Grouping Parts for Cellular Manufacturing with CADFind

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Introduction

This paper briefly reviews the nature of cellular manufacturing and examines the reasons why Group Technology (GT) cells have become very popular in recent years. It goes on to examine one of the core tasks faced by the cell design engineer – identifying the family of parts around which the cell will be designed. The recent development of a 'GT' version of the CADFind graphical retrieval system has meant that this process has been made faster and easier than was previously possible for coding and classification based approaches. Traditionally coding and classification systems (like Opitz or CAMAC) used manual methods to encode the properties and characteristics of parts into a numerical or alpha-numeric 'code'. Parts with similar codes were likely to be geometrically similar. Thus once all a company's parts had been coded, simple searches or sorts could be used to identify groups of parts with similar codes that would form the basis of the cells' families. These systems worked well but suffered from the long delays and costs associated with the manual coding stage. In my experience manual coding rates rarely exceeded 100 parts per day per engineer (a rate also confirmed by academic studies) and at this rate an engineer would take over a year to code even a modest range of, say 25,000 parts. Such delays (or the costs associated with extra manpower) have often proved unacceptable given the tight timescales that commercial realities frequently require of manufacturing system redesign projects. This meant that other, less effective methods have often been used. The automatic coding ability of CADFind can cut the time to code the parts range to a few days and thus for the first time makes grouping based on coding and classification a viable option for any GT cell design project.

Design of Cellular Manufacturing Systems

The idea that all manufacturing systems can be organised as cells is clearly wrong (unless the definition of a cell is devalued to the point of having no utility). Circumstances will arise in which more traditional alternatives will offer the most effective solution. However, cells remain a key concept in modern manufacturing system design and therefore this section will start by considering why they are now seen as so important.

Functional Systems	*Flowline Systems*
Advantages	
supports wide product range	low work in progress (WIP)
flexible processes yield long system life	short flow or throughput times
supports specialist process expertise	predictable performance (volume/mix/throughput times)
insensitive to minor stoppages	simple progress control;
Disadvantages	
complex material flow paths	very limited product range
high levels of work in progress	life tied to product (system tailored to the product)
long throughput times	unsocial working conditions
unpredictable throughput times	short cycle work tasks
complex sequence planning	inflexible working practices
complex progress control	long change-over times
inefficient material handling	sensitive to disruption

Table 1 Characteristics of Functional & Flowline Systems

To understand why cells frequently offer the most effective design solution it is useful to examine the nature of the alternatives. In high volume and low variety environments production flow line systems are commonly used. Some of the key characteristics of flow lines are listed in the Table 1.

In lower volume, high variety manufacturing functional layout was (and is still) commonly used. Functional layout organises all the plant on the basis of commonality of process - leading to separate departments, or sections, which specialise in particular types of operation (like milling, turning, heat treatment etc.). These long-established systems have a particularly poor operational record but it should be appreciated that these difficulties follow inevitably from their organisation which is linked to the demand for product flexibility placed upon them. Functional systems also offer poor accountability for product delivery, cost, or quality because the product has to pass through several production 'departments', each the responsibility of a different foreman or manager. Their characteristics are also listed in Table 1.

Cells offer a different mix of characteristics, both good and bad, which may produce a better fit to the needs of the business. For example Group Technology (GT) cells offer lower work in progress and easier planning than functional shops but are also likely to suffer from much shorter operational lives. To understand how this works we must examine what characteristics define a cell.

Cell Characteristics

A cell is formed by collecting together all the resources (people, plant, tooling, support services etc.) needed to completely manufacture a range of products. In this context ‘product’ has a special meaning: it can be a collection of saleable products but is more commonly a range of broadly similar components or assemblies. In the latter case the cell’s customer may be another cell elsewhere in the factory.

A cell must be readily identifiable as such. This means that:

- its physical boundaries will be clearly defined;
- input/output areas will be identified;
- all the cell’s equipment will be located within the boundary area;
- its products will have an obvious identity;
- people are seen to belong to a cell, or rather they ‘own’ it.

Cells must be modest in size, typically less than 20 machines or 15 operators. This size limitation leads directly to many of the reasons behind the good performance of cellular systems:

- the scope and activities of the cell can be understood easily by everyone;
- everyone will be familiar with the cell ‘product’ range, since it will, by definition, be limited;
- key control, capacity and quality decisions will be taken by people who are the most knowledgeable about the current manufacturing situation and are thus the best qualified to take them;
- assignment of priorities and allocation of resources is controlled locally and assessed against local objectives.

The similarity of the cell ‘products’ implies a reduction in the variety of process routes which must be managed. Careful plant layout should further simplify material flows through the cell, thus:

- material movement will be easier to control;
- batch or material progress will therefore be more predictable;
- the reduction in uncertainty permits operation with much lower levels of work in progress (WIP);
- lower levels of WIP lead to reductions in flow (or throughput) time;
- shorter flow times reduce the need to make against forecast demand, thus reducing uncertainty at the input to the system, permitting further reductions in WIP;

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- stable material flow rates also limit flow time variability leading to improved delivery reliability and thus better customer service.

Throughout this discussion it has been clear that the cell's 'product range' is key to both the way it has to be designed and the benefits that flow from cellular organisation. Therefore the way that product range (or family) is defined is key to the design of a successful cellular manufacturing system.

The Basis of Cell Creation

Cells can be created on the basis of a wide variety of common factors. These may include similar product types, customers, lead times, volumes, varieties and manufacturing routes. Manufacturing process characteristics can also be used, for example: process stage (i.e. assembly, component manufacture, etc.), type (i.e. mills, autos, etc.), or level of precision are all possible criteria. However over-emphasis on process characteristics risks the creation of functional cells with little potential for improvement in material flow paths.

The main objective is to produce a cell structure which will permit operation to most closely approximate that of a complete business unit. Whilst a variety of common factors may be used, the most effective solutions are invariably those based on finished product or parts family orientations, see Figure 2.

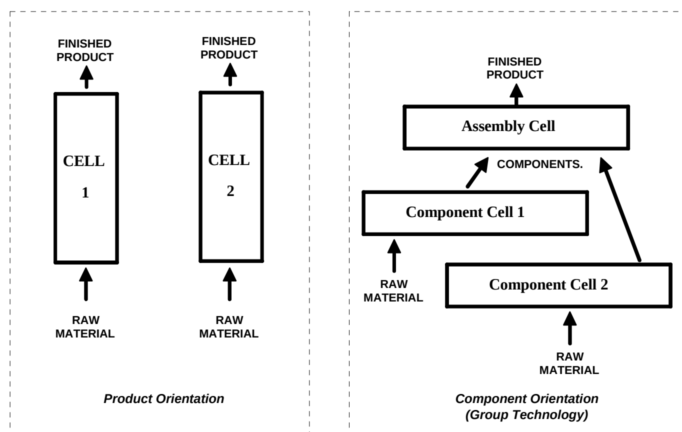

Figure 2 Business Unit Orientation

A 'finished product' cell is responsible for the complete manufacture of a product from receipt of raw material to shipment to end customer. A group of cells, operating in parallel, which produce related products might form a business unit or module. This structure clearly offers excellent accountability, good control, rapid market response and close approximation to the micro-business concept. However, the limit on cell size tends to restrict the complexity of product that can be accommodated and cell viability is likely to be vulnerable to shifts in product mix and volumes. This means that in many cases a broader basis must be used for the cell's product range.

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Cells based around the manufacture of a family of components, sub-assemblies or assemblies tend to be more robust in absorbing variation in demand. Such cells, which follow the Group Technology tradition, are used where the finished product is complex, the manufacturing route long, and where many common parts exist. In this case the identification of the range of parts that will be produced by the cell is much more challenging because the manufacturing commonality required is not obvious from a simple comparison of part numbers, bills of material or item descriptions. Further a viable family may need to contain several thousand parts and the total range to be produced all a company's cells could extend to hundreds of thousands of components and assemblies.

Definition of Cells & Part Families

Cells are initially defined in terms of their product families and process equipment. Physical layout, precise manning levels and job specification, tooling, materials handling and other aspects of the detail design are tackled at a later stage. Here we are concerned with the fundamental question of what will be made by each cell and how that will be achieved.

As was mentioned earlier, a 'product family' may be related to true finished products or (more commonly) to a range of components or assemblies which are supplied to other cells in the factory. Identifying which parts should be grouped to form each 'product family' is a fundamental aspect of cell definition.

Grouping for GT cells is based on the need for similar manufacturing facilities, thus two parts are similar only if they can be made in the same way. The function the parts perform from a design point of view is irrelevant. Simple manual sorting of parts into groups by inspection of drawings or process plans is likely to prove tedious and ineffective (unless the number of parts is small). More specialist techniques have been developed; the most widely used being Component Coding & Classification and Production Flow Analysis (PFA).

Component Coding & Classification

Component Coding & Classification utilises the simple idea of encoding information about a component in a number. In most coding systems the recorded information would include aspects such as the main geometrical features (flats, slots, threads, holes, tapers etc.), dimensions (major plus an indication of tolerances) and material (type and initial form). Although popular (particularly in the USA) as the basis of family identification, classification systems may be used for a number of other purposes. These include: process planning, estimating, drawing retrieval (in CAD), variety reduction and the generation of work piece statistics. Traditionally, it would be unusual to implement classification purely to support a grouping exercise.

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Many classification systems have been developed for manufacturing applications, including Brisch, Opitz, and MICLASS (see Gallagher and Knight, 1986). The latter was designed as a computerised system which includes extensive on-line search and analysis facilities; as do later systems like CAMAC (Love and Love, 1988).

Groups are identified either by simple code sorts or, more effectively, by progressive refinement using an iterative search through the parts database applying a range of selection criteria. It should also be noted that the approach assumes that parts which have similar codes will require similar manufacturing facilities. This does not necessarily follow; it is quite possible to have two parts which look geometrically similar but which are made in totally different ways. On the other hand coding makes no assumptions about the validity of the existing method of manufacture; indeed it requires no knowledge of it. Thus in circumstances where methods are likely to be changed (e.g. by the introduction of new plant) the coding approach provides a reliable basis for cell formation and encourages a fundamental review of manufacturing requirements.

The major drawback with traditional coding systems is that they require a skilled person to interpret the geometry from part drawing to produce the code 'number'. This process is slow – our experience at Aston University suggests that coding rates are usually less than 100 parts per day for a skilled and dedicated engineer. A study by Wemerlov & Hyer (1989) in the USA confirms this figure. He also found that many companies abandoned coding & classification systems because they were expensive to set up and maintain (and presumably many never start on the road for the same reason). The significance of this problem can be simply illustrated: if a company has 25,000 parts in its database then it would take an engineer over a year to code them manually. It is worth noting that most engineering companies have far more than 25,000 parts in their range and the majority add new parts to the range all the time.

Most factory or cell redesign projects are tasked to be completed in a period of weeks or months – a year's delay before design work can start is obviously unacceptable so it is unsurprising that coding based redesign usually occurs only when companies have implemented coding & classification for other reasons (typically to encourage design re-use). The development of the CADFind system has changed this situation radically as its automatic coding of 2D drawings and 3D models means that a company's parts range can be coded in a matter of a few days since CADFind can code over 1000 parts per hour.

Production Flow Analysis

Production Flow Analysis (PFA), developed by J.L. Burbidge (1975), is an alternative means of identifying GT families. This technique concentrates the analysis on the existing methods of manufacture, as recorded by

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the process planning documentation. Families are formed from parts which visit the same group of work centres (irrespective of the sequence of these operations).

One of the best ways of visualising this process is to produce a 'Production Flow Analysis Chart' which shows, in matrix form, which parts visit which machines. Two methods are commonly used to process the matrix: Cluster Analysis and Rank Order Clustering both of which are well explained in Gallagher & Knight (1986). Whichever method of clustering is employed it is inevitable that awkward parts will emerge that fit no obvious group. Re-planning of these jobs may be needed to deal with this problem.

On the other hand PFA is quick to apply and thus relatively inexpensive. It avoids any assumptions concerning the links between component geometry and manufacturing methods and results in direct assignment of parts to families and plant to cells.

However a major drawback of PFA concerns its dependence upon the accuracy of the process planning information. Manufacturing documentation may not be completely up to date or reflect the most appropriate production method. Process route data is frequently the least accurate manufacturing-related data held in the company.

PFA also assumes that the existing plant and process technology will be used in the cells. This is not always the case as the existing plant will be divided across the cells so that the machines called up in the process plan may not be available in the target cell. The opportunity (or need) to purchase new equipment will also lead to the opportunity for review of the parts' process plans. Further, since the choice of appropriate manufacturing methods is dependent on production quantities and since grouping fundamentally changes effective manufacturing volumes it follows that the existing method will very often be a sub-optimal choice for the cell. All these issues undermine the basic assumptions that are made by PFA.

PFA also has a further drawback in that once the cells are established new parts can be assigned to families only during the process planning stage, i.e. after design is complete, whereas coding and classification techniques allow the designer to test for family membership before the design is finalised.

Grouping Parts with CADFind

In practice fully automatic grouping is rarely practical - even with PFA the group membership has to be checked by production engineers and outlying parts that do not fit well with any group have to be re-planned to use the actual processes that will be available in the planned cells. There are many academic papers on GT

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grouping but the vast majority treat the issue as a simple mathematical problem and ignore the practical realities of the task.

Given that automatic systems will always include some unsuitable parts (called false positives) it follows that they that will have to be eliminated during the review process. That means that any system intended to support the engineer in this process has to provide intuitive ways of working with groups to refine and review their membership. For example it is common to split and merge groups in order to form a viable final family. Frequently it is necessary to examine a particular drawing or model in more detail and the system needs to be able to display and export details of group membership in a convenient form.

So given that fact that engineers will need to use their experience throughout this process it is important that the system does not restrict them in this, but makes the process of grouping, adding and removing parts as easy (and visual) as possible.

CADFind GT is designed with these requirements in mind.

CADFind is Simple to Use

To avoid the costs and delays associated with the need to train staff it is important that the system is straightforward to use. Anyone can be shown how to use the system in a few minutes because the process is very visual and interactive. In particular:

- parts are displayed with thumbnail images but if more information is needed CADFind will load the 2D drawing or 3D model into the engineer's CAD system for detailed review
- parts are listed by catalogue and by family
- parts can be grouped automatically based on their shape similarity, refined and allocated to groups
- a set of parts parts can be selected by the engineer and then CADFind will find all those parts that are like them
- grouping can be based on a minimum level of similarity to any of the individual parts that formed the original set or based on a part's similarity to the group as a whole
- standard CADFind searches (text or graphical) can also be used to find suitable parts

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- with a simple mouse click parts can be added or removed from the group
- Once satisfied the engineer can add the group of parts to an existing family or create a new one
- details of the family can be output to a file and uploaded into excel for further analysis

Once the cell is implemented it is still necessary to manage the consequences of shifts in the market, the introduction of new products or the impact of engineering changes. Such change will result in the need to add new parts to existing families, remove obsolete parts and periodically review family boundaries.

At design time (even before detailing is complete) CADFind can review the potential match of a part to existing families. This means the design changes that will improve the fit of the part to an existing cell family can be made early in the design process.

Use in Standardisation

Standardisation is known to yield major economies in production and overhead costs but finding a way to rationalise an existing parts range may be difficult if the range is large and been subject to uncontrolled growth over many years.

The CADFind grouping mechanisms can be used to find parts that are so similar that rationalisation can be achieved. The automatic grouping process is run on the complete parts range (or a subset of it). The user defines a ‘target’ percentage level of similarity and the system creates an output a file that identifies all parts that are at least that similar to each other. Alternatively the visual grouping facilites in CADFind GT can be used to identify and review target groups of parts for rationalisation. The ability of the system to group legacy 2D drawings with more modern 3D models is important here as is the convenient way that detail drawings or models of individual parts can be viewed in CADFind or loaded into to the appropriate CAD system at the click of a mouse.

Conclusion

One of the core tasks faced by the cell design engineer is identifying the family of parts upon which all the facilities and organisation the cell will be based. The recent development of a ‘GT’ version of the CADFind graphical retrieval system has meant that this process has been made faster and easier than was previously possible for coding and classification based approaches. Traditionally coding and classification systems (like

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Opitz or CAMAC) used manual methods to encode the properties and characteristics of parts into a numerical or alpha-numeric 'code'. Parts with similar codes were likely to be geometrically similar. Thus once all a company's parts had been coded, simple searches or sorts could be used to identify groups of parts with similar codes that would form the basis of the cells' families. These systems worked well but suffered from the long delays and costs associated with the manual coding stage - an engineer would take over a year to code even a modest range of 25,000 parts. Such delays and the costs associated with extra manpower needed to overcome them have often proved unacceptable given the tight timescales that commercial realities frequently require of manufacturing system redesign projects. This meant that other, less effective methods like PFA have often been used. The automatic coding ability of CADFind can cut the time to code the parts range to a few days removing this impediment to the use of the coding approach. The analysis and review facilities in CADFind have been designed to maximise the use of an engineer's experience and knowledge through simple, visual functionality that for the first time makes grouping based on coding and classification a viable option for any GT cell design project.

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