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DEVELOPMENT OF A FRAMEWORK FOR OUTSOURCING MACHINING OF COMPONENTS

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1 Introduction

Outsourcing is the transfer of services or functions previously performed within the organization to a provider outside the organization. Wasner [1] defines outsourcing as sourcing out business activities, which were done in-house previously, to an outside organization. By Outsourcing the buyer sources out the ownership or control of the internal process to a supplier for a specific period at an agreed price. Emphasis on total control means incentives to supplier for his innovativeness and expertise, which adds value to client's business. The more value that supplier can add the more profit available to both sides. Outsourcing in Manufacturing is one of the major trends discussed in the Foresight Manufacturing Conference held at Cambridge in March 2000. For example Odilia [2] from the Netherlands stated that '*In the Netherlands only a small number of original equipment manufacturers can be distinguished, followed by a large number of main suppliers, co-makers and jobbers. Original equipment manufacturers concentrate more and more on their core competencies and outsource large parts of their production to subcontractors*. 'Emerging Global Manufacturing Trends [3] states that (a)'*Migration to Higher Value Added Service*' and (b) '*Restructuring of Manufacturing Enterprises into Makers, Innovators and Integrators*' as some of the internal responses for the manufacturing trends. Thus it can be seen that outsourcing in manufacturing is becoming popular. However, Berggren and Bengtsson [4] identify that in Manufacturing Outsourcing the research work is concentrated on management level (Buyer-supplier relationship) and work is still to be done in linking Design and Manufacturing. Kam and Tu [5] looking at tool and die making in New Zealand identify that traditional methods of selecting manufacturers by looking into yellow page directory or web, selecting those easily located with in driving distance or with those they maintain a long time trading partnership fails to reap the benefits of high quality and low cost products. They argue that customers should look for an appropriate manufacturer among manufacturing companies by comparing the products cost, facility level (e.g. multi-axis CNC milling machines, wire cutting machines, EDM etc) and manufacturability.

Provision of metal cutting operations, often called 'Precision Engineering' services, is a key manufacturing activity in the UK. Precision Engineers produce components for a client using machine tools. In the past all major companies had the so-called precision engineering activity in-house. However the growing trend in many companies now is to outsource this activity. The web is greatly assisting this activity. In its present stage, at best it is an efficient business process where a web-based transaction of a machining contract can take place. This situation can be improved very much by having a systematic procedure for selecting the precision engineers with the optimum level of capability for the manufacture of a given component. This linking of design and manufacture for outsourcing is the theme of this paper. It outlines the formulation of a framework for outsourcing the machining of components based on the complexity of components measured in terms of the manufacturing features and associated number of set-ups and the manufacturing capabilities of machine tools.

2 Aims and Objectives

The broad aim of this paper is to establish a feature-based methodology to classify components according to their complexity and to group the precision engineering companies according to their feature producing capability. In the process the following objectives were set out:

1. Investigate the definitions of Machining Features and establish a comprehensive set of machining features.
2. Consider candidate components and identify the machining features.
3. Explore the possibility of classifying the components into families and
4. Explore the possibilities of classifying the Precision Engineers according to their manufacturing capabilities.

3 Methodology

Precision components are usually high value low volume components. Tighter tolerances and complex designs are some of the characteristics of precision components. Precision industry is not different to other industry where high quality with lower cost is the winning criteria. Machining of the precision components requires minimum number of setting-ups, which include tasks like dismounting from fixture, reorientation considering tool approach direction and remount in order to realise the required design at minimum cost and maximum quality [6]. Higher number of setups has adverse effect on lead-time, dimensional accuracy and cost. Number of setups increases if the machining centre is not capable of removing material in a single setup. Thus the criteria for selecting a machine tool for the manufacture of a component are the capability of the machine tool to produce all quality sensitive manufacturing features in a single set-up and at minimum cost.

Application specific machining feature classification has many different approaches but sharing similarities. They all defined manufacturing features along the material removed from the raw stock in some operation. For instance Kramer [7] developed a library of Material Removal Shape Element Volumes (MRSEV's) as a means of categorizing the shape volumes to be removed by machining operation on a 3-axis machining centre. This leads to the development where modern machining can be organised based on machining features instead of traditional machining where it is as organised based on the operations such as drilling, face milling, slab milling, boring, planning, shaping etc. To facilitate this process ISO 10303-224 has developed 19 machining feature categories [8]. Expert Machinist, the feature based milling scheme supported by Pro/Engineer software, defines machining-specific features as "material to be removed by 2-1/2 axis production milling based upon "shop floor" terminology. These features define the material to be removed, based upon machining geometric shapes such as pocket, slot, profile etc and are independent of tool path creation. It is envisaged that these features are capable of describing the manufacturing process involving any milling type operation. A mapping methodology to map the milling features supported by the Expert Machinist software module in Pro/Engineer from the design feature model has been developed [9]. Table 1 gives the main milling features of expert machinist that have been used to create a manufacturing model from a design model using automatic feature mapping. This will also require the identification of the number of set-ups required or the number of axis required. The machining orientation can be selected by defining the machining Z-axis and then a filtration process to identify the mapped manufacturing features that confirm the particular orientation. The framework therefore should aid the establishment of the manufacturing feature model for a given raw stock and establish and check the manufacturability of all quality critical features in a single setup.

Table 1. Expert Machinist Milling Feature Definition

Feature	**Description**
Face (F1)	The Face feature establishes the top of the part at the Z-level of its floor, with respect to the coordinate system active. A Face consists of a hard floor and a single, closed loop of soft walls. The soft walls that form the boundary are the outermost set of soft walls that form a closed loop.
Slab (F2)	The Slab feature enables removal of material from the top of a part where islands on the floor and/or edges of the part. A Slab has a hard floor. The walls of a Slab can be a combination of hard and soft walls. If the walls are a hard/soft combination, internal islands may be present on the floor. If the external walls are all soft, internal islands must be present. A Slab feature cannot have all hard walls.
Pocket (F3)	The Pocket feature is used for material removal where in respect to the coordinate system the removal takes place entirely within the periphery of the part. A Pocket consists of a hard floor and a single, closed loop of hard walls.
Thru Pocket (F4)	Taking place within the periphery of the part, the Thru Pocket is used for material removal extending through the Z-axis of the part. A Through Pocket consists of a soft (is a through feature) floor and a single, closed loop of hard walls.
Step (F5)	The Step allows for the removal of material located at the edges of the part, or on the edges of other features. Form 1 consists of a single chain of hard walls and a single chain of soft walls that together form a closed loop. Form 2 consists of a single chain of hard walls that forms a closed loop in and of itself, and a single chain of soft walls that forms a closed loop in and of itself. These two loops do not intersect each other.
Profile (F6)	The through, Profile feature is used for the removal of material at the edge of the part or at the edge of other features. Form 1: consists of a single chain of hard walls and a single chain of soft walls that together form a closed loop. Form 2 consists of a single chain of hard walls that form a closed loop in and of itself, and a single chain of soft walls that form a closed loop in and of itself. Two loops do not intersect each other.
Channel (F7)	The blind, Channel feature applies to material removed at the edges of the part, and/or edges of other features. A Channel has a hard floor. The walls of a Channel consist of multiple, alternating chains of hard and soft walls. There must be at least two chains of each type and they must be present in equal numbers.

Slot (F8)	The Slot feature is used when it is desired to use a cutting tool diameter, equal to, or slightly smaller than the width of the feature. All forms have a hard floor. Form 1: consists of all hard walls. Form 2: consists of a single chain of hard walls and a single chain of soft walls that together form a closed loop. Form 3 consists of two chains of hard walls and two chains of soft walls that together form a closed loop.
Thru Slot (F9)	The Thru Slot feature is used when it is desired to use a cutting tool diameter, equal to, or slightly smaller than the width of the feature. All forms have a soft floor. Form 1 consists of all hard walls. Form 2 consists of a single chain of hard walls and a single chain of soft walls that together form a closed loop.
Chamfer (F10)	The Top Chamfer is normally located at the top of another feature. The floor of the Top Chamfer can consist of one or more surfaces but the surfaces must be adjacent to each other. The surface(s) that define the Top Chamfer feature can be plane(s), cone(s) or ruled surface(s). The floor must also have a constant angle to the feature coordinate system. A Top Chamfer feature can have one or more of both hard and soft walls.
Round (F11)	The Top Round allows for the independent machining of rounds located at the top of another feature. The floor of the Top Round can consist of one or more surfaces but the surfaces must be adjacent to each other and each surface must have the same radius. A Top Round feature can have one or more of both hard and soft walls.
Hole (F12)	Holes normal to the Program Zero coordinate system can be defined and drilled using the Hole Group.

3.1 The Framework

The traditional method of selecting a precision engineer has many draw backs and it is important that a more technically sound method is developed based on the product's design, its functionality and the manufacturers manufacturing capability and their resources. In the proposed framework the products' design is converted into machining feature model and the number of settings required to access all the manufacturing features present in the model are determined. This will facilitate to determine the quality critical manufacturing features that require additional set ups, with machine tools that have less flexibility in terms of number of axis. This provides the opportunity where precision engineers who do not have the additional multi-axis CNC milling machines can be eliminated in the initial selection process. This initial short-listing of precision engineers based on their capability to manufacture the quality critical features in the given design should precede the current commercial practices of outsourcing. This is the main thrust of the proposed framework illustrated in Figure 1.

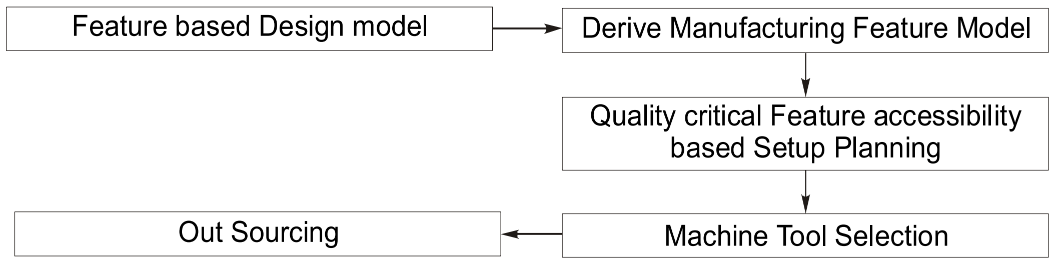


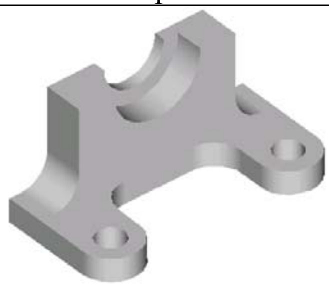
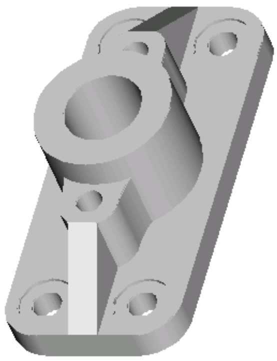
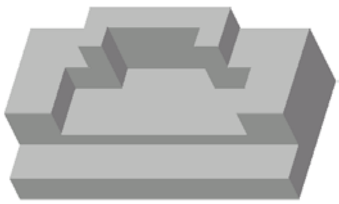
Figure 1. Frame work for outsourcing of machining component based on its design

Following sections demonstrates with case studies of the transformation of design models into manufacturing models and the number of settings varying with the machine tools selected.

3.2 Case Study set 1

This set consists of the components that were found to be suitable for a three-axis machine with a single set-up. For uniformity it was assumed that the components are machined from their rectangular block of raw stocks. Twenty-one components investigated fell into this category. Examples from this set and their corresponding manufacturing feature trees as identified by Expert Machinist are given in Table 2.

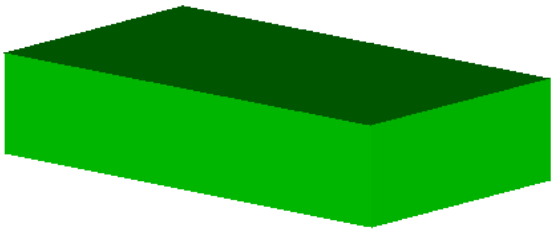
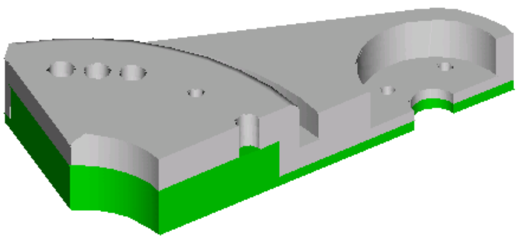
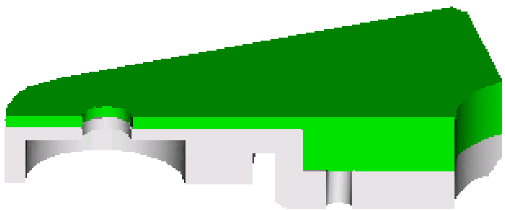
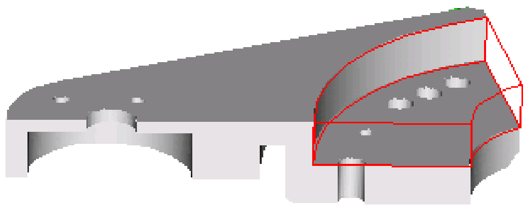
Table 2. Components with single setup 3-axis Milling Features

Component	Manufacturing feature tree
	BEARINGREST1.ASM BEARINGREST1ASM.ASM FSETP0 MACH01 ACS0 OP010 [MACH01] PROFILE1 [OP010] PROFILE2 [OP010] TOPROUND1 [OP010] STEP1 [OP010] STEP2 [OP010] DRILL_GROUP_1 [OP010] ACS1
	BRAKEROD1.ASM BRAKEROD1ASM.ASM FSETP0 MACH01 ACS0 OP010 [MACH01] FACE1 [OP010] STEP1 [OP010] STEP2 [OP010] STEP3 [OP010] STEP4 [OP010] TOPCHAMFER1 [OP010] TOPCHAMFER2 [OP010] PROFILE1 [OP010] DRILL_GROUP_1 [OP010] DRILL_GROUP_2 [OP010] DRILL_GROUP_3 [OP010] DRILL_GROUP_4 [OP010] FACE2 [OP010] SLOT1 [OP010] ACS1
	BEAMSUPP1.ASM BEAMSUPP1ASM.ASM FSETP0 MACH01 ACS0 OP010 [MACH01] PROFILE1 [OP010] PROFILE2 [OP010] STEP1 [OP010] STEP2 [OP010] ACS1 ACS2

Inspection of the manufacturing feature trees showed that a three-Axis machine can manufacture all of the twelve feature types defined by Expert Machinist and thus the machining complexity is access dependent only.

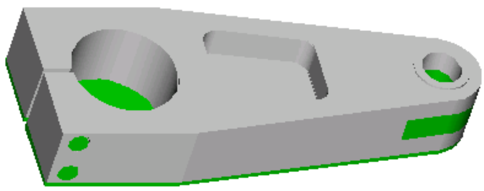
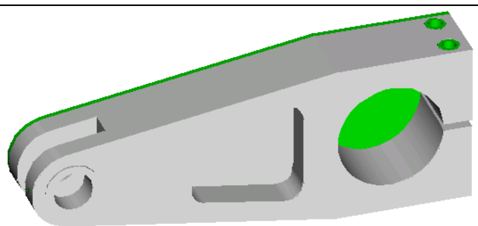
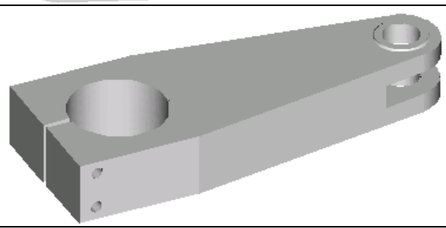
To illustrate this consider the component analysed in Table 3. It shows a component from a pharmaceutical assembly line. The first column shows the 8 machining features that were created for operation10 with a 3-axis machine (MACH01) for set up1. The second column shows the two machining features (face 2 and Step 2) created in operation 2(OPO20) for the second set-up. Because features affect all six faces of the work piece the second set-up is inevitable and a machine of higher calibre would not be able to eliminate it.

Table 3. Components with single setup 3-axis Milling Features

Component	Manufacturing feature tree
 (a) Work piece  (b) Machining features created in set up 1	HOFLIKER2.ASM HOFLIKER2ASM.ASM HOFLIKER2.PRT HOFLIKER_WRK.PRT MACH01 OP010 [MACH01] FACE1 SLAB1 TOPROUND1 TOPCHAMFER1 DRILL_GROUP_1 SLOT1 STEP1 PROFILE1
 (c) Stock to be removed in machining set up2  (d) Machining features created in set up 2	OP020 [MACH01] FACE2 STEP2

3.3 Case Study set 2

Table 4. Components with three setup 3-axis Milling machine

Component	Manufacturing feature tree
	HOFLIKER1.ASM HOFLIKER1MFG.ASM HOFLIGER1.PRT HOFLIKER1_WRK.PRT FSETP0 MACH01 ACS0 OP010 [MACH01] FACE1 [OP010] SLAB1 [OP010] POCKET1 [OP010] DRILL_GROUP_1 DRILL_GROUP_2 THROUGHSLOT1 PROFILE1
	OP020 [MACH01] THROUGHSLOT2 DRILL_GROUP_3
	OP030 [MACH01] FACE2 SLAB2

This set shows components where machines with higher capability can reduce the number of set-ups required. Table 4 shows a component that requires 3 different set ups for the tool to access its 11 different manufacturing features present. The component requires 3 different set-ups to machine the features on a 3-axis machine. But the same component can be machined with two set-ups on a 4-axis or a 5-axis machine. Thus depending on the quality required for each feature the outsourcer can choose a 3 axis precision engineer at a lower cost or a relatively cheaper 4-axis precision engineer. Choosing a precision engineer with a 5-axis machine is unnecessary.

3.3 Case Study set 3

This set consists of component with features where all quality critical machining features require machines with very high capabilities. If some are not quality critical a medium calibre machine only is required and if many are not quality critical a basic three-axis machine is adequate. For instance if the component shown in Figure 2 is considered for machinability (drilling) of its hole features in a three axis, four axis and five axis machine respectively the outcome in terms of the number of set-ups required will vary. Thus for components of this group the choice is quality critical and the outsourcing of them is not a pure commercial exercise.

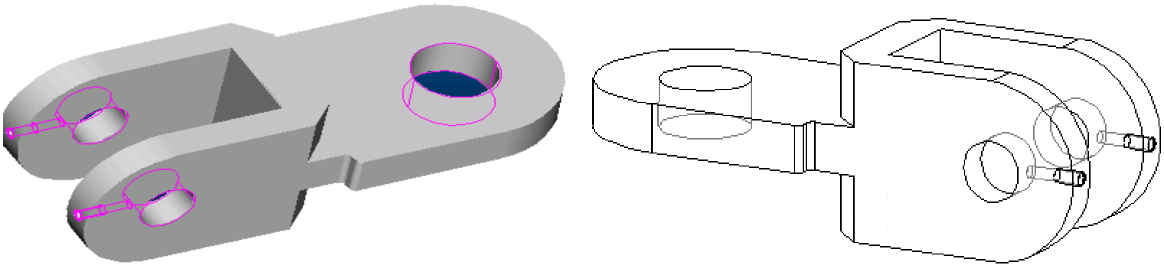


Figure 2. Brake lever Bracket of a Railway Wagon

Table 5. Component with three setup and three axis milling machine

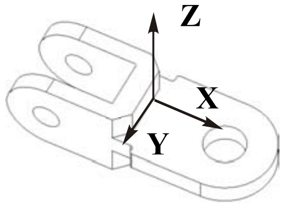
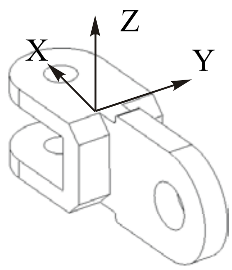
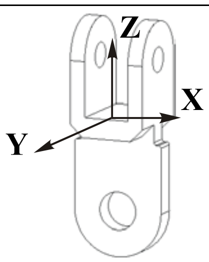
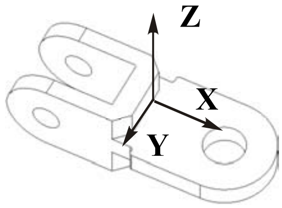
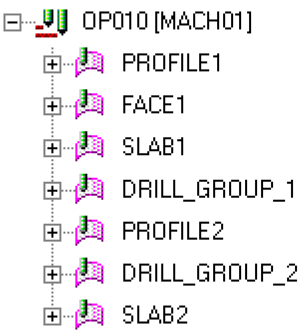
 Machine Coordinate for Operation 1 (OPO10) OP010 [MACH01] FACE1 SLAB1 PROFILE1 DRILL_GROUP_1 Machine Features created in OPO10	 Machine Coordinate for Operation 1 (OPO20) OP020 [MACH01] DRILL_GROUP_2 PROFILE2 Machine Features created in OPO20
 **Machine Coordinate for Operation OPO 30**	OP030 [MACH01] DRILL_GROUP_3 7. DRILL_GROUP_3_TP1 8. DRILL_GROUP_3_TP2 **Milling Features created in OPO30**

Table 5 shows the manufacture of this component in a 3-axis machine. Under operation OPO10 with the selected orientation DRILL_GROUP_1, features can be manufactured. Similarly under operation OPO20 with its given orientation features DRILL_GROUP_2 only can be manufactured. For the remaining feature DRILL_GROUP 3 OPO30 is needed. Thus for the component to be machined on a 3-axis machine three different set-ups are needed. Similarly the same part can be machined in a 4-axis machine with two set-ups as shown in Table 6. In the same way the machining of the component can be achieved with a single set-up in a 5-axis machine as shown in Table 7. Thus it can be seen that with additional degrees of freedom the flexibility of the tool motion increases which results in less number of setting-ups. Reduction in the number of setting-ups significantly enhances precision and also accrues savings in time needed for setting up, extra fixture costs and labour. However the penalty is the higher machine rate due to its higher capital cost. The decision is purely engineering based. Modifying the design and assessing the quality requirements are steps that have to be taken to choose the precision engineer. Thus the prior short-listing of precision engineers becomes crucial.

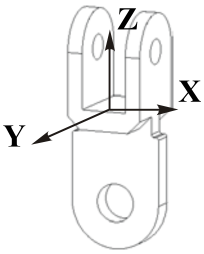
Table 6. Component with two setup and four axis milling machine



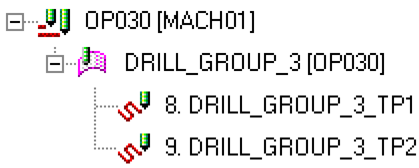
Machine Coordinate for Operation 1 (OPO10)



Milling Features in Operation 1

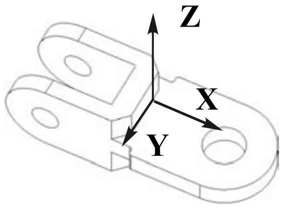


Machine Coordinate for Operation 1 (OP030)

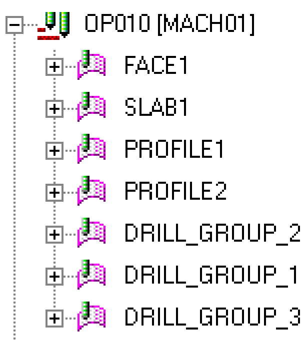


Milling Features in Operation 2

Table 7. Component with single setup and five axis milling machine



Machine Coordinate for Operation 1 (OPO10)



Milling Features Operation 1

4 Conclusion

The choice of a precision engineer is not just a commercial exercise. A proper match between the engineering content of the work and the capability of the machine tool only will produce high quality components at optimum cost. Manufacturing feature based evaluation of the operations and accessibility is a method that can be employed to establish this match. A framework based on this approach is proposed and case studies have been given to show the effectiveness of the approach.

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