Linking Product Design and Manufacturing Capability through a Manufacturing Strategy Representation

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ABSTRACT

This paper presents a global manufacturing data model that can provide information structures to capture the manufacturing capability information in a global enterprise. In particular it focuses on a manufacturing strategy representation which links shape production to manufacturing processes and resources.

An object oriented manufacturing model based on the machining process, designed using UML and implemented using ObjectStore is discussed. A range of machining strategies for pockets, holes and planar faces are represented and their links to manufacturing processes and resources is described. The relationship between this model and manufacturing features within a product model is highlighted.

1 INTRODUCTION

The traditional feature based design approaches that have been the subject of integrated CADCAM research for many years are typically concerned with the incorporation of manufacturing features into CAD models (1). These features are generally geometric descriptions with some added, but limited, manufacturing information. Although these approaches include the manufacturing information required by the product, they keep only one possible method of manufacturing in one factory with specific facilities, making them inadequate for supporting products in global enterprises (1). Further, CAD systems focus heavily on the geometric description of a product and hence relevant manufacturing information known to the designer is lost because it can not be stored in these models (2).

The provision of relevant manufacturing information to support design decisions is important. Some component parts of a product may be costly simply because the designer did not understand the capabilities and constraints of the production process. For example, a designer may specify a small internal corner radius or excessively tight tolerances on a machined part without realizing that physically creating such a shape requires an expensive machining operation (3). The provision of such information is crucial so that the constraints of a process can be concisely communicated to designers.

In global enterprises products can be manufactured in different factories that have different resources and processes. In order to provide a flexible representation of manufacturing information that can support a range of alternative manufacturing methods there is a need for a new approach that goes beyond traditional machining features. This paper proposes such an approach based on the use of both product and manufacturing models.

Manufacturing models aim to capture manufacturing capability information in terms of manufacturing processes, manufacturing resources, and the manufacturing strategies that constrain their relationship (4). The focus of this paper is on the definition of machining strategies within a manufacturing model and how these can be flexibly linked to feature descriptions within a product model.

Machining Strategies can be defined as methods that utilise resources and processes to reduce manufacturing cost and increase manufacturing productivity. Defining sets of machining strategies involves defining sets of machining operations along with the constraints upon their use. The availability of tools, machine capability, surface conditions of the workpiece, component shape and dimensions are among the constraints to be considered. This paper explores how a manufacturing model can capture these alternatives and their constraints, relate them to available processes and resources in the enterprise and use this combined set of information to support design decision making. In addition to defining the necessary data structures, this paper goes on to explain the development and implementation of an Object-Oriented experimental environment. A simple example is illustrated to highlight the value of the approach taken.

2 MANUFACTURING INFORMATION MODELS

'Manufacturing Information Models' is the title of an EPSRC research grant (5) concerned with understanding of the roles of the product and manufacturing models and the enhanced data structures they require in order that they can support the generation of manufacturing information. The Product Model captures the information related to a product throughout its life cycle, whilst the Manufacturing Model captures the information of manufacturing facility (4). Both models have been defined as the central elements of a Model Oriented Simultaneous Engineering System (MOSES) (6) to support design and manufacturing functions in the product realization process (4).

The high level structure of a Manufacturing Data Model (7) captures manufacturing facility information from a general enterprise level through factory, shop and cell levels and down to individual station level manufacturing information. It is at the station level that this paper is concerned.

An example of a set of manufacturing resources and processes for machining is illustrated in Figure 1. Thus, resources include cutting tool descriptions and machine descriptions. Processes for machining in this case are defined as Machining Operations such as EndMilling, Drilling and FaceMilling etc. Strategies for machining capture the alternative methods by which machining features, such as pockets, holes and planar faces can be produced.

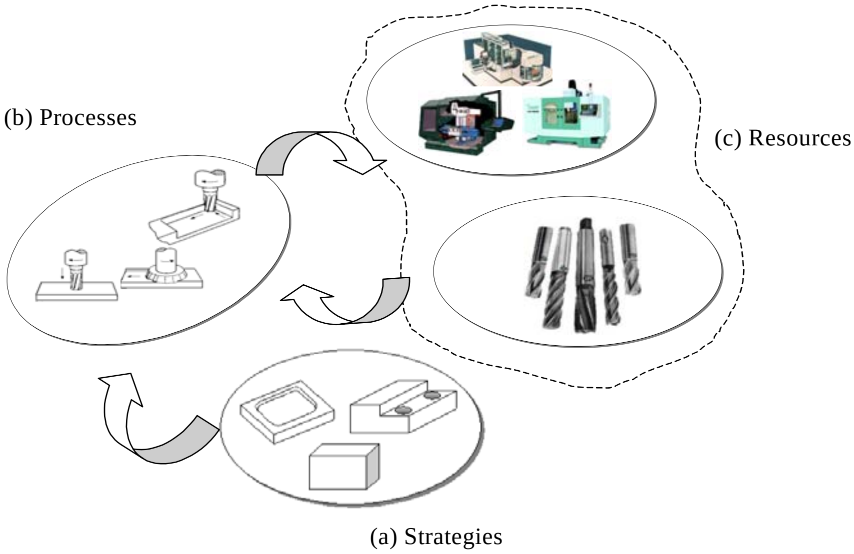

Figure 1 Shape production methods decisions

3 LOW LEVEL MANUFACTURING STRATEGIES IN A MANUFACTURING DATA MODEL

The role of Manufacturing Strategy for machining at the station level of a manufacturing model is concerned with the definition of sets of methods which can be used to produce particular shapes. Strategies have been represented in the Manufacturing Model for the typical machined shapes of ThroughPocket, ClosedPocket, RoundHole and PlanarFace. These are illustrated as a set of shapes in Figure 1(a), but it should be registered that the strategies capture the range of ways in which these shapes can be produced. These machining strategies are termed as ThroughPocketStrategy, ClosedPocketStrategy, RoundHoleStrategy and PlanarFaceStrategy in the Manufacturing Data Model. An example of producing a cylindrical hole is used to describe the development of RoundHoleStrategy.

There are a number of processes and process relationships associate with producing a cylindrical through or blind hole such as drilling, slot drilling, reaming and boring. Figure 2 illustrates these processes and some of their relationships. How these are used is dependent on the limits require on the hole in terms of dimensional accuracy, positional accuracy, size and surface finish. Centre Drilling is used for positional accuracy by ensuring the drill does not drift off the centreline. Improvements in finish and accuracy of drilled holes can be made by reaming. Boring offers the maximum in accuracy, roundness, alignment, straightness and finish. The range of methods to produce a hole defines the set of RoundHoleStrategies as illustrated in Figure 3. The data in the illustration can be captured in the Manufacturing Model along with the limitations and constraints on their use.

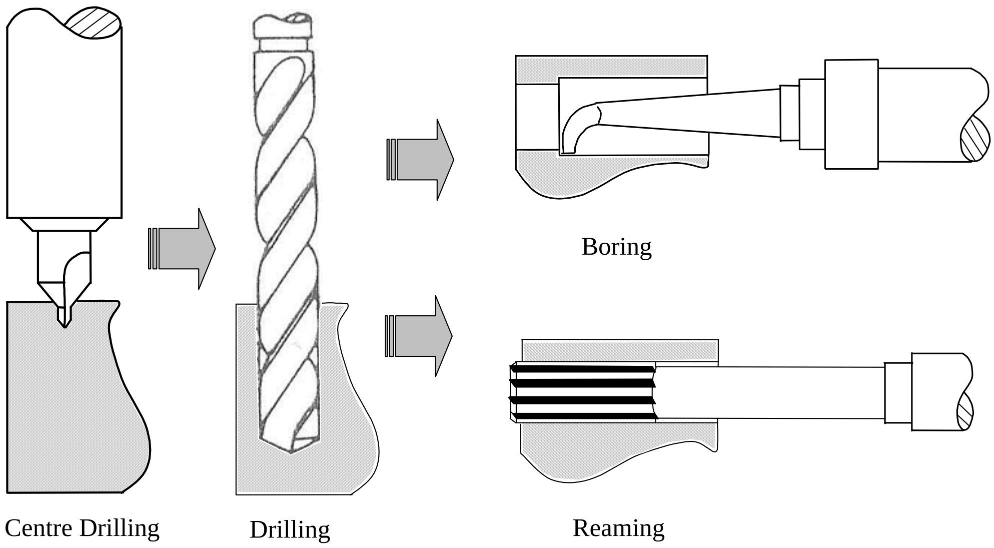

Figure 2 Hole producing processes and their relationships

The strategies are governed and restraint by the rules that indicates the operations needed, surface roughness requirements, dimensional and positional tolerances, the minimum and maximum hole diameter range etc. These rules typically relate to the condition of the workpiece before or after a process. The rules have therefore been captured as 'Pre' and 'Post' conditions of the operations in the manufacturing model. The availability of these options in the Manufacturing Data Model offers information to directly support design for manufacture decisions.

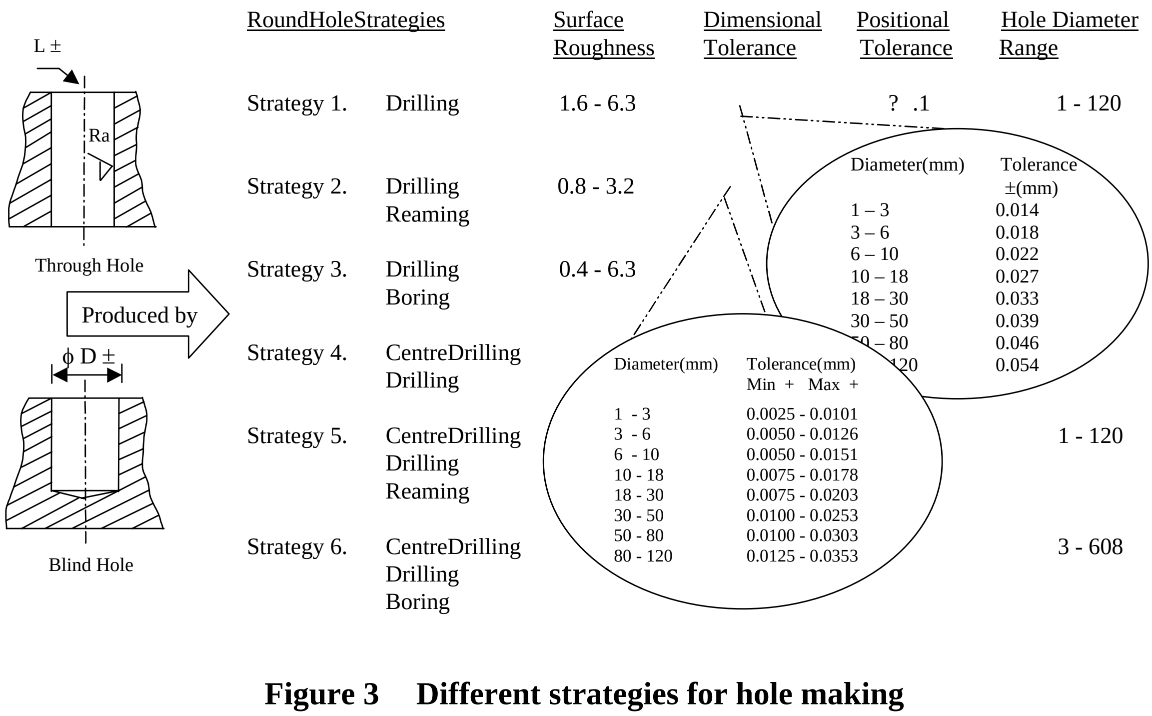

Figure 3 Different strategies for hole making

Feature based systems typically link manufacturing methods directly to product features. In this work the product feature parameters can be used to search the Manufacturing Model for appropriate manufacturing strategies. Figure 4 uses a simple cylindrical through hole to highlight the relationship of machining strategies to Manufacturing Processes and Resources. A set of basic parameters from a Product Model will be extracted and used to perform queries on the Manufacturing Model. The RoundHoleStrategies to be selected depends upon the information and rules stored in ‘Pre’ and ‘Post’ conditions of individual machining processes in the Manufacturing Model. Thus, an appropriate sequence of operations and resources associate with that particular strategy will be output to produce the shape.

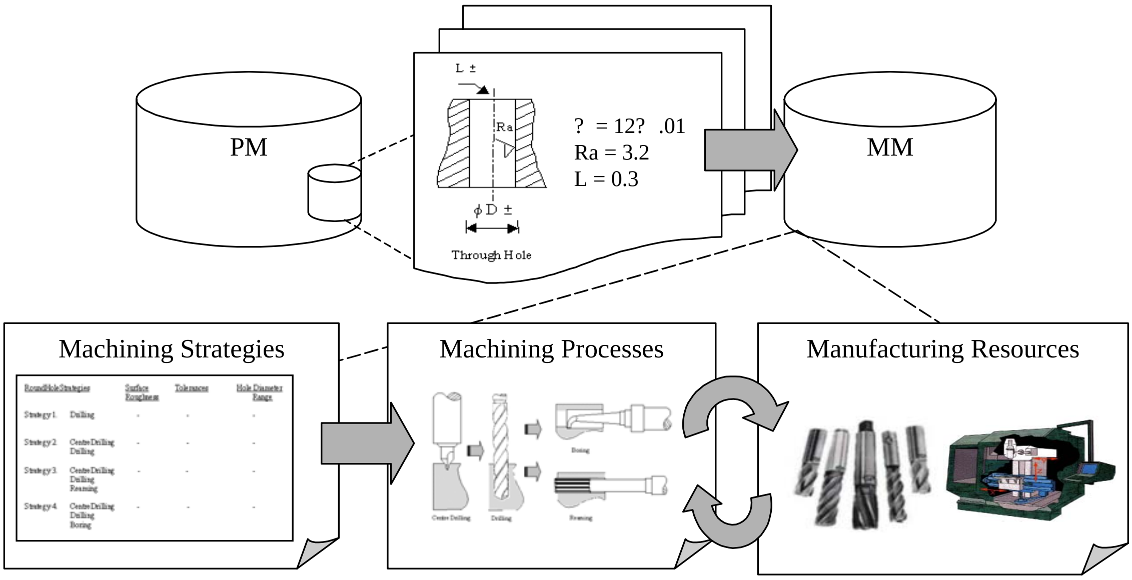

Figure 4 Relationships between product and manufacturing information

4 MANUFACTURING STRATEGIES LINK TO ‘PRE’ AND ‘POST’ CONDITIONS

Figure 5 is an example to illustrate how the Manufacturing Model is used to capture the relevant manufacturing capabilities. The example emphasizes particularly the relationship of MachiningStrategy with MachiningOperation ‘Pre’ and ‘Post’ conditions.

The example is focused on two strategies, *‘Drilling’* and ‘C*entreDrilling / Drilling / Reaming’* respectively. The first strategy *‘Drilling’* supports the production of a cylindrical hole with low requirements on surface roughness (1.6 – 6.3) μm and positional tolerance ± 0.1 etc. Vice versa, if better quality requires for the finishing product then a second alternative such as *‘CentreDrilling / Drilling / Reaming’* will be used. In order to select the appropriate RoundHoleStrategies the Product Model is checked to identify the limitations specified by the product designer. The manufacturing model can then check against surface roughness, tolerances etc in the MachiningOperation ‘Post’ conditions and to establish the possible finishing operations. The 'Pre' conditions will establish the operation sequence needed.

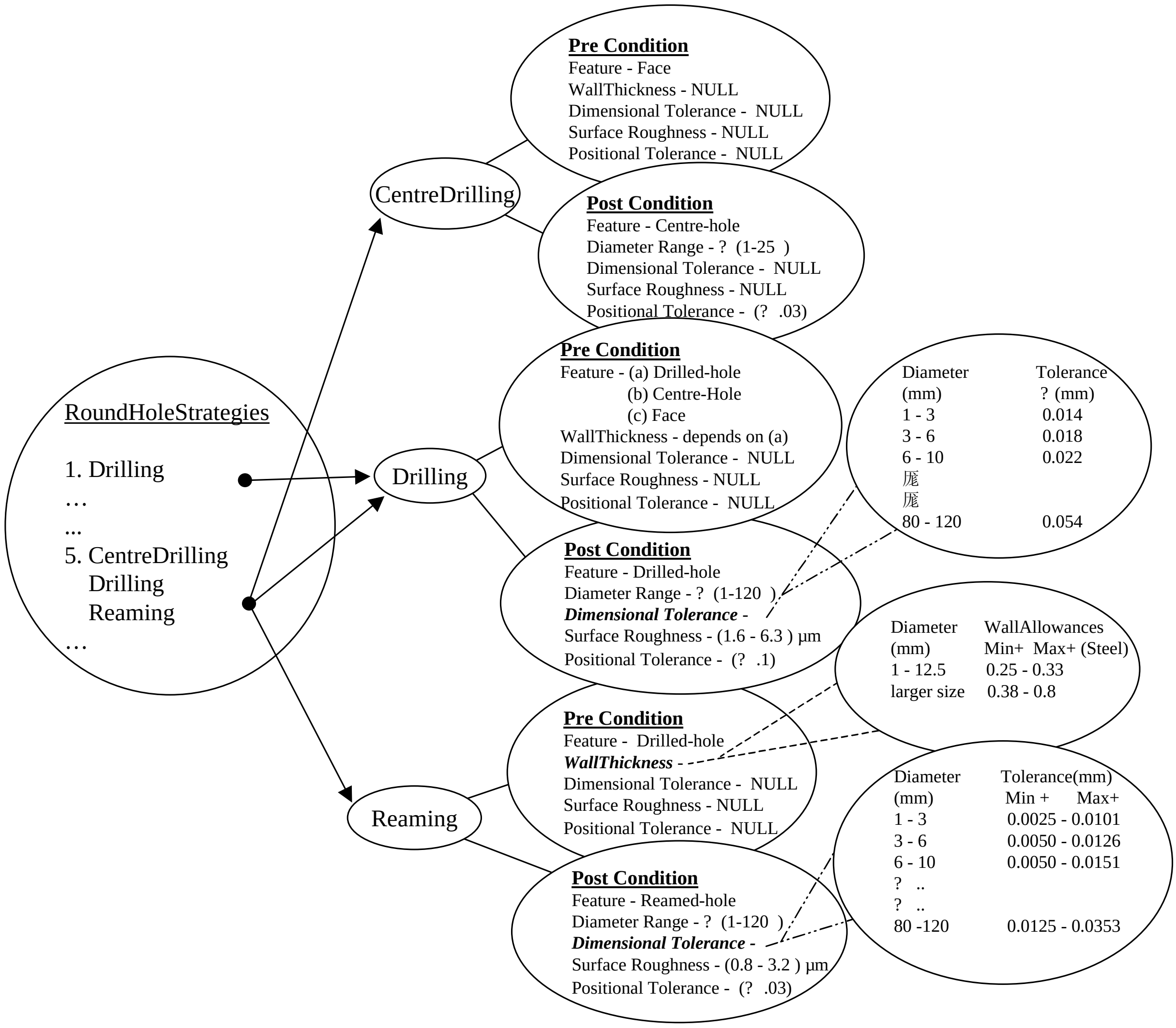

Figure 5 Example of manufacturing strategies link to 'Pre' and 'Post' conditions.

5 AN UML OBJECT ORIENTED MANUFACTURING DATA MODEL

Figure 6 illustrates a single conceptual manufacturing model and represents the high-level UML diagram. This is the core element of the complete MDM infrastructure which consists of main classes and relationship for a manufacturing enterprise. Details and descriptions of individual class and their relationship can be found in reference (7).

The low-level representation of this MDM has been developed based on the Resources, Processes and Strategies super-classes. The low-level structure has focused on the capture of manufacturing facility information at the station level. Manufacturing Resource is defined as the base class of Resources and consists of RawMaterial, MachineCentre and Tooling respectively. Tooling consists of several sub-classes such as CuttingTool and CuttingToolType. Process at this level is described as MachiningOperation including CentreDrilling, Drilling, Reaming, Boring, SlotDrilling, RoughEndMilling etc. Each operation has a unique set of 'Pre' and 'Post' conditions which dictates the process capabilities for that operation.

Machining Strategy is defined as the *base class* of Strategies and including *sub-classes* of throughpocket, closedpocket, roundhole and planarface strategies. The fundamental aspect of Machining Strategy class is to provide all the methods for manufacturing that shape. These methodologies are sequences of machining operations, where each operation is defined in the MachiningOperation class. Thus, Machining Strategies is the core element in Manufacturing Model to support information sharing and interact with Product Model.

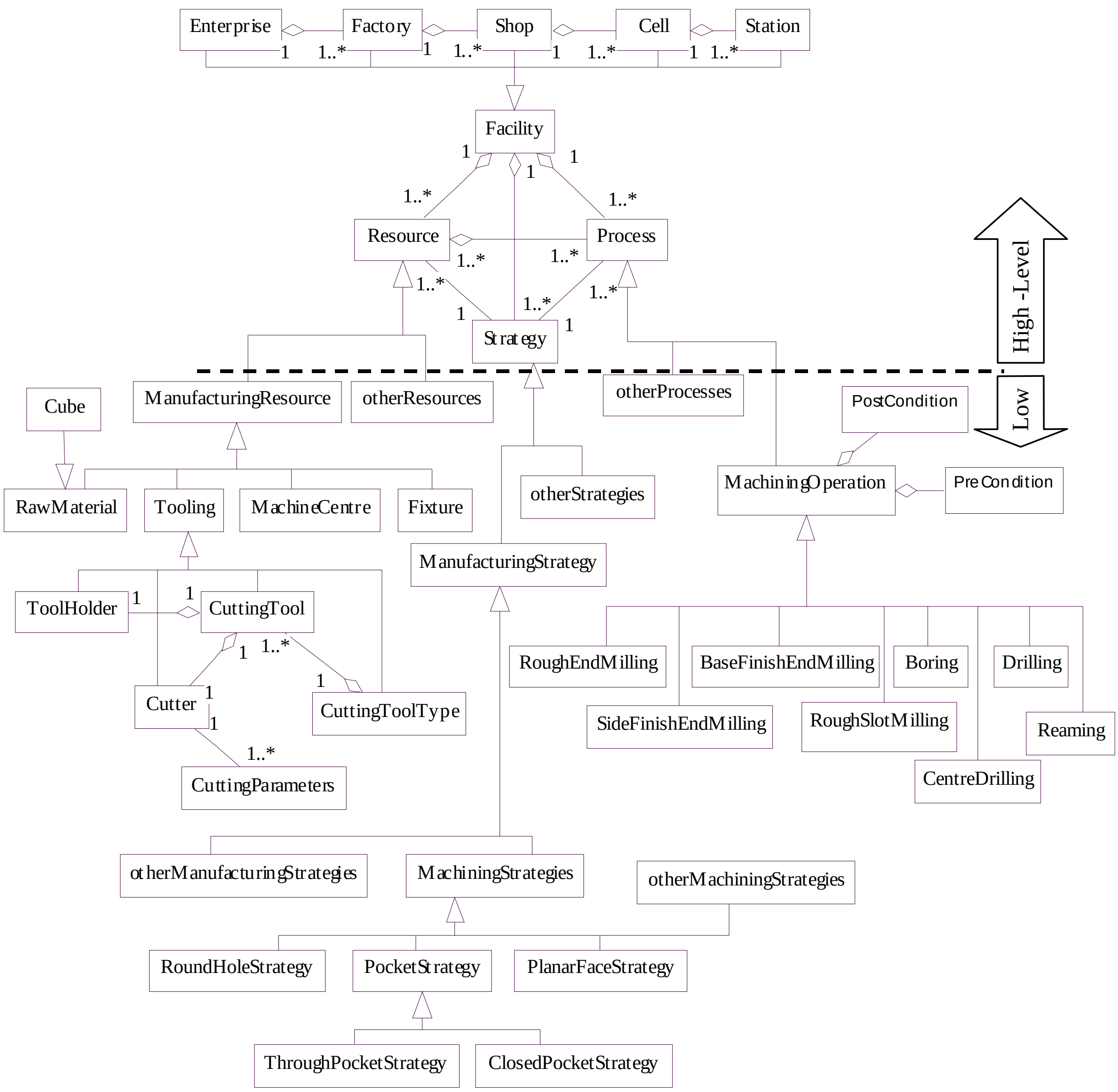

Figure 6 Manufacturing data model in UML representation

DISCUSSION/CONCLUSION

This paper has defined the relationship between manufacturing features in a product model and manufacturing facility information through the use of manufacturing strategies. In this way the information contained in two distinct, but related, models can be shared. One of the advantages of information sharing in this way is that product designers can check manufacturing capabilities to enhance and assist the design and subsequently identify product manufacturability. This is a significant advance on traditional feature based approaches in terms of the flexibility of manufacturing representation.

The machining strategies being implemented in the experimental system are based on the basic shapes of pockets, roundholes and plannarfaces. The Manufacturing Data Model is being constructed using the ObjectStore Object Oriented Database Management System and Visual C++ programming language.

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