." International Conference on Knowledge-Based Intelligent Information and Engineering Systems No. 9 (KES 2005) (2005): 221-227

Costa, C.A. and Young, R.I.M. "Product range models supporting design knowledge reuse." Proceedings of the Institution of Mechanical Engineers - Part B - Engineering Manufacture 215 (2001): 323-338

Howard, L. and Lewis, H. "Support tool for material and process combinations during early design." International journal of production research 44 (2006): 3379-3390

Kosanke, K. "CIMOSA – Overview and status." Computers in Industry 27 (1995): 101-109

Kumara, Shailendra, Singh, Rajender and Sekhon, G.S. "CCKBS: A component check knowledge-based system for assessing manufacturability of sheet metal parts." Journal of Materials Processing Technology 172 (2006): 64-69

Liu, S. and Young, R.I.M. "Utilizing information and knowledge models to support global manufacturing co-ordination decisions." International Journal of Computer Integrated Manufacturing 17 (2004): , 479

Molina, A. and Bell, R. "A Manufacturing Model Representation of a Flexible Manufacturing facility." Proceedings of the Institution of Mechanical Engineers, Part B (Journal of Engineering Manufacture) 213 (1999): 225-246

Molina, A. and Bell, R. "Reference models for the computer aided support of simultaneous engineering." International Journal of Computer Integrated Manufacturing 15 (2002): 193-213

Molina, A., Rodriguez, C. A., Ahuett, H., Cortés, J. A., Ramírez, M., Jiménez, G. and Martinez, S. "Next-generation manufacturing systems: key research issues in developing and integrating reconfigurable and intelligent machines." International Journal of Computer Integrated Manufacturing 18 (2005): 525-536

Rodriguez, K. and Al-Ashaab, A. "Knowledge web-based system architecture for collaborative product development." Computers in industry 56 (2004): 125-140

Rodriguez, K. and Al-Ashaab, A. "Knowledge web-based system to support e-manufacturing of injection moulded products." International Journal of Manufacturing Technology and Management 10 (2007): 400-418

Shakeri, M. "Implementation of an automated operation planning and optimum operation sequencing and tool selection algorithms." Computers in industry 54 (2004): 223-236

Sharma, R. and Gao, J. X. "A Progressive design and manufacturing evaluation system incorporating STEP AP224." Computers in Industry 47 (2002): 155-167

Valentincic, J and Brissaud, D "A novel approach to presenting manufacturing knowledge on the design level in toolmaking." Strojniski vestnik - Journal of Mechanical Engineering 51 (2005): 620-633

Young, R. I. M., Gunendran, A. G., Cutting-Decelle, A. F. and Gruninger, M. "Manufacturing knowledge sharing in PLM: a progression towards the use of heavy weight ontologies." International Journal of Production Research 45 (2007): 1505-1519

Specifying a manufacturing knowledge reuse framework

Baxter, David

2007-09-19