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Development of a Model for Computing Similarity Indices for the Application in Group Technology

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Abstract: *In this research, a model for computing the group similarity indices was developed. The grouping objective functions and parameters were formulated and can be used for grouping parts into part families and at the same time for computing similarity indices.*

This module introduces the technique of group technology, discusses its general application in batch manufacturing.

Keywords: *Group Technology, Parts similarities, Parts classification and coding, manufacturing system*

1. Introduction

Ever since the industrial revolution, manufacturing and engineering personnel have been searching for ways to optimize manufacturing processes. The mass production industries are characterized by the manufacture of large numbers for parts/components of the same size and configuration and high productivity is attained by the extensive use of automation, special purpose machinery and flow line production methods. Such production equipment needs high capital investment and is inherently inflexible in operation (Gallagher & Knight, 1973).

The major part of industry is however concerned with production in medium and small batches, where individual elaboration of a method for each new component needs an enormous amount of time and resources. There is a growing need to make batch manufacturing more efficient and productive. Also, there is an increasing trend to achieve a higher level of integration of the design and manufacturing functions in a firm. As such, technical development today calls for the introduction of scientific principles in solving many of the problems associated with this type of manufacturing (Gallagher & Knight, 1973; Funchs, 1988).For instance, a particular company makes thousands of different parts, in many different batch sizes, using a variety of different manufacturing operations, processes and technologies. It is beyond the capability of human mind to comprehend and manipulate such vast amounts of detailed data. Though, people still need to make decisions regarding how to run a manufacturing company and succeed in today‘s competitive environment on local and foreign markets. The pressures on management continue to escalate as global competition drives the need for producing a greater variety of high quality products, in smaller lot sizes and at lower costs. These ongoing demands continuously increase the level of complexity present in a manufacturing environment (Lenka, Krchova, & Kuric, 2014).

One of the approaches that are directed at both of these objectives is Group Technology (GT). Research has it that GT is regarded as the backbone for designing various types of manufacturing systems (Kamal, Gazal, & Rakesh, 2014). The development of manufacturing systems and changes and variety of customers' interests, push companies to produce various products with high capacities. Therefore, manufacturing systems must be changed from job shop and mass production systems to new systems. In this respect, many manufacturing companies have noticed the effectiveness of 'Group Technology (Arash & Nassibeh, 2010). It is the best production system to produce various products in large amounts with high productivity. A broad definition as given by Professor V. B. Solaja of the Institute of Machine Tools, Belgrade, Yugoslava is (Gallagher & Knight, 1973). “Group Technology is the realization that many problems are similar and that by grouping similar problems, a single solution can be found to a set of problems, this saving time and efforts”. More precisely, as applied to manufacturing, group technology could be defined as a manufacturing technique and philosophy based on a principle that similar products should be processed similarly and for identifying and bringing together related or similar components in order to take advantage of their similarities in the production process. In the manufacturing context, GT can be defined as a manufacturing philosophy identifying similar parts and grouping them together into families to take advantage of their similarities in manufacturing and design (Selim , Askin, & Vakharia, 1998). The basic idea of GT is to decompose a manufacturing system into subsystems. It reduces production lead time; work-in process; labour; tooling; rework; scrap material; set-up time; delivery time; and paper work. The idea behind GT is to improve efficiencies by exploiting similarities. The applications of GT influences time power of operation, Work-in process inventory, material handling, job satisfaction, jig and fixture, required space, quality, finished product and labor cost.

Although it is relatively simple to define GT, it is difficult to create and install a GT system because of the difficulty in defining clearly how similar one part is to another. The GT concept requires that attributes associated with the parts can be identified and classified. Attributes can be visual, such as the surface finish or shape of a part; mechanical, such as the strength of the material; or functional, such as the clock aspect of a printed circuit board. The attributes may also be related to the environment of the part, such as the processes or equipment necessary to make it. And because of the numerous possible coding strategies, it is hard to know in advance exactly what attributes base is used by more and more kinds of software. It is therefore important to guarantee that the data base structure is flexible enough to add attributes and to modify coding schemes as necessary for new applications.

Actually, GT philosophy advocates simplification and standardization of similar entities (parts, assemblies, process plans, tools, instructions, etc.) in order to reduce complexity and achieve economies of scale effects in batch manufacturing. One vehicle for implementing GT is classification and coding (CC), a methodology which organizes similar entities into groups (classification) and then assigns a symbolic code to these entities (coding) in order to facilitate information retrieval (Tatikonda & Wemmerlov, 1992).Part classification and coding is concerned with identifying the similarities among parts and using it to select production groups. Part similarities are of two types: Design attributes (such as geometric shape and size) and manufacturing attributes (the sequence of processing steps required to make the part). The reason for using a coding scheme is to facilitate retrieval for design and manufacturing purposes. In design, for example, a designer is faced with the task of developing a new part which can sue the design retrieval system to determine if a similar part is already in existence. A simple change in an existing part would be much less time consuming than designing from scratch. In manufacturing the coding scheme can be used in an automated process planning system.

Group technology and parts classification and coding are closely related. Group technology is the underlying manufacturing concept, but some form of parts classification and grouping usually required in order implementing it. And to achieve these challenges, there is need to develop a model for GT applications that can adequately accommodate GT ideology.

The main criterion for parts classification and grouping is similarity of parts (Mikell, 1987). Similarity has been expressed several ways. The use of group similarity indices as a measure of group homogeneity is one such approach. However, the main goal of grouping parts is to reduce manufacturing cost. The extent similarity indices relate to manufacturing cost is therefore, important information in group technology manufacturing systems. Such a relationship has not, however, been reported. It is the purpose of this study to examine possible relationship between similarity indices and manufacturing cost.

2. PARTS FAMILIES

A part family is a collection of parts that are similar either because of geometric shape and size or because similar processing steps are required in their manufacture. The parts within a family are different, but their similarities are close enough to merit their inclusion as members of the part family. There are three general methods for solving part families grouping. All the three are time consuming and involve the analysis of much of data by properly trained personnel. The three methods are: Visual inspection, Parts classification and coding, and Production flow analysis.

2.1. Visual Inspection Method

The visual inspection method is the least sophisticated and least expensive method. It involves the classification of parts into families by looking at either the physical parts or their photographs and arranging them into groups having similar features.

2.2. Parts Classification and Coding

In parts classification and coding system, codes are assigned to parts. Based on these codes, parts can be grouped into part families (Kusiak, 2007; Sacchetti, Sanvido, & Kumara, 1992). Two categories of part similarities can be distinguished: Design attributes, which concerned with part characteristics such as geometry, size and material; Manufacturing attributes, which consider the sequence of processing steps required to make a part. One of the reasons for using parts classification and coding is the design retrieval because most times designers are faced with the task of developing a new part but with the use of a design retrieval system can be very helpful to determine if a similar part already exist. A simple change in an existing part would take much less time than designing a whole new part from scratch.

The automated process planning is another reason for using parts classification and coding system, such that the part code for a new part can be used to search for process plans for existing parts with identical or similar codes. The part codes can be used to design machine cells capable of producing all members of a particular part family, using the composite part concept. A part coding system consists of a sequence of symbols that identify the part’s design and/or manufacturing attributes. The symbols are usually alphanumeric, although most systems use only numbers.Three types of coding systems exist:

(a) Chain-type structure

Also known as a polycode, in which the interpretation of each symbol in the sequence is always the same, it does not depend on the value of the preceding symbols.

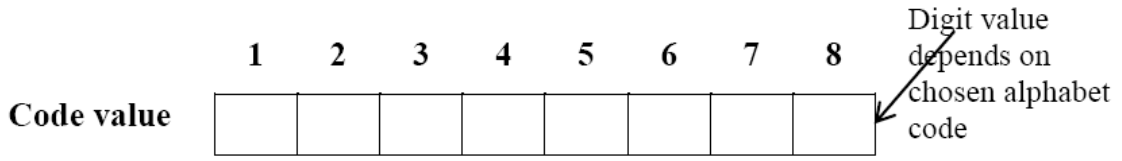


Fig1. *Chain-type structures*

Where each of the code value may represent: 1-Material, 2-Material form, 3-Material property, 4-Bending method, 5-Tolerance, 6-Surface finish, 7-Test method, 8-Special requirement.

(b) Hierarchical structure

Lso known as a monocode, in which the interpretation of each successive symbol depends on the value of the preceding symbols. Each character (code) is a further expansion of the previous character. This indicates that the meaning of the code is dependent on the meaning of the previous character in the code´s string. The advantage of this approach is the amount of information which the code can represent in a relatively small number of digits. However, a coding system based on this structure is complicated and very difficult to implement.

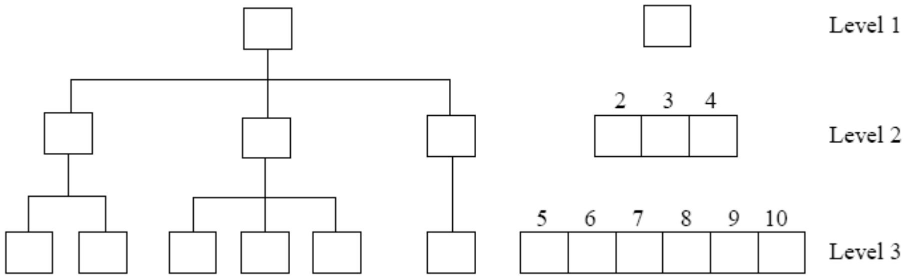


Fig2. *Hierarchical structure*

(c) Hybrid

A combination of hierarchical and chain-type structures, i.e. A hybrid coding system is a combination of both monocode and polycode structures, taking advantage of the characteristics of the two previously described structures. Examples of this coding structure are the OPITZ coding system. Most of the available coding systems are implemented using this type of structure.

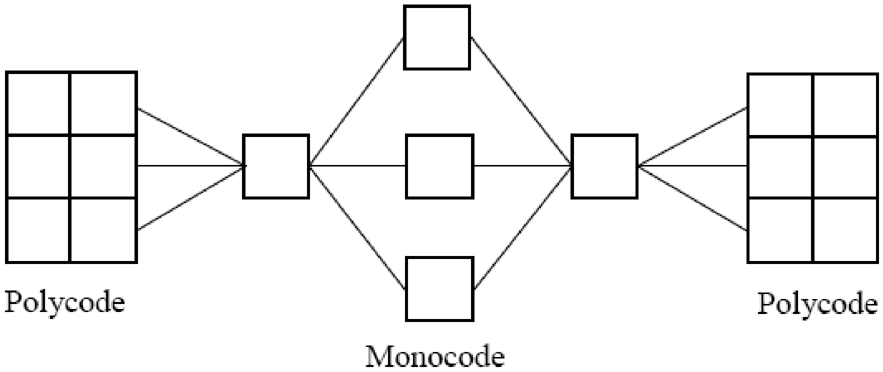


Fig3. *Hybrid structure*

Opitz Classification and Coding System

It is intended for machined parts and uses the following digits sequence

- Form Code 1 2 3 4 5 for design attributes
- Supplementary Code 6 7 8 9 for manufacturing attributes
- Secondary Code A B C D for production operation type & sequence.

2.3. Production Flow Analysis

Production flow analysis (PFA) is a method for identifying part families and associated machine groupings that uses the information contained on process plans rather than on part drawings. Workpiece with identical or similar process plans are classified into part families. These families can then be used to form logical machine cells in a group technology layout. The procedure in production flow analysis must begin by defining the scope of the study, which means deciding on the population of parts to be analyzed (Asoo, 1986). The procedure of Production flow analysis (PFA) consists of the following steps: (1) Data Collection. (2) The minimum data needed in the analysis are the part number and operation sequence, which is obtained from process plans. (3) Sortation of process plans. A sortation procedure is used to group parts with identical process plans. The processes used for each group are then displayed in a PFA chart as shown in Fig. 1.1.

	Parts								
Machines	A	B	C	D	E	F	G	H	I
1	1			1					
2		1					1		
3			1			1			
4		1						1	
5	1				1				
6			1						1
7					1			1	

Fig4. *Process flow chart*

3. SIMILARITY INDICES

The use of within group similarity indices is defined and considered and shown to relate to group manufacturing cost (Chase, Aquilano, & Jacobs, 1998). The similarity indices for set of parts within the grouping system will be evaluated. The index number is between 0.0 and 1.0 and a value closer to 1.0 is said to have a better grouping of parts.

3.1. Machine Set-up Related Parts' Characteristics

The set-up of parts used is designed to have a single operation on center lathe machine, and seven machine set-up related characteristics were considered. This includes overall shape, overall size, operation type, dimension of feature, surface finish; tolerance and material type are listed in table 3.1 and was used in coding the parts. The part's characteristic described below:

1. Operation Type: There are two main types of operations that need to be considered; they are the turning and boring operations. The turning operation provides a means of machining external surfaces where in the work piece rotates and a longitudinally fed, single-point tool does the cutting.

The boring operation is a variation of turning operation. It involves internal turning where single point cutting tool produces internal cylindrical or conical surfaces.

(i). Overall size: the overall sizes of parts are classified into two categories, each depending on its length (L) to maximum diameter (d) ratio, (L/d). A word piece with $L/d < 3$ is referred to as the disc type while those having $L/d > 3$ are the shaft type.

(ii). Surface Finish: Two types of surface finish were considered namely: the high quality finish and the low quality finish.

2. The high quality finish is like super finishing which produces a highly wear resistant finish on parts that are applicable for the super finishing process. The objective in super finishing is the removal of fragmentation or small metal regularizes to restore surface geometry and the surface of the work piece by eliminating surfaces stresses and burn. Stock removal may range from 0.002 to 0.001 inches. Scratch patterns of 30/min RMS (root mean square) or more to a minor finish may be produced.

3. Tolerance: The tolerance requirement for each of the thirty parts was estimates and shown below:

Up to 0.125 inches diameter ± 0.0003 inches

0.1875 to 0.4375 inches diameter ± 0.0005 inches

0.5000 to 1.5000 inches diameter ± 0.0001 inches

4. Dimension of Feature: The internal and external dimension of parts was randomly selected. The internal dimensions are within a range of 2” to 5” (50.8mm to 127.0mm) diameter while the outer dimension lies within a maximum of 8” (203.2mm) diameter.

5. Material Type: The parts were assumed to come from five different types of materials: the mild steel, the cast iron, steel, the aluminium alloy and copper alloy.

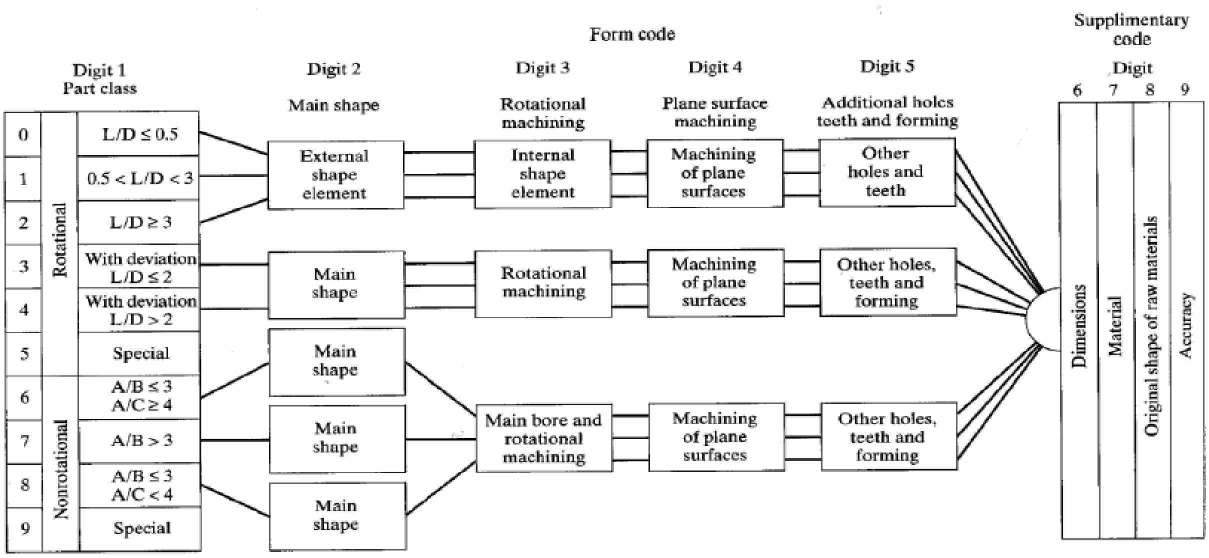
3.2. Parts’ Coding System

A coding system on part design characteristics based on Optiz coding system was adopted in classifying and coding the parts selected as shown in table 3.1.

The Optiz coding system uses alphanumeric symbols to represent the various attributes of a part. These digits are represented in the following sequence:

1 2 3 4 5 6 7 8 9 A B C D

However, the interpretation of each digit stated above are shown in Fig. 3.1.



Source: **Fig3.1.** *Opitz parts’ coding*

Table 3.1 .*Coding System Based on Part Design Characteristics*

Digit 1	Digit 2	Digit 3	Digit 4	Digit 5	Digit 6	Digit 7
Overall shape	Overall size	Operation	Dimension of Feature	Surface finish	Tolerance	Material type
0 Non-rotational	0 Disc type	0 Boring	0 L/D ≤ 0.5	0 High quality finish <50µm	0 ± 0.01 - 0.3	0 Cast iron
1 Rotational	1 Shaft	1 Drilling	1 0.5 < L/D < 3	1 Low quality fini >50µm	1 ± 0.35 - 0.5	1 Mild steel
		2 Turning	2 L/D ≥ 3		2 ± 0.55 - 09.5	2 Steel
		3 Knurling			3 ± 1.00 above	3 Aluminium
		4 Reaming				4 Copper alloy
						5 Brass

3.3. Formulation of Group Similarity Indices

In computing the group similarity indices, a general group technology problem and classification of various parts using the operation Research (OR) was applied. Some grouping objective functions, problem types, variable constraints and parameters were identified and used to relate to GT cost component.

One such function within group similarity, H_K defined as follows:

$$H_k = \frac{\sum_{i=1}^{n_k}\sum_{j=1}^{n_k-1} R_{ij}}{n_k(n_k-1)} \quad ; \quad \begin{array}{l} i, j \in g_k \\ and\ i \neq j \end{array} \qquad (1)$$

Where H_k is the similarity index of parts within group k and

n_k is the number of parts in group k

g_k is a set of parts in group k

But $$R_{ij} = \frac{\overline{D}^{t}_{ij\alpha}\,\overline{D}_{ij\alpha}}{\overline{D}^{t}_{io\alpha}\,\overline{D}_{io\alpha}} \qquad (2)$$

where R_{ij} isthe similarity index of parts i and j

$$\overline{D}_{ij\alpha} = \begin{cases} 1 & if\ i\ and\ jare\ similar\ in\ shape\ in\ design\ characteristics\ \alpha \\ 0 & \end{cases}$$

And $\overline{D}_{io\alpha} = 1 \forall \alpha$

While t means transpose

For N groups, the overall within group similarity is

$$H = \frac{\sum H_k}{N} \qquad (3)$$

Where H is the within group similarity index of all parts in GT system

Observing that $0 \leq R_{ij} \leq 1$; the following equation holds

$0.0 \leq H_k, H \leq 1.0$

By definition,

$$\overline{D}_{(1)} = \begin{Bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{Bmatrix}$$

The similarity state vector with relevant design characteristics, D_{ij} which represent the state of similarity or dissimilarity of part *i* and *j* respect to characteristic α . The similarity indices of part *i* and *j* are computed using equation (1), (2), and (3), and can be applied in group technology for computing the similarity indices of parts between all parts of groups, the binary similarity column vector of part i and j with respect to characteristics α has to be computed first. The binary similarity vector implies that elimination of a set-up task is possible only if a state similarity exists.

3.4. Grouping of Parts and Group Similarity Index

Before computing the similarity indices of parts between all parts of groups, the binary similarity column vector of part i and j with respect to characteristics α has to be computed first. The binary similarity vector implies that elimination of a set-up task is possible only if a state similarity exists.

3.4.1. Algorithm for computing the similarity indices of parts within the group

Step 1: The binary similarity vector of part i and j with relevant design characteristics, D_{ij} is computed. This represent the state of similarity and dissimilarity of part i and j with respect to characteristics

Step 2: Compute the similarity index, R_{ij} of part *i* and *j* as shown in equation (2)

Step 3: The similarity index of parts within the group k, H_k is computed as defined by the function in equation (1).

Step 4: Compute the similarity indices for all parts within the group, H as stated in equation (3)

4. CONCLUSION

In this study an attempt was made to formulate and develop a model for computing similarity indices of parts within the group which can be used for group technology to determine parts that are similar in terms of their design characteristics. And as such can be used to reduce the cost of setting up the machine, to increase production efficiency by exploiting the similarity of component shape, dimensions, process, route etc.

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