In P. Phelan (Ed.), *"Servicing Manufacturing", the Proceedings of the Twenty-first International Manufacturing Conference*, *IMC21* (pp. 3-10). University of Limerick, Ireland, 1-3 September 2004.

KNOWLEDGE SHARING BETWEEN DESIGN AND MANUFACTURE

S. Cochrane[1], K. Case, R. Young[1], J. Harding[1], S. Dani[1]

[1]Wolfson School of Mechanical & Manufacturing Engineering,
Loughborough University, Leicestershire, LE11 3TU, UK Contact:
s.d.cochrane@lboro.ac.uk

ABSTRACT

Object-oriented modelling has become an established technique for product and manufacturing knowledge representation. Various *models* offering generalised classes and class hierarchies have been proposed for this purpose. Additional bespoke classes are however typically required for specific domain representations. This causes problems when knowledge needs to be shared between domains using different models to describe common entities. These issues are especially complex when several systems are involved. For example, a designer accessing product, manufacturing, and third party systems may face multiple definitions of components, facilities and processes. This paper proposes a model that addresses some of these issues. The proposed model can describe manufacturing knowledge without additional bespoke classes. The detailed semantics of the model are based on recent work on ontologies, notably the Process Specification Language (PSL). Whilst PSL provides detailed semantics, it is not inherently object-oriented. The integration of PSL with object-oriented modelling methods is therefore the principle contribution of this work.

KEY WORDS

Key words/phrases include: Formalised Knowledge Representation, Object-oriented product and manufacturing models, and The Process Specification Language / PSL Ontology.

1. INTRODUCTION

Knowledge formalisation involves the representation of knowledge in a *"consistent, formal, neutral format (which is independent of any application platform)"* [1]. Various object-oriented models have been proposed for representing design and manufacturing environments. These however, provide only a structure for modelling domains, leaving the detail to bespoke modelling activities. This results in semantic differences between representations that limit *knowledge sharing* (i.e. the use of a shared model to link several knowledge domains). Detailed (semantically defined) models are needed to overcome these issues. This paper describes the leading object-oriented product and manufacturing models, and discusses their limitations with respect to knowledge sharing. An extended manufacturing model containing detailed modelling constructs is then proposed.

2. OBJECT-ORIENTED KNOWLEDGE REPRESENTATION

The MOKA Product Model [2] describes classes and an associated hierarchy for: Structure, Function, Behaviour, Technology, and Representation views. Figure 1 shows a subset of the Product Model that can be used to describe the relationship between products, parts, features, manufacturing processes, and materials. Descriptions should for example, be able to link product features and consumed materials to manufacturing processes.

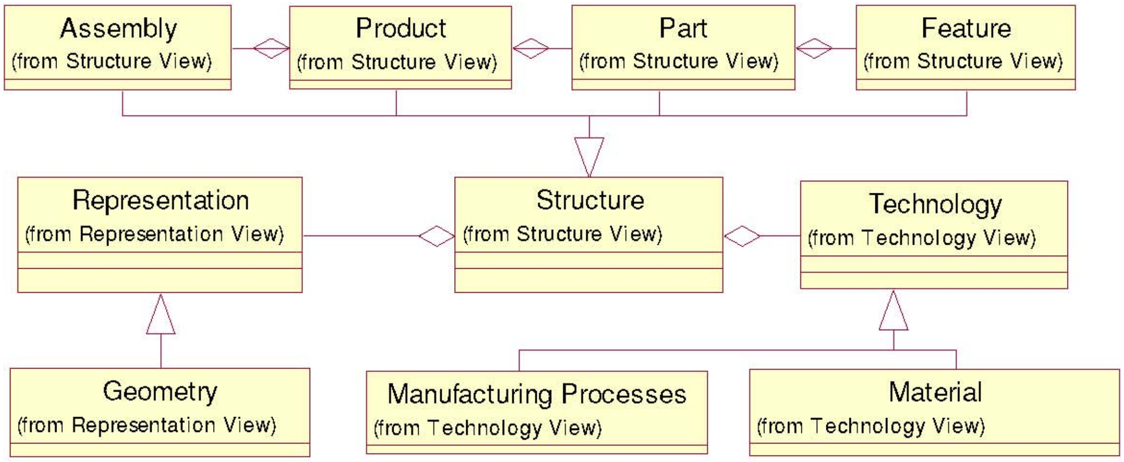


Figure 1: Product Model -adapted from MOKA [2]

The Manufacturing Model [3, 4] is similar to the MOKA Technology View, and includes an additional strategy class. This can be used to describe objectives separately from manufacturing processes and resources/materials (see figure 2). This makes it easier to analyse multiple processing options. "Making a round hole" may for example be achieved by several combinations of drilling, boring and/or reaming.

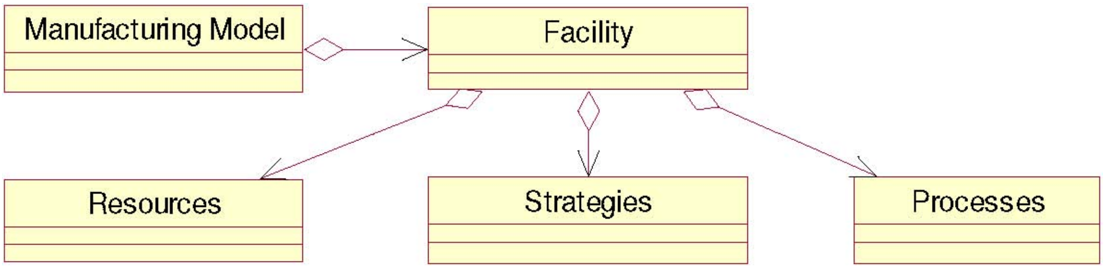
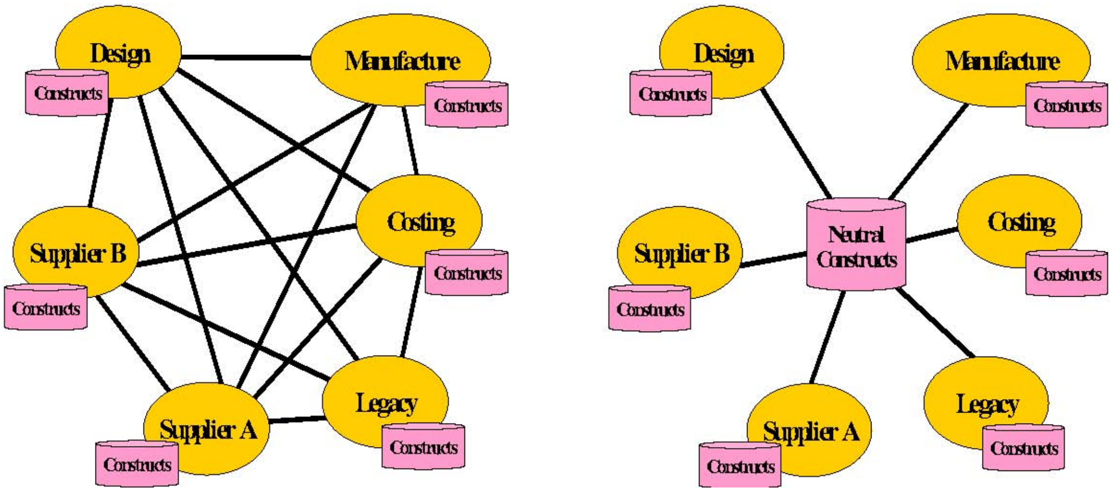


Figure 2: The Manufacturing Model [4]

A further refinement of the Manufacturing Model is the Factory Data Model [5]. This develops a hierarchy of strategy specialisations that include: rules, constraints and objectives. Rules describe what actions to take when specified conditions are met, constraints place limits on class attributes (e.g. processing times), and objectives describe desired results that can be linked to processes and/or sequences of processes.

3. KNOWLEDGE SHARING

Knowledge based systems are often developed in isolation for specific design, manufacturing, and suppliers domains. Often these replicate knowledge of other domains (e.g. a designer's knowledge of manufacturing). This gives scope for inconstancies that lead to poor decision making. Knowledge sharing overcomes this by using the same representation in several domains. This is not however straight forward. The product and manufacturing models previously described leave the detailed definition of *constructs* (modelled entities) to bespoke extensions of the basic model. This results in semantic differences between domain representations.



Attribute/Operation Map

Figure 3: Interfaced and Neutral Approaches

A number of mechanisms for resolving semantic differences can be applied, including: interfaced and integrated systems [6]. *Interfaced* systems map the attributes and operations of each construct onto their equivalents in other domains. This is depicted in figure 3 (left). *Integrated* systems use a centralised knowledge base with common/shared constructs that are custom built for the environment. As each domain only needs to map to/from the shared structure, the number of mapping arrangements needed to link domains is considerably reduced.

Interfaced systems can result in mapping arrangements that are difficult to maintain. Integrated systems ease these problems, but are limited in scale by the need to agree shared construct definitions. This is difficult when several parties (e.g. suppliers) are involved, and ideally, a *neutral* (open/published) set of constructs would be available for this purpose. This ideal situation is depicted in figure 3 (right), and is analogous to the way businesses use an open/shared language (usually American-English) to communicate across national boundaries.

Recent work on ontologies (and especially neutral ontologies) offer a possible way forward. An ontology is a "formal description of the entities within a given domain: the properties they possess, the relationships they participate in, the constraints they are subject to, and the patterns of behaviour they exhibit" [7]. This usually involves a formally defined lexicon of relevant terms. Neutral ontologies are open, published and support rich lexicons. The lexicon should be rich enough to represent all potential domains in a shared environment. This eliminates the need for additional bespoke terms (and their semantic inconsistencies).

Several neutral ontologies have emerged for business and manufacturing environments. These include: *The Enterprise Ontology* [8], which defines terms for process planning, organisational structures, business strategies, and marketing operations; *The Language for Ontological Knowledge* [9], which details terms for manufacturing operations; and *The Process Specification Language* (PSL) [10], which targets process related environments such as manufacturing and construction. It is worth noting that various other ontological efforts are describe in the literature. These tend to concentrate on tools and formats for defining bespoke ontologies (e.g. OWL [11]). Such tools and formats assist ontology development, but do not address knowledge sharing (which requires rich and standardised lexicons).

Whilst certain neutral ontologies provide detailed and relevant semantics, they are not the complete answer to knowledge sharing. Ontologies are not inherently object-oriented, and can not be directly integrated with existing Product and Manufacturing Models. It should however be possible to develop "neutral constructs" derived from suitable ontologies, and integrate these with an object-oriented product model. Constructs for a complete product model are the ultimate goal. This work however, focuses on constructs for the manufacturing model / technology view.

4. THE PROCESS SPECIFICATION LANGUAGE

PSL has been selected as the underlying ontology for the manufacturing constructs proposed by this research. The adoption of PSL by the International Standards Organisation (ISO) made it the obvious candidate. PSL uses the Knowledge Interchange Format [12] to semantically define entities and relationships relevant to processes. Formal definitions of entity kinds such as activities, activity occurrences, objects, timepoints and states are provided. The actual entities within a domain are represented by instantiated entity kinds. For an example "tea-making" knowledge base, instantiated kinds may include:

- Objects such as: water, milk, sugar, teabag, spoon, cup, mug . . . .
- Activities such as: filling, boiling, pouring, mashing, stirring . . .
- Activity Occurrences such as: making tea for 4.00PM.
- Timepoints such as: starting the tea-making occurrence at 3.50PM.
- States such as: cold, hot, boiling, full, empty . . .

PSL provides additional terms to describe the relationships between kinds, e.g. prior, holds, and participates_in. Functions are also defined for returning the start and end times of activities and the existence of objects (i.e. beginof and endof). Figure 4 shows informal and formal (PSL) statements relevant to our "tea-making" knowledge base. This describes the relationships between a kettle, water, and boiling.

A kettle and water are needed before you can start boiling:

```
forall(S) implies (occurrence_of(S, boiling) (AND participates_in(kettle, boiling,
beginof(S) participates_in(water, boiling, beginof(S)))
```

The activity of boiling results in boiling-water:

```
forall(S) implies (occurrence_of(S, boiling) holds(boiling-water,
       S))
```

Filling a kettle is not possible when the kettle is full:

```
forall(S) implies (poss(filling, S) prior(not kettle-full,
       S))
```

Figure 4: Example "Tea-Making" Knowledge Base

The involvement of both NIST and the ISO has established PSL as the focal point for research into process related ontologies. PSL builds on several previous ontologies, including: A Language for Process Specification (ALPS), the Toronto Virtual Enterprise (TOVE), the Enterprise Ontology, Core Plan Representation (CPR), Shared Planning & Activity Representation (SPAR), The Process Interchange Format (PIF), and the WorkFlow Management Coalition (WfMC).

5. THE EXTENDED MANUFACTURING MODEL

This section describes an extended Technology View for a simplified version of the MOKA Product Model. This is referred to as the Extended Manufacturing Model (EMM). The proposed extensions include a strategy class and detailed constructs derived from the PSL ontology. Figure 5 shows the class hierarchy for the overall Product Model, and figure 6 shows the relationships between the proposed constructs. To demonstrate the operation of the EMM, our tea-making knowledge base is further explored below.

Firstly, a "tea-order" is represented by an instantiation of the Product class. The tea-order itself instantiates several "cups-of-tea" represented by the Part class. Each cup in turn has several features (instantiated from the Feature class). Features include:

- drink (options: tea)
- temperature (options: hot, iced)
- flavour (options: English-Breakfast, Earl-Grey, Darjeeling)
- container (options: china-cup, mug, polystyrene-cup)
- additives (options: none, milk, lemon)
- sweetener (options: none, one-sugar, two-sugars, three-sugars)

An instantiation of the Technical-Solution class holds the requirements for the tea order. This stores several statements describing the solution required by each customer (e.g. "tea, hot, Earl-Grey").

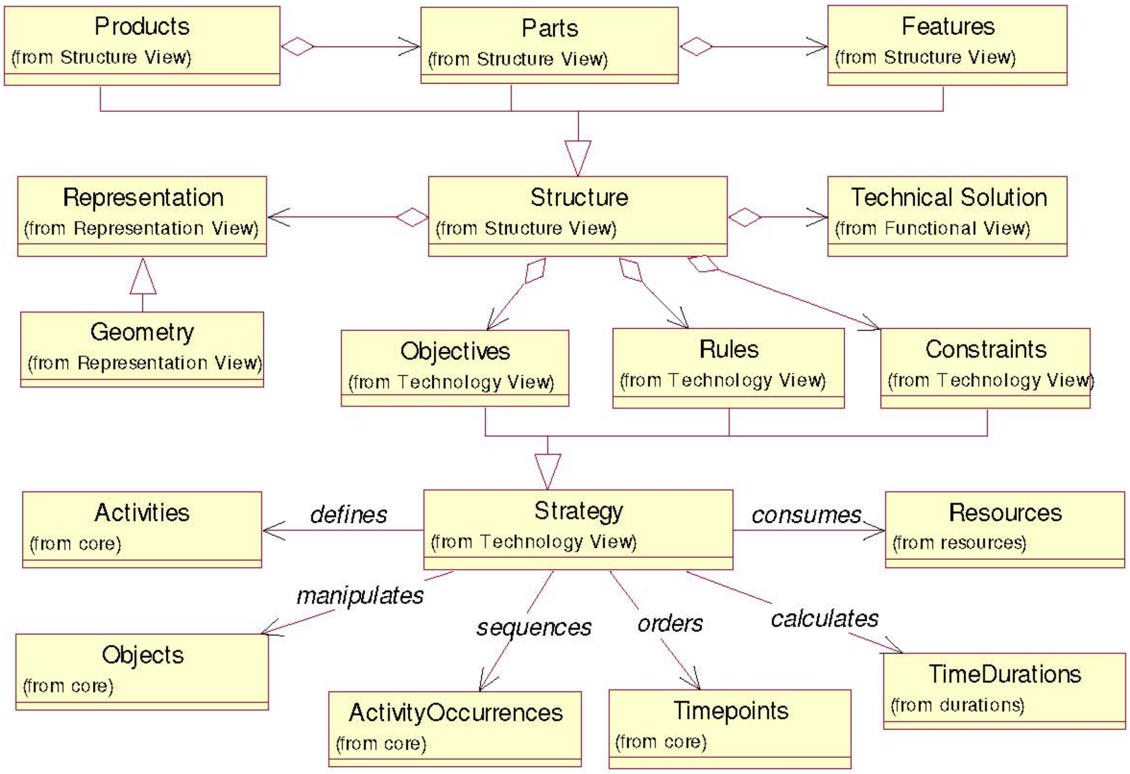


Figure 5: Extended Manufacturing Model

Note that the Representation and Geometry classes are not used in this example, but will be required for a further stage of worked examples based on the casting and milling of industrial components.

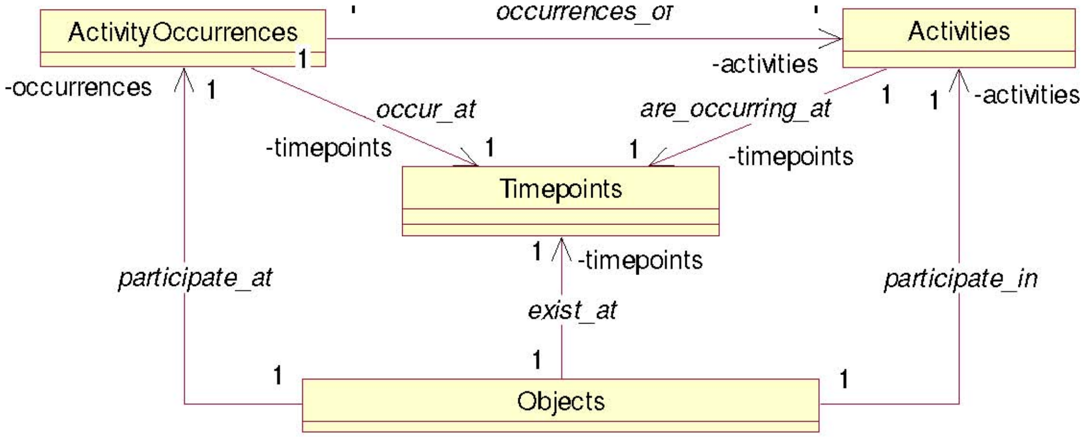


Figure 6: Modelling Constructs Based on the PSL Core

occurrences_of

Strategies for making the tea-order can now be determined. These may consist of rules, constraints and objectives relevant to the task. Strategies are expressed using constructs derived from the PSL core, i.e. instantiations: Objects, Activities, Activity Occurrences, and Timepoints. Relevant entities may then be instantiated as: Objects (e.g. spoon, kettle, and milk), Activities (e.g. boiling and pouring), Timepoints (e.g. 4.00PM), and Activity Occurrences (e.g. making-tea-for-4.00PM).

Methods associated with the four core classes are based on the PSL core relationships i.e.: before, between, beforeEq, betweenEq, occurrence_of, exists_at, is_occurring_at, and participates_in. These can be used to describe the relationships between entities, e.g. “participates_in (kettle, boiling, 3.50PM)”.

Additional constructs are being developed from the full PSL ontology. These will include (amongst others) classes for States, Resources and TimeDurations. The extended PSL ontology supports rich knowledge representations, and can be added in a modular fashion. The final set of constructs will be capable of describing any process related knowledge, and fully support a design/manufacturing knowledge sharing environment.

6. CONCLUSIONS & FURTHER WORK

Manufacturing knowledge is required during design to evaluate a product’s manufacturability, cost and quality. Ideally this knowledge should be shared between manufacturing and design applications, rather than replicated and maintained in separate knowledge bases.

Object-oriented Product Models are an established form of knowledge representation. However, existing models lack the detailed constructs needed to fully support knowledge sharing. This research contributes a set of detailed constructs derived from the PSL ontology. These can be used as an extension to existing Product Models, providing detailed class and class hierarchy definitions for the Technology View / Manufacturing Model.

Further work includes the integration constructs derived from the complete PSL ontology (so far only the PSL core has been fully modelled). Additional testing of the proposed model is also required. Initial proof tests have been conducted using the “tea making” example knowledge base. Tests based on the casting and machining of an industrial component are planned for the near future.

7. ACKNOWLEDGEMENTS

This work is part of an ongoing research project entitled “Knowledge Representation and Reuse for Predictive Design and Manufacturing Evaluation”, and has been funded under EPSRC GR/R64483/01. The authors would also like to acknowledge the work of Dr. J. Gao and D. Baxter, from the Enterprise Integration group at Cranfield University, Bedfordshire. Further information on the project and team members can be found on: http://wwwstaff.lboro.ac.uk/~mmsdc.

8. REFERENCES

1. Oldham, K, Kneebone, S, Callot, M, Murton, A and Brimble, R, in N. Mårtensson, R. Mackay and S. Björgvinsson (eds.), 1998. “Changing the Ways We Work.” Advances in Design and Manufacturing, Volume 8, Proceedings of the Conference on Integration in Manufacturing, Göteborg, Sweden, IOS Press, Amsterdam, October 1998, 198-207. http://www.kbe.cov.ac.uk/moka

2. The MOKA Consortium, 2000. MOKA User Guide, MOKA Modelling Language Core Definition. June 28 2000. http://www.kbe.cov.ac.uk/moka

3. Molina A, Bell R, 1999. “A Manufacturing Model representation of a flexible manufacturing facility.” *Journal of Engineering Manufacture: Proceedings of the Institution of Mechanical Engineers, Vol 213, Part B, pp.225-246.*

4. Dorador J, Young R, 2000. “Application of IDEF0, IDEF3 and UML methodologies in the creation of information models.” *International Journal of Computer Integrated Manufacturing.*

5. Harding J, Popplewell K, 2001. “Enterprise design information: the key to improved competitive advantage.” *Int. J. Computer Integrated Manufacturing, 2001, Vol. 14, No. 6, 514–521*

6. Young R, 2003. “Informing decision makers in product design and manufacture.” *International Journal of Computer Integrated Manufacturing, Vol. 16, No, 6, pp. 428-438.*

7. Uschold, M, Gruninger M, 1996. “Ontologies: Principles, Methods, and Applications*.” Knowledge Engineering Review, 1996, Vol. 11, pp. 96-137.*

8. Uschold M, King M, Moralee S, Zorgios Y, 1997. The Enterprise Ontology. Edinburgh University. Web Accessed 13th Oct 2003. http://tmitwww.tm.tue.nl/staff/gwagner/EnterpriseOntology.pdf

9. Roche C, 2000. “Corporate ontologies and concurrent engineering.” *Journal of Materials Processing Technology 107 (2000) 187±193.*

10. Schlenoff C, Gruninger M, Tissot F, Valois J, Lubell J, Lee J. The Process Specification Language (PSL) Overview and Version 1.0 Specification. [Web Accessed 3rd October 2003]. http://ats.nist.gov/psl

11. McGuinness D, Harmelen F, 2003. OWL Web Ontology Language Overview. W3C Working Draft 31 March 2003. . [Web Accessed 14th July 2003] http://www.w3.org/TR/2003/WD-owl-features-20030331

12. Genesereth M. Knowledge Interchange Format. Draft proposed American National Standard (dpANS). NCITS.T2/98-004. [Web Accessed 13th October 2003]. http://logic.stanford.edu/kif/dpans.html#Scope