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Integration of part classification, cell formation and capacity adjustment

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ABSTRACT

Purpose: Improving the productivity of a large manufacturing firm through development and implementation of a group technology model in a real manufacturing environment. This incorporates classification of parts, coding of parts and par families, formation of machine cells, and minimization of machine idle times through machine cell capacity adjustment.
Design/methodology/approach: An algorithm has been developed for classification of all the parts into part families on the basis of manufacturing similarities. This formed 144 par families for more than 7500 different parts in production. The algorithm assigned group technology code to each part and a part family code to each part family. The former represents manufacturing characteristics of the part and the latter simplifies determination of part families. A number of machine cells were developed to produce all of the part families. After classification the system automatically directs each part to the appropriate machine cell for manufacturing. A computer software has been developed that automated the functions of classification of parts and assigning a group technology code to each part, determination of part families and assigning part family codes, and directing part families to appropriate machine cells for production.
Findings: Introducing part family codes in addition to group technology codes considerably simplified the task of part family determination. Application of the system immediately resulted in an increased productivity of about 50%. This was due to the reduced setup times, less flow of parts in the workshop, production of similar parts due to parts classification, etc. Yet a productivity improvement of 100% or more is anticipated in near future.
Research limitations/implications: As the manufacturing firm was producing a wide range of products at the time of implementation of this work, it was difficult to implement the project without affecting the production flow significantly. There has also been some resistance from technical people opposing a change in traditional production methods.
Originality/value: Integration of machine cell formation with capacity adjustment is of great value that resulted in significant productivity improvements. Also some issues regarding actual implementation of group technology and associated problems and issues, coding of parts and part families, formation of machine cells, and capacity adjustment of machine cells have been dealt with and discussed in this paper.
Keywords: Productivity; Machine cell; Capacity adjustment

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1. Introduction

In today's competitive market improving productivity is of great concern for any manufacturing firm. Production engineers continuously adapt state-of-the-art techniques and methodologies in order to achieve this goal. These techniques include advanced manufacturing and management systems [1-4], quality improvement methods [5], systems integration [6], Kaizen [7], optimum process planning [8, 9], etc. Among these, group technology (GT) and cellular manufacturing (CM) systems play an important role in improving productivity [10-12]. GT is defined as a production methodology that takes advantage of geometric and manufacturing similarities [13]. It examines products, parts and assemblies and then groups similar items to simplify design, manufacturing, purchasing and other business processes. This technology benefits design and manufacturing functions in many ways. It reduces the time needed for preparing engineering drawings for similar parts, and reduces the cost and time needed for designing auxiliary machining equipment such as special cutting tools, jigs and fixtures and so on. Process planning is also simplified as similar parts would often require similar processes. Similar processing of parts would result in utilizing similar machine tools, cutting tools, clamping method, and a consistent skill level for operators. Computer-aided process planning (CAPP) is an important tool for this function resulting in easier and more consistent process plans. In addition, as process planning is automated the time required to perform this function is significantly reduced. A CAPP system uses the coded similarities to plan consistently, standardize and accurately estimate costs. It then assigns the part to a GT machine cell. These machine cells reduce throughput times and work-in-process. They simplify schedules, reduce transportation and ease supervision. As reported in the literature [14-17] a successful implementation of GT can:

- reduce engineering costs;
- enable cellular manufacturing;
- accelerate product development;
- improve costing accuracy;
- simplify process planning;
- reduce tooling cost; and
- simplify purchasing.

There has been a good number of publication reporting advances made on GT, CM and related technologies in recent years. For instance, Mukhopadhyay et al. [18] successfully employed a modified Hamiltonian chain graph theoretic approach to the group technology configuration problem. They presented an algorithm, MBSMHCA that consisted a two stage process. Stage I formed a graphical depiction of the component flow routes (from given knowledge of the facility component incidence matrix), whilst Stage II generated a modified Hamiltonian chain (a linear arrangement of the facilities employed to process the given component set). The approach suggested was simple both to understand and apply and, the authors reported that the results obtained were superior to other solution methods. Later John et al. [19] examined and compared Mukhopadhyay's methodology and offered possible solution approaches to a potential problem identified.

The goal of CM is to have the flexibility to produce a high variety of low demand products, while maintaining the high productivity of mass production. CM system designers try to achieve this goal through modularity in both product design and process design [20]. Properly designed and implemented CM offers the flexibility of job-shops, while retaining the efficiency of flow-shops, permitting batch production to gain economic advantages similar to those of mass production [21]. The part-machine cell formation problem is one of the most important steps in the design of a CM system. CM systems group a variety of machines together into what is called a manufacturing cell (MC). Meanwhile, parts with similar characteristics and operating requirements are grouped together into part families in which parts of the same family are manufactured on the same MC with little or no inter-cell movement of the parts. Consequently, via forming MCs, manufacturers can capture the inherent advantages of CM, such as reductions in lead times and setup costs, which lead to reduce lot sizes [22].

Despite existence of many publications on GT, CM and related technologies, the number of publications reporting actual implementation of these technologies in real manufacturing environments addressing associated problems is very limited. This paper describes design of a GT model that leads to actual formation of machining cells in a large manufacturing firm. It also addresses some of the problems raised in design and implementation stages.

The above-mentioned manufacturing firm produces a wide range of products used in mining, construction, and automotive industries. First, a comprehensive study was undertaken focusing on the factories involved in manufacturing of a variety of products. These included materials, machining processes, machine tools, auxiliary machining equipment, processing times, operators' skills, and other manufacturing-related issues. The manufacturing firm employs more than 550 workers and machinists. There are about 350 machine tools in 74 different types including lathes, millers, drills, grinders, deep hole boring machines, broachers, various grinders, etc. Variety of parts being produced is in excess of 7500 ranging from very small and precise optometry components to very large and rough components of cement industries. Following critical analyses and considerations it was concluded that the productivity of the manufacturing firm was significantly lower than its actual production capacity. This was mainly due to poor production planning, high work-in-progress inventories, large number of parts flowing between machines, and excessive manufacturing lead-times. It was also noted that implementation of GT could help improve productivity and reduce lead-times and costs significantly. Results of this study were discussed with CEO of the company and other deciding parties. After extensive discussions and considering short- and long-term difficulties of implementing GT, the management of the company agreed with designing a small scale GT model and its pilot implementation. A full implementation of GT model was subjected to a successful implementation of the proposed small scale GT model. It was then decided to design a GT model for a non-critical product not severely affecting production of other parts.

2. Classification of parts

The project started by classification of parts. This function is central to the GT concept. There are a number of methods for

Table 1.
Description of the coding system

Digit	Possible values	Represents
1st	0, 1 , 2 , 3, 4, A to Z	overall shape, dia or width to height ratio
2nd	0, 1 , 2 , 3, 4, 5, 6, 7, 8, 9, A	Length
3rd	0, 1 , 2 , 3, 4, 5, 9	external shape
4th	0, 1 , 2 , 3, 4, 5, 9, A to Z	external shape elements
5th	0, 1 , 2 , 3, 4, 5, 6, 7, 8, 9, A to Z	internal shape
6th	0, 1 , 2 , 3, 4, 5, 6, 7, 8, 9	raw material shape
7th	0, 1 , 2, 3	raw material
8th	0, 1 , 2 , 3, 4, 5, 6, 7, 8	tolerances, surface finish
9th	Reserved	Reserved
10th	Reserved	Reserved

classification of parts. Among these is the coding method in which a code is defined for each part specifying its design and/or manufacturing attributes. In comparison with other methods available, the part coding method is the most complicated and time-consuming method, however, it is also the most powerful and accurate method recognized. After a detailed study of the parts in production, associated manufacturing processes and technical issues and after a critical consideration of many classification methods, it was concluded that part-coding method is the best method to be used for this project. The decision was made mainly due to accuracy of coding method in comparison with other known classification methods. All the departments of the company were consulted and their needs in introducing a coding system were collected. Many coding systems such as Miclass, Opitz, Code and KK-3 [13] were considered and it was concluded that a customised coding system should be developed to meet all the needs of the company. Accordingly, a coding system similar to Opitz [23] has been designed and used.

The proposed coding system introduces a ten-digit code foreach part. As illustrated in Table 1 each digit represents an information about the part or its production attributes. The first digit represents the shape of the part and its overall size. A value of 0 to 4 represents a rotational part and specifies its diameter range. When the value of the first digit is not a number, the part is non-rotational and the letter used represents its width to height ratio. The value of the second digit represents the length range of the part where letter 'A' is used for very long parts (longer than 8000 mm). Interpretation of the third, fourth and fifth digits depend upon the value of the first digit since the interpretations for rotational and non-rotational parts are different. The third digit represents main external shape of the part. For rotational parts this digit specifies whether it is a plane cylinder, stepped to one end, stepped to both ends, and other possibilities. For non-rotational parts this digit specifies whether the part must be machined from one face or more and represents the main shape as plane, pyramid, etc. Digit four indicates the existence of external shape elements. For rotational parts these include slot, thread, cam, radial holes, gears etc. For non-rotationals these include protrusions, depressions, steps, profiles, gears, holes, etc. If the fourth digit is represented by a letter rather than a number, then there is a combination of the shape elements in the part where each letter defines a possible combination. Digit five is used to indicate the internal shape elements where a number denotes an internal shape element and a letter indicates a combination of the shape elements. For rotational parts these shape elements include hole, thread, one end, both ends, broach, multiple steps, etc. For non-rotational parts these include hole, protrusion, step, gear, slot, non-circular protrusion, etc. Only numbers represents digits six to eight. Digit six indicates the shape of the raw material such as sheet, pipe, bar, cast part, forged billet, etc. The seventh digit specifies the quality of workpiece material such as plain carbon steels, alloy steels, other metals and non-metallic materials. Digit eight indicates the accuracy of the part and its surface finish. All the parts are grouped into three grades including rough, medium and fine as defined by ISO standard. Each tolerance grade also has three grades for surface finish as coarse, medium and fine. The last two digits are reserved for the future use.

2.1. Part families

A part family is a collection of parts which are similar either because of geometric shape and size or because similar processing steps are required in their manufacture. The parts in a family are different but their similarities are close enough to merit their identification as members of the part family. On the basis of the classification criteria described, user friendly computer software has been developed for quick classification of all the parts in production. The software requests geometrical and technological information of the part in question and generates appropriate GT code for the part given in a very short time. The software also determines the part family for each part based on its characteristics. Fig. 1 shows the flowchart of introducing GT code and determining part family. Once a part is introduced to the software, the system searches the database to find out if this part is already processed. In this case its code will be retrieved from the database. Otherwise, the system determines appropriate GT code based on the criteria just described. The next step is determination of the appropriate part family for each part. The technical committee of the project predefined a number of part families based on similarities on production methods, accuracy and size of the parts in production. These included 72 families for rotational parts and 72 families for non-rotationals. The system uses the first, second, fourth, fifth and eighth digits and determines a new five digit family code for each part for part family determination. This is due to the fact that these digits represent the most important characteristics of the part for family determination. Other digits are used for other purposes not described here. Two typical parts and assigned codes are shown in Fig. 2 (a) and (b). The characteristics of the rotational part shown in Fig. 2 (a) are:

- Material: plain carbon steel
- Overall dimensions: 50 mm in diameter and 150 mm in length
- Tolerance range: fine
- Surface finish: fine

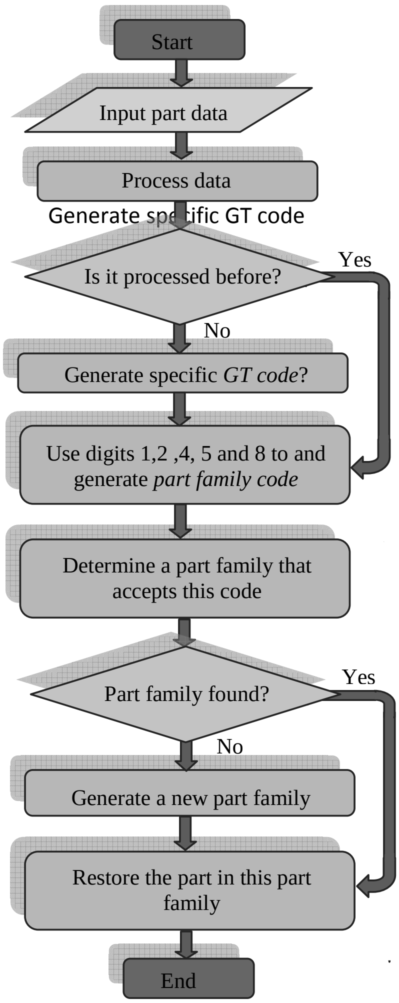


Fig. 1. Flowchart of determining GT code and part family

The part is stepped to both ends, threaded on one end and slotted to the other end and has axial holes on the external diameter. The GT code for this part is determined as 024A6108 and its family code as 11222. The characteristics of the non-rotational part shown in the Fig. 2 (b) are:

- Material: alloy steel
- Overall dimensions: 100 mm X 250 mm X 50 mm
- Tolerance range: medium
- Surface finish: medium

The non-rotational part is stepped on one face, with a number of couterbored and plain holes, slots, protrusions and depressions all machined from one face. The GT code for this part is determined as C21DB51400 and its family code as 20221.

It is noteworthy that the method of interpretation of family code digits is different from corresponding GT code digits. The value of each digit in part family code is only restricted to 1, 2 or 3 in order to reduce the variety of codes used. This significantly simplifies the task of determination of part families. The reason for introducing part family codes in addition to the GT codes is that a very large number of GT codes were produced making part family determination difficult. Also due to utilization of already determined GT codes by various departments of the company it was impossible to narrow down the range of these codes. However, introducing family codes helped simplify the task of determination of part families, and these could be revised at any time without affecting the activities of other department.

Using the developed software all the parts in production were classified and grouped into part families in about three months. Subsequently, a number of machine cells were defined such that each cell was devoted to producing certain part families. The main objective in designing machine cells has been to minimize inter-cellular movement of parts. The arrangement of machines in cells was so configured to allow more efficiency and easier control of manufacturing the parts. After classifying each part, it was directed to the appropriate machine cell by the system.

3. Machine cell formation

Efficient implementation of GT leads to the use of CM that involves grouping machines and processes to form machine cells so that each machine cell is devoted to producing certain part families. The part-machine cell formation problem is a crucial step in the design of a cellular manufacturing system and has received considerable research attention over the last five decades [24]. The main objective in designing machine cells is to minimize inter-cellular movement of parts. A part-machine processing indicator matrix is used to define part-machine relationship. Instead of inserting only 0 and 1 binary values in the indicator matrix, as most researchers do, the machining time of the part on each machine is inserted in the matrix.

The pilot implementation if the GT project was started with 11 machine tools. These formed two machine cells with five and six machine tools respectively. Machine cell 1 (MC1) was devoted to producing non-rotational parts for car industries. This cell included a mechanical saw (M1), a shaper (M2), a vertical milling machine (M3), a horizontal milling machine (M4), and a radial drill (M5). MC2 was devoted to producing rotational parts for hydraulic jacks and included a mechanical saw (M6), a duplicating lathe (M7), two regular lathes (M8, M9), a deep-hole drilling machine (M10), and a cylindrical grinder (M11). Here only MC1 is considered. The part-machine indicator matrix (P) of MC1 is shown in Table 2. The number inserted in row i column j indicates the machining time of ith part on jth machine. All the times are given in minutes. Table 2 also indicates the quantity of each part required. Table 3 illustrates a similar part-machine matrix (S) indicating setup times for each type of parts on each machine. It should be noted that this setup time should be applied when the machine changes its job from one pert type to another. The corresponding setup time for each part within each type is considered in the machining time of the part. Table 4 represents the total machine times (T) for producing a batch of each part. This matrix can be achieved by:

$$Tij = Ni \cdot Pij + Sij \quad (1)$$

where Tij is the machining time for jth machine to produce Ni quantity of Pi parts including corresponding setup time Sij. Table 4 also indicates the total machining time required to produce the given batch of each part type for each machine. As can be seen in the table, machine M2 has the highest machining time and all other machines will have free times. This is given in the table as.

Minutes and as a percent of total batch production time. The free time for machines M1 and M4 are low. However for other machines this time is relatively high. The sum of the free times of all the machines in MC1 is 80% (7%+0%+46%+4%+23% = 80%). The sum of free times of machines should be as reduced as much as possible. To do so the following methods can be used:

- Using the free times of machines to serve other cells
- Determination of the optimum number of parts in order to minimize free times of machines (*f*).

The first method is not desirable since in an ideal machine cell; there will be no flow of parts between cells. However, researchers have pointed out that for practical problems, it is almost impossible to form machine cells between which there is no flow of parts. Thus, in practice the objective is to minimize inter-cellular flow of parts. The second method is also studied in this project.

4. Capacity adjustment

Minimum inter-cellular flow of parts can be achieved through (1) proper selection of machine tools within each cell; (2) capacity adjustment for machine tools employed. Proper selection of machine tools is a function of production planning and scheduling. Machine tool capacity adjustment is a very important problem in cellular manufacturing systems. It is necessary to ensure that adequate capacity is available to process all the parts. Heragu and Gupta [10] proposed a model for machine capacity determination. A similar approach has been adopted here:
Minimize:

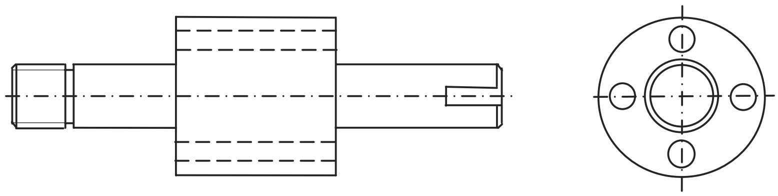
$$\sum_{i=1}^{p}\sum_{j=1}^{m}\sum_{k=1}^{n} x_{ijk}c_{ijk} + \sum_{j=1}^{m} CM_jNM_j \quad (2)$$

Subject to:

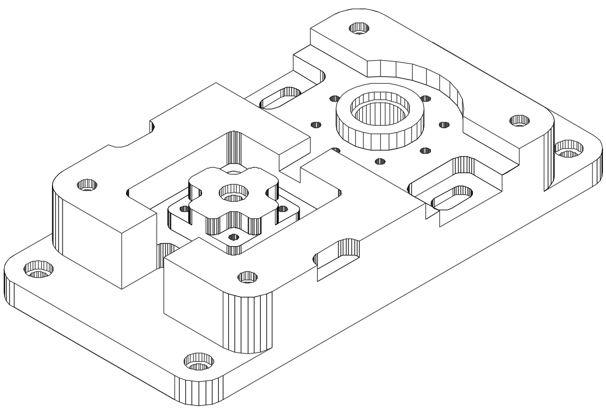
$$\sum x_{ijk} = NP_k \quad \text{for each i, k} \quad (3)$$

$$\sum_{i=1}^{p}\sum_{k=1}^{n} x_{ijk}t_{ij} \leq T_jNM_j \quad \text{for each j} \quad (4)$$

$$x_{ijk}, \quad NM_j \quad \geq \quad 0 \quad \text{and integer for each } i, j, k \quad (5)$$



(a) GT code: 024A610800; part family code: 11222



(b) GT code: C21DB51400; part family code: 201221

Fig. 2. Two typical parts produced by company (a) a rotational part with, and (b) a non-rotational part

Table 2.
Part-machine indicator matrix (P). Time unit is minute in all tables

		Machines					Sum of parts
		M1 (saw)	M2 (shaper)	M3 (ver. mill)	M4 (hor. Mill)	M5 (drill)	N
P	P1	15	55	0	22	45	
a	P2	15	40	0	32	20	150
r	P3	18	0	25	15	0	300
t	P4	18	30	0	20	20	720
s	P5	18	0	20	0	19	480 220

Table 3.
Setup times (S)

		Machines					Visits to each machine
		M1	M2	M3	M4	M5	
P	P1	25	45	0	35	30	1
a	P2	25	64	0	33	20	1
r	P3	25	0	42	53	0	1
t	P4	25	30	0	30	30	1
s	P5	25	0	40	0	20	1

Table 4.
Total machine times for a batch production (T)

		Machines				
		M1	M2	M3	M4	M5
P	P1	2275	8295	0	3335	6780
a	P2	4525	12064	0	9633	6020
r	P3	12985	0	18042	10853	0
t	P4	8665	14430	0	9630	9630
s	P5	3985	0	4440	0	4200
Total Machine time		32435	34789	18870	33451	26630
Free time (f)		2354	0	15919	1338	8159
f %		7%	0%	46%	4%	23%

Where the following notation is used:

- type of operations to be performed on the various part: $i = 1, \ldots, p$
- types of machines available: $j = 1, \ldots, m$
- types of parts to be produced: $k = 1, \ldots, n$
- number of parts k to be produced: NP_k $k = 1, \ldots, n$
- cost of performing operation i on part k using machine type j: c_{ijk}, $i = 1, \ldots, p, j = 1, \ldots, n, k = 1, \ldots, n$
- time of performing operation i on part k using machine type j: t_{ijk}, $i = 1, \ldots, p, j = 1, \ldots, n, k = 1, \ldots, n$
- number of machine tools type j used in the cell: NM_j $j = 1, \ldots, m$
- purchase cost of machine type j prorated over the planning period: CM_j $j = 1, \ldots, m$
- time for which machine type j is available: T_j $j = 1, \ldots, m$
- number of times operation i is to be performed on part type k on machine type j: x_{ijk}

The first constraint ensures that the required number of each operation is performed on the machines. The second constraint is a capacity constraint and ensures that the available time on each machine is not exceeded. The last constraint needs no explanation. In the above model it is assumed that each machine tool can perform all the operations on each part type. If a machine type j cannot perform an operation i on part type k, then the corresponding x_{ijk} can be set to 0. The above objective function minimizes the machine purchase and operating costs. The above model only ensures that the required number of each machine type is available. While allocating machines to cells, it is equally important to verify that there is adequate capacity in each cell to completely process all the part families assigned to it. The number of machines of each type may be sufficient to process all the parts, the machine grouping may be such that there is not enough capacity to process one or more parts entirely within their corresponding cell. Thus, it is necessary to ensure that the capacity constraint in each cell is not violated while allocating machines to cells or parts to part families.

The main problem in implementing CMS in this manufacturing firm was estimating the practical machine times for each operation. Estimated times were not accurate and it was the most difficult task to apply the presented mathematical model and proper determination of the number of machines. After modifying the estimated machining times and trials and errors, use of this equation reduced the total free time of the given machine cell significantly. No accurate data can be given at this stage since the implementation is still under progress but a reduction of 20% to 35% in the total free times of the cell is achieved.

5. Conclusions

The design and pilot implementation of a model of the group technology and cellular manufacturing philosophy at this manufacturing firm is described in this paper. This implementation increased the productivity by about 50% in comparison with traditional use of machine tools. This improvement was due to the reduced setup times, less flow of parts, production of similar parts due to parts classification, and so on. This is a very promising improvement and still better results can be achieved. An improvement of 100% or even higher can be achieved when more experience and expertise in use of GT technology is gained. The most important achievement of this implementation was to convince everybody that GT can really improve productivity. Finally, in implementing GT and CM, as one works more and gets more experience, he/she better understands how to achieve better results.

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