Object Oriented Modelling of Product Oriented Manufacturing Systems

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Abstract

Models are essential for studying the behaviour, design and operation of manufacturing systems. Many approaches, tools and methods can be used for developing such models. An analysis and discussion of the characteristics, possibilities and implementation aspects of the Object Oriented (OO) approach to the modelling of cellular manufacturing systems are presented. One particular set of such cellular systems, namely the product oriented manufacturing systems (POMS) is emphasised. It is argued that characteristics such as easiness of model developing and understanding, fast and simple testing and reusing of model components act in favour of the OO approach to modelling manufacturing systems in general, and POMS systems in particular.

Keywords

Object Oriented Modelling, Product Oriented Manufacturing Systems, Distributed Autonomous Production Cells

INTRODUCTION

Design and operation of manufacturing systems are interrelated in such a way that, in many instances, it may be difficult to identify when one starts and the other finishes. Most of the time the two aspects are so dynamically interdependent that during operation, system changes are repeatedly carried out, for example, by changing system or machine configuration. These interrelationships are frequently complex, intricate and difficult to understand through traditional forms of entity specification, and representation and system modelling.

The original version of this chapter was revised: The copyright line was incorrect. This has been corrected. The Erratum to this chapter is available at DOI: 10.1007/978-0-387-35390-6_58

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To simplify analysis and design and to better understand manufacturing systems operation a form of entity and system specification and modelling must be sought which guarantees completeness precision and simplicity and, at the same time, allows for testing and understanding of system functions. These functions are direct or indirect contributions to implementation of the manufacturing process required by an object, usually referred to as a product.

We believe that Object Oriented System Design (Yourdon, 1994) can provide de requirements for a comprehensive and appropriate approach to modelling for manufacturing systems design and operation. This OO approach creates a very close relationship between a model and the real world system, allowing for a better understanding of manufacturing systems. Moreover it is likely to reduce substantially the time for system modelling. This is possible, among other reasons, because of the reusing of objects in different parts of a model.

We are working on OO modelling of distributed manufacturing systems, with a focus on product oriented manufacturing systems (POMS) (Silva and Alves, 1997).

In this paper we make a short presentation of some work on the application of object oriented theory to production systems, and discuss important advantages and characteristics of this theory. Additionally, we define a framework for manufacturing system modelling, which includes the representation, and modelling of products and manufacturing cells. Finally, a brief view to manufacturing system control will be presented.

2 WORK ON OO MODELLING OF PRODUCTION SYSTEMS

It is usual to find work dedicated to production systems that uses an object oriented approach, in most of the cases with the objective of developing the information system that will allow to control the production system.

Yoo (1997) presents an OO database to support CIM (Computer Integrated Manufacturing) systems. This database is based on object classes related to workpieces characteristics. Therefore, it is a CAD (Computer Aided Design) and technological database description.

Hoche, Broomhead and Grieve (1996) describe a framework for developing object oriented software for the control of manufacturing cells. This is based primarily on classes of objects representing real cell elements (like operators, robots, and machines), and by a cell control object. This object has the function of implementing the control method and co-ordinating the communication between the objects. Hoche et al (1996) describes the implementation of a control system based on this framework.

Aguiar, Murgatroyd and Edwards (1996) present an object oriented CASE tool for production resources modelling. This tool is named SEW-OSA, and allows OO resources modelling at different levels, namely at requirements, design and implementation levels.

A methodology for the construction of object oriented software for manufacturing systems is presented by Adiga (1993). Some well known tools for system information modelling are used, namely entity relationship (ER) diagrams, and data flow diagrams (DFD). However, they base the system behaviour model on message flow diagrams (MFD), and not on DFD. So, the fundamental tools of this methodology are ER diagrams and MFDs. According to Adiga (1993), the manufacturing information system should have three fundamental modules, the production system state model, the decision module, and the interface modules.

Among different authors dedicated to study enterprise modelling, we can find some who deal with this problem in an object oriented way. We can briefly describe in the work of Mertins, Sussenguth, and Jochem (1992) an enterprise modelling based on three fundamental object classes: product, order and resource. Based on these objects it is built the enterprise model kernel, with two main views: the function modelling view and the information modelling view. The three referred objects, and appropriated descendant objects, model the information of different enterprise parts, creating the information modelling view. Aiming at describing the function modelling view it is presented a generic activity model, and a set of structures to form a function chain. The main characteristic of this method resides on the object oriented vision, which allows aggregating the information with the correspondent processing functions and also allows the possibility to build different views of the enterprise model using filters.

This is a small sample of work on object oriented theory application to modelling, design and implementation of production systems. This work reinforces the possibility of widespread application of the OO theory to production system design and implementation.

3 OO PRODUCTION SYSTEMS MODELLING ADVANTAGES

Advantages and disadvantages of OO theory have been largely presented in generic OO bibliography. Up to now OO theory has been fundamentally a methodology and tool for developing software.

At this point, it is relevant to present some of the main envisaged advantages of OO theory to the modelling of manufacturing systems.

3.1 Easiness of Modelling

Object oriented theory models systems around existing objects (Meyer, 1988; Yourdon, 1994), instead of focussing on system functions. This capacity, to model the application domain from existing objects (real), physical or not, makes it easy to develop production system models (Adiga, 1993). In this theory, information and the correspondent processing functions are encapsulated, within an entity (object).

3.2 Reusing

Reusing of software can be done at different levels, namely at specification, design, source code and data levels (Yourdon, 1994). Specification and design reusing is possible, from pre-defined classes and objects, mainly due to the inheritance mechanism. This mechanism allows conceiving an object from ascendant object information and functions, bringing up the possibility of building an object library, which can be reused. Adiga (1993) referred some examples of object libraries applied to production systems.

3.3 Testing and System Evolution

Object oriented systems can grow from small elements (objects) to full functional elements (Adiga, 1993), allowing system testing and prototyping. The object oriented approach is adequate to make an evolutionary development of the system, since it is possible to enlarge capabilities of the system, with minor disturbances, until all functions are implemented. Moreover, a system state model can be used to control the system itself, or to simulate it and in that way used to test the behaviour.

3.4 Information Hiding

The definition of visible information to the exterior of the object is known as information hiding principle (Meyer, 1988). The autonomy of objects is reinforced by this principle, since interest is kept focussed on the result (the interface with user of the object should not change), although the way in which it is achieved could change. The principle also allows hiding information, which should not be known to users.

This fundamental principle of object oriented theory is implicit in the work for information systems for manufacturing by Camarinha-Matos et al (1997) and Mertins, Sussenguth, and Jochem (1992).

4 MANUFACTURING SYSTEMS MODELLING

We consider a product to be a unit primitive or complex obtained by transformations in a manufacturing cell. Some products can be components of other products (Figure 1).

We assume in this modelling framework that a product is always manufactured in a dedicated manufacturing cell. This means that the manufacturing cell is designed for the sole purpose of manufacturing the product. However this does not rule out the possibility of part or all of the resources of the cell, such as machines, operators and tools, to be part of other cells. This very much depend on the spare capacity of cell resources which may make them eligible as candidates to integrate other cells for the manufacture of other products.

A cell may be seen as a manufacturing unit, which processes in an autonomous manner the product. This means that the required transformations of the product as well as the necessary controlled functions are completely carried out by the cell.

A number of cells can co-operate with other cells to enlarge the processing capabilities required by a product, originating in this way, a new cell. In this sense cells are building blocks of other cells (Figure 1). This cell concept is similar to the one presented by Silva and Putnik (1995), although more restricted because it is focused onto product oriented cells.

We are working on the development of a generic OO model of product oriented manufacturing systems (POMS). These systems will be conceived only when a need for the manufacturing of a product or a range of products exists. In such a modelling, object instances of classes of products and classes of manufacturing cells can be created. This approach to manufacturing systems modelling includes, to a great extent, the virtual enterprise OPIM - One Product Integrated Manufacturing - concept put forward by Putnik and Silva (1995).

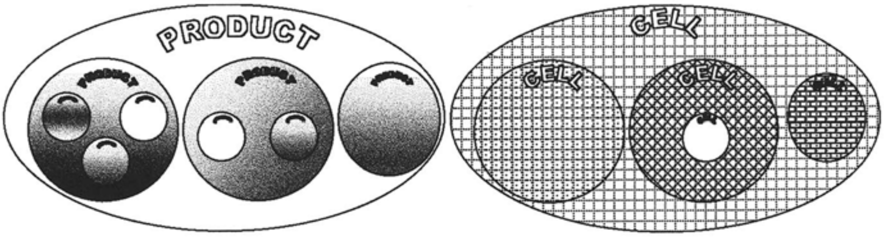

Figure 1: Product and Cell as Elements of a Manufacturing System

The OO strategy to manufacturing systems modelling is a natural one and may be seen as intuitive. The generic OO model of POMS systems can be perceived as comprehending a set of objects (products and manufacturing cells), composed by attributes and functions. We can envisage product objects to be characterised mainly by attributes, such as shape, dimensions, kind of materials, hardness, and object manufacturing cells essentially by cell functions.

5 OBJECT ORIENTED PRODUCT CHARACTERISATION

We are lucky to be able to draw upon the work done on product specification already standardised in forms like IGES, SET, DXF or STEP. It is our believe that these standards will be useful for OO product specification under the modelling framework for manufacturing systems here advanced. Most probably the ISO standard model STEP (STandard for The Exchange of Product model data) (PDTAG, 1997) may be used to OO product specification. In fact STEP configures an OO like characterisation of products through specification of their attributes, such as geometry, shape, composition or structure, material, tolerances and features (Figure 2).

Important attributes of each product object must allow the identification of the manufacturing process for each product. For this purpose forecasted or known production quantities can be critical. This is important to identify the manufacturing cell and its auxiliary means, based on attributes, necessary for the manufacture of the product in the quantities required. Okino uses a similar approach, according to Tharumarajah, Wells and Nemes (1996), in his concept of Bionic Manufacturing. Here, for example, workpieces are characterised by information related to their manufacturing process, such as tools, fixtures and machines.

In the modelling framework, which we propose, both product and product oriented manufacturing cell are represented in a similar way. These two objects are associated to carry out the required product transformation operations.

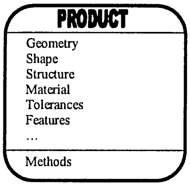

Figure 2: Product Object (Coad/Yourdon notation, Yourdon (1994))

6 OBJECT ORIENTED CELL CHARACTERISATION

Under the OO theory, an object can be considered autonomous in the way it can access and transform its own information, being relevant only the result obtained and not the form how it is obtained.

In our modelling approach we define cell autonomy as the capability of a cell to completely carry out the processing required by the product without external aid. This means that the cell is self organised and auto-controlled, i.e. does not need external aid or the co-operation of other cells to carry out the required processing to completely manufacture a product. The cell with such a capability is called *autonomous cell.* This cell can be constituted by a number of cells, autonomous, or non-autonomous. A *non-autonomous cell* is a cell that is not self-controlled and must co-operate with other cells to completely manufacture a product.

A similar view is presented in the concept of holonic manufacturing systems (Kádar, Monostori and Szelke, 1997; Tharumarajah, Wells and Nemes, 1996) that refer the autonomy of the holonic entity as "the capability of an entity to create and control the execution of its own plans and/or strategies".

We can imagine that a cutting cell constituted by an operator, a cutting machine and a set of tools is an autonomous cell as long as it can organise and control itself in carrying out the cutting work required to completely process a product. The operator, the machine and the tool set can all be seen as non-autonomous cells.

Both autonomous and non-autonomous cells, namely manufacturing resources, are represented in the same way, within the same OO approach. By doing so we simplify the communication process, through message passing between objects which is a simplified and more natural mode of communication between entities of a system.

7 MANUFACTURING CONTROL

One aspect of study that we wish to emphasise is the manufacturing control in POMS systems. These systems can integrate a variety of cells, which may or may not be locally distributed.

Thus we are concerned with building up a generic manufacturing control model configurable for a variety of such systems and manufacturing requirements in order to be able to study operative strategies in different instances of product oriented manufacturing systems. In particular the concept of simultaneous manufacturing presented by Silva and Putnik (1995) will be studied in depth.

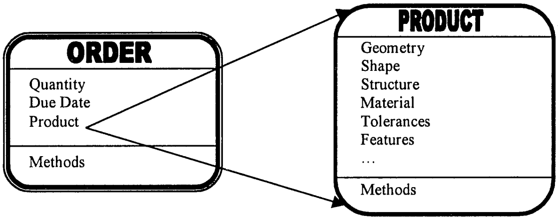

Figure 3: Object oriented representation of an order

The referred manufacturing requirements are, direct or indirectly, completely defined through a customer order. This includes information that clearly identifies the product to be manufactured through product object identification, quantity and delivery data (Figure 3). The manufacturing systems must ultimately satisfy all the customer order requirements, namely to manufacture the required product in the required quantities at the negotiated delivery date.

The satisfaction of customer orders is the ultimate objective of a manufacturing system and the primary motor of manufacturing control. In fact manufacturing control starts with the confirmation of a customer order.

We can think of customer orders as having a broad meaning to include management orders originated by market demand forecasts.

8 MODEL EXAMPLE

In order to demonstrate the applicability of the modelling framework and to clarify some of the design implementation aspects we present a simplified example. The example is based on one main product, a sweatshirt. This sweatshirt is made of one front, one back and two sleeves (Figure 4). These parts are all made of the same fabric.

The hierarchy of classes shows the control mechanism, the order class and five products, i. e. the sweatshirt and its parts, namely the front, the back and the two sleeves.

According to the modelling framework, all products and parts are viewed as products. Therefore they all inherit characteristics of the product class.

Once the product class hierarchy is described it is necessary to describe the cell class hierarchy to complete the manufacturing system model.

The fabrics are considered to be available at a stock point. The front, the back, and the sleeves are cut and, then, sewed at a sewing machine by an operator to make a sweatshirt. So, we can identify three main cells: cut, stock and sewing cells (Figure 5), each of them made of other cells.

Because here it is inappropriate to represent the detail of specific processes and functions of the manufacturing system, we describe only its generic behaviour. When a new order is released into the system, it must trigger the formation of the cells, needed to manufacture the products. In order to achieve this, product objects must be associated with generic cell objects (example: sweatshirt – sewing cell).

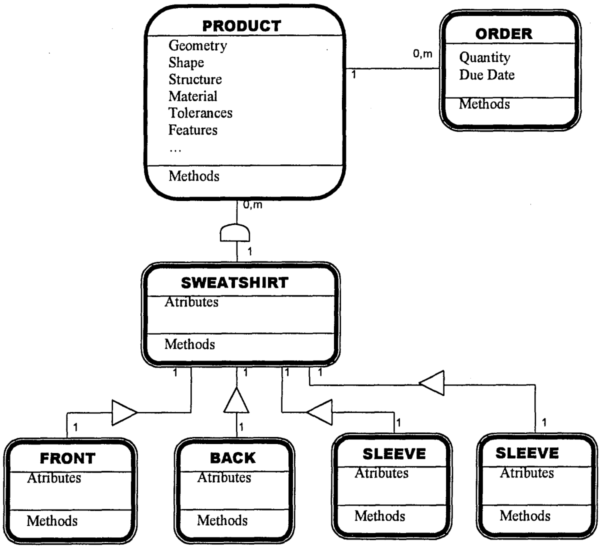

Figure 4 Products Class Hierarchy.

Cell objects will be required to carry out a service, which will make necessary the instantiation of autonomous and non-autonomous cells belonging to it. In this case the cell formation could be based on the analysis of machines and operators free capacity, and, for example, on distributed artificial intelligence agents (Rich and Knight, 1991), appealing to co-ordination and co-operation mechanisms.

9 CONCLUSION

In studying manufacturing systems design and operation we use manufacturing systems models. We defend, in this communication that these models can be efficiently developed through an OO approach.

An object oriented modelling approach of manufacturing systems, based on product and cell objects was presented.

The intention is to develop a compact generic model through repetitive use of similar elements, which allows the representation of manufacturing system objects. Views similar to those of the holistic and the bionic manufacturing systems (Tharumarajah, Wells and Nemes, 1996), with their concepts of holons and modelons respectively, can be explored through definition of objects within objects.

We assume that the manufacturing system is instantiated for a particular product order and therefore may have a short life time duration. So a dynamic view of manufacturing systems is considered through its adaptation to each product or even to each product order. This view can improve system flexibility and utilisation of resources, because they are not linked to one physical cell, but can be associated to numerous different virtual and product oriented cells. This is only dependent on the capability and free capacity of resources. Moreover system design time can be shortened based on product and cell databases that can be replicated, with few changes, to build new manufacturing systems.

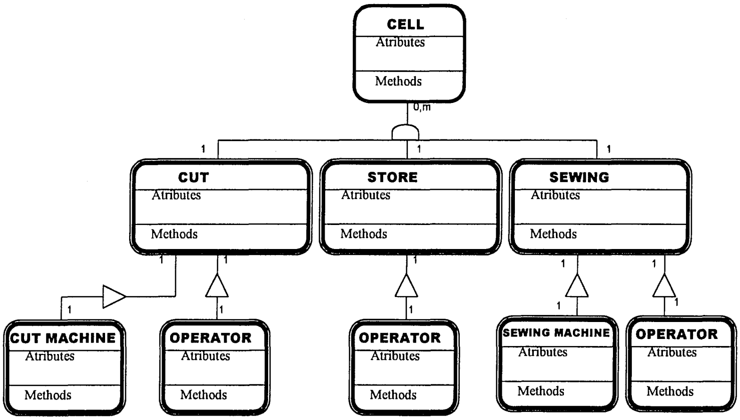

Figure 5 Cells Class Hierarchy.

10 REFERENCES

Adiga, S. (ed.) (1993). Object-Oriented Software for Manufacturing Systems. Chapman & Hall.

Aguiar, M. W., Murgatroyd, I. S. and Edwards, J. M. (1996) Object-Oriented resource Models: their Role in Specifying Components of Integrated Manufacturing Systems. *Computer Integrated Manufacturing Systems*, **9**(1), 33-48.

Camarinha-Matos, L. M., Afsarmanesh, H., Garita, C., and Lima C. (1997) Towards an Architecture for Virtual Enterprise, in *Proceedings of The Second World Congress on Intelligent Manufacturing Processes & Systems* (ed. Lászlo Monostori), Springer Verlag, 531-541.

Crowe, T. J. and Stahlman, E. J. (1995) A Proposed Structure for Distributed Shopfloor Control. *Integrated Manufacturing Systems*, **6**(6), 31-36.

Hoche, O., Broomhead, P. and Grieve, R. J. (1996) Developing an Object Oriented Framework for the Control of Small Manufacturing Cells. *Computer Integrated Manufacturing Systems*, **9**(4), 217-229.

Hoche, O., Broomhead, P., Grieve, R. J. and Chesttney, J. A. (1996) Application of an Object-Oriented Framework Methodology to the Control of Manufacturing Cells. *Computer Integrated Manufacturing Systems*, **9**(4), 231-243.

Kádar, B., Monostori, L., and Szelke, E. (1997) An Object Oriented Framework for Developing Distributed Manufacturing Architectures, in *Proceedings of The Second World Congress on Intelligent Manufacturing Processes & Systems* (ed. Lászlo Monostori), Springer Verlag, 548-554.

Mertins, K., Sussenguth, W., and Jochem, R. (1992) An Object Oriented Method for Enterprise Modelling as a Basis for Enterprise Coordination, in *Enterprise*

Modelling: Proceedings of The First International Conference (ed. C.J. Petrie), MIT, 249-258.
Meyer, Bertrand (1988) Object Oriented Software Construction. Prentice Hall.
PDTAG (1997) Standardisation Product Data Model and Associated Economic Benefits: Tutorial. Product Data Technology Advisory Group - PDTAG.
Putnik, G. D. and Silva, S. C. (1995) One-Product-Integrated-Manufacturing, in *Balanced Automation Systems: Architectures and Design Methods* (ed. L. M. Camarinha-Matos and H. Afsarmanesh), Chapman & Hall.
Putnik, G. D., Guimarães, P. F. and Silva, S. C. (1996) Virtual Enterprise / OPIM Concept: An Institutionalization Framework, in *Balanced Automation Systems II: Implementation Challenges for Anthropocentric Manufacturing* (ed. L. M. Camarinha-Matos and H. Afsarmanesh), Chapman & Hall.
Rich, E. and Knight, K. (1991) Artificial Intelligence. McGraw-Hill, 2nd edition.
Silva, S. C. and Alves, A. C. (1997) Different Perspectives of Product Oriented Production Systems. *1st National Meeting of Industrial Engineering and Management.* (portuguese).
Silva, S. C. and Putnik G. D. (1995) Project on Intelligent Manufacturing Cell at University of Minho, in *Proceedings of The First World Congress on Intelligent Manufacturing Processes & Systems*, 105-111.
Tharumarajah, A., Wells, A. J., and Nemes, L. (1996) Comparison of the Bionic, Fractal and Holonic Manufacturing System Concepts. *International Journal of Computer Integrated Manufacturing*, **9**(3), 217-226.
Yoo, C-H (1997) An Object Oriented Database for Information Management in Computer Integrated Manufacturing, in *Advances in Industrial Engineering Applications and Practice II* (ed. J. Chen and A. Mital), 207-213.
Yourdon, E. (1994) Object-Oriented Systems Design: An Integrated Approach. Prentice Hall.

11 BIOGRAPHY

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