Framework for Part Families Associated with Setup Sequence based Similarity in Cellular / Reconfigurable Manufacturing System

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DECLARATION

I certify that this research work titled *"*Framework for Part Families Associated with Setup Sequence based Similarity in Cellular / Reconfigurable Manufacturing System*"* is my own work. The work has not been presented elsewhere for assessment. The material, used from other sources, has been properly acknowledged / referred.

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LANGUAGE CORRECTNESS CERTIFICATE

This thesis has been read by an English expert and is free of typing, syntax, semantic, grammatical and spelling mistakes. Thesis is also according to the format given by the university.

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To my beloved parents, family and teachers…

ABSTRACT

The configurations of Reconfigurable Manufacturing System (RMS) evolved around market requirements and corresponding manufacture capabilities, exploiting all available resources. Similar products / parts families are grouped together and require a specific manufacturing configuration in term of setups and respective tool changes in RMS. The recognition of minimum number of setup changes in multi parts production and its application for part family formation is an important step in RMS. In the present work, a novel method has been developed for recognition of minimum number of part setups with tool change options for calculation of similarity relation of parts, keeping in view the precedence constraints, machining constraints and good manufacturing practices. By Pass Moves and Idle Machines in Setup Sequencing (BMIMS) similarity coefficient based on setup sequence of parts has been developed. BMIMS is based on Longest Common Subsequence (LCS) for setup sequences. The developed coefficient of similarity was compared for analysis with the existing similarity/distance coefficients, already available in literature. The Average Linkage Clustering (ALC) algorithm has been applied for classification of example parts using this similarity coefficient. The developed methodology is useful for RMS as well as in Cellular Manufacturing System (CMS).

Key Words: *Reconfigurable Manufacturing System, Part Family Formation, Feature Grouping, Setup Sequence, Similarity Coefficient*

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LIST OF ABBREVIATIONS

RMS	:	Reconfigurable Manufacturing System
CMS	:	Cellular Manufacturing Systems
GT	:	Group Technology
MGI	:	Machines Groups Identifications
PFA	:	Production Flow Analysis
CFA	:	Component Flow Analysis
LCS	:	Longest Common Subsequence
BMIM	:	Bypass Moves and Idle Machines
BMIMS	:	Bypass Moves and Idle Machines in Setup
TAD	:	Tool Approach Direction
SCS	:	Shortest Common Superseqence
ALC	:	Average Linkage Clustering
SLC	:	Single Linkage Clustering
LCC	:	Linear Cell Clustering
CLC	:	Complete Linkage Clustering

LIST OF SYMBOLS

J_{ij}	:	Jaccard Similarity Coefficient
CO_{xy}	:	Complaint Index Similarity Coefficient
CF	:	Forward compliant index
CB	:	Backward compliant index
Sxy	:	Similarity between operation sequence of part x and y
Nx	:	Number of operations in operation sequence of part x.
BPM	:	By pass moves during part manufacturing
IM	:	Idle machines during part manufacturing
TM	:	Total moves during part manufacturing
SCSxy	:	shortest common supersequence for manufacturing the parts X and Y
LCSxy	:	Longest common subsequence between parts X and Y
$\|x\|$	:	Number of operation for part X
Mc	:	Merger coefficient
Md	:	Merger distance (number of insertions and substitutions of operations)
Id	:	Interruption distance (number of internal deletions of operations)
Omax	:	Maximum number of operations for part X or part Y
NOBLx	:	Number of setups of setup sequence x, appended before LCSxy to form SCSxy
NOALx	:	Number of setups of setup sequence x, appended after LCSxy to form SCSxy
ξ x	:	Number of bypass moves before LCSxy while producing part x
φ x	:	Number of bypass moves after LCSxy while producing part
RFsn	:	Normalised value of RF similarity coefficient
C1	:	C1 is set of tree T1

M1	:	M1 is node of tree T1
Dij	:	Demand similarity coefficient
Di	:	Demand of products i
Dj	:	Demand of products j
Mi	:	Modularity levels of products i
ψ_i	:	Shared component of product i
φ_i	:	Total components of product i
TRxi	:	Tool required in ith setup of part x where i=1, 2, 3…n
OPxi	:	Operations in ith setup of part x
TRyj	:	Tool required in jth setup of part y where j=1, 2, 3…m
OPxj	:	Operations in jth setup of part y

:

CHAPTER 1

INTRODUCTION

1.1 Cellular and Reconfigurable Manufacturing Systems

Reconfigurable manufacturing system evolved significantly over the decades. For production of a product family, RMS requires changes in hardware and software structures. In RMS, parts / products are grouped together in families on the basis of similarities. In case of products, similarities are based in terms of common parts, and for parts it is in terms of common manufacturing operations. The effectiveness of RMS depends upon recognition of parts/products families which contribute towards maximum utilization of system and productivity. System is configured for production of a one part family at a time catering for its operational requirements and requires reconfiguration for the production of next part family. Therefore, finding appropriate part family is core issue for designing a RMS. Group technology (GT) is used to accomplish this task, which take advantages of manufacturing design parameters between parts and group together similar parts to make a part family.

GT approach introduced by Burbigde in 1975, to manufacturing systems, recognized as an effective tool for reduction of setup times, flow times, inventories, work-in-process and throughput time. GT focuses on subsystems i.e. decomposition of manufacturing system into subsystems based on parts grouping into families and machines cells of specific operational requirements. The term cellular manufacturing is used for such manufacturing facilities having part family and machines cell. Specific part family is manufactured in reach cell. A set of parts having similarities in terms of operations and require set of machines for its manufacturing is known as part family. These dedicated machines in the form of group become a manufacturing cell thus makes a subsystem of the manufacturing system. The effectiveness of cellular manufacturing depends upon recognition of part family.

RMS is designed to cater for the needs of a part family by adjusting its hardware and software components. It is built for a part family and reconfigured later for next part family quickly due to rapid market requirements Koren et al. and Xiaobo et al. [1-3]. Abdi and

Labib [4] identified product family which were based on quantitative and qualitative aspects of products along with operational similarities. Galan et al. [5] adopted an approach based on product modularity, compatibility, commonality, reusability and product demand for product family formation. Grouping of parts or products without their manufacturing processes and merely based on their commonality, modularity, reusability and demand would not help in efficient and cost effective manufacturing of parts shop floor level. Kashkoush [6] used product assembly sequence tree, parts commonality in the product and its demand similarity coefficients for product family formation.

In cellular manufacturing system, machines are grouped on the basis of operational requirement of part families. Thus, the grouping of parts based on operational similarities ensures multiple part production on the same flow line and also reducing frequent reconfigurations. Abdi et al, Galan et al., and Rakesh et al. [4,5,7] considered only Jaccard similarity coefficient and neglected operation precedence. Goyal et al., Choobineh et al., Tam et al., and Irani et al. [8-11] used operation sequence based similarity coefficients to develop part families. Goyal et al., [8] considered not only operation sequence but also developed BMIM (bypass moves and idle machines) similarity coefficient which determines minimum bypass movement and idle machines during part flow. Goyal analysed in detail the limitations of already developed similarity coefficients based on operation sequence with reference to BMIM similarity coefficient.

1.2 Proposed Methodology

Different authors have developed operation sequence based similarity coefficients for similarity of parts, whereas this work is based on setup sequencing similarity coefficient which includes operation sequence for part family formation. The methodology will focus on identification of feature groups, number of setups, selection of datum, operation sequence within a setup, setup sequence and similarity coefficient for parts. Setup sequencing symmetry will ensure smooth flow of material as well as achievement of better dimensional tolerances. Maximum of dimensional tolerance errors are outcome of repeatedly changing of setups. Completion of machining in minimum number of setups will ensure reduction of tolerance errors. In order to take the advantage of minimum setups for maximum of operations to achieve better accuracy and tolerance, BMIMS (bypass moves and idle machines in setup) similarity coefficient is developed. BMIMS similarity coefficient uses tool change option for completion of maximum operations in a setup to avoid frequent changes of setups.

1.3 Thesis Outline

The thesis is presented in five chapters. Chapter 2 presents a review of the related techniques for calculation of parts/products similarities. Chapter 3 introduces the theoretical and mathematical model formulation of BMIMS similarity coefficient to address the part family formation problem in cellular manufacturing. Chapter 4 presents a detailed description of proposed methodology application on four sample parts and associated parts families and its analysis. Finally, conclusion and future recommendations are presented in chapter 5.

CHAPTER 2

METHODS OF PRODUCTS / PARTS FAMILY FORMATION

2.1 Grouping methods

Dedicated Manufacturing System focuses on the production of one specific part type, whereas, cellular manufacturing systems (CMS) focus on cost effective manufacturing of part families. The effectiveness of CMS depends upon recognition of products / parts families and associated machine cell formation. Plenty of methods are developed to obtain part families and machine cells formation as shown in Fig 2.1. Methods include descriptive procedures, mathematical programming, group analysis, artificial intelligence and graph partitioning [5]. Focus of study will be on descriptive procedures and group analysis. Descriptive procedures which are machines groups identifications (MGI), part families identification (PFI), and part families/machine grouping (PF/MG).

MGI methods consist of two stages i.e. grouping of machines on the basis of part routings and allocation of parts to that machine group. PFI methods also have two stages. Firstly, identification of part families and then allocations of machines to manufacture these part families. PFI category has sub-classification into informal system and formal system. Visual inspection method based on experience of experts, is an example of informal system. Coding and classification method in which parts are coded according to its geometry properties such as size, shape and features is example of formal system. PF/MG methods take into consideration both factors simultaneously i.e. identification of part families and associated machine groups. Examples of methods are (a) Production Flow Analysis (PFA), (b) Nuclear Synthesis & (c) Component Flow Analysis. PFA uses information contained on production route sheets and identify part family and associated machine group. Key machines play important role in Nuclear Synthesis manufacturing. CFA and PFA are similar to each other and have only difference of division of problem at the outset by PFA whereas CFA does not divide it at outset [5].

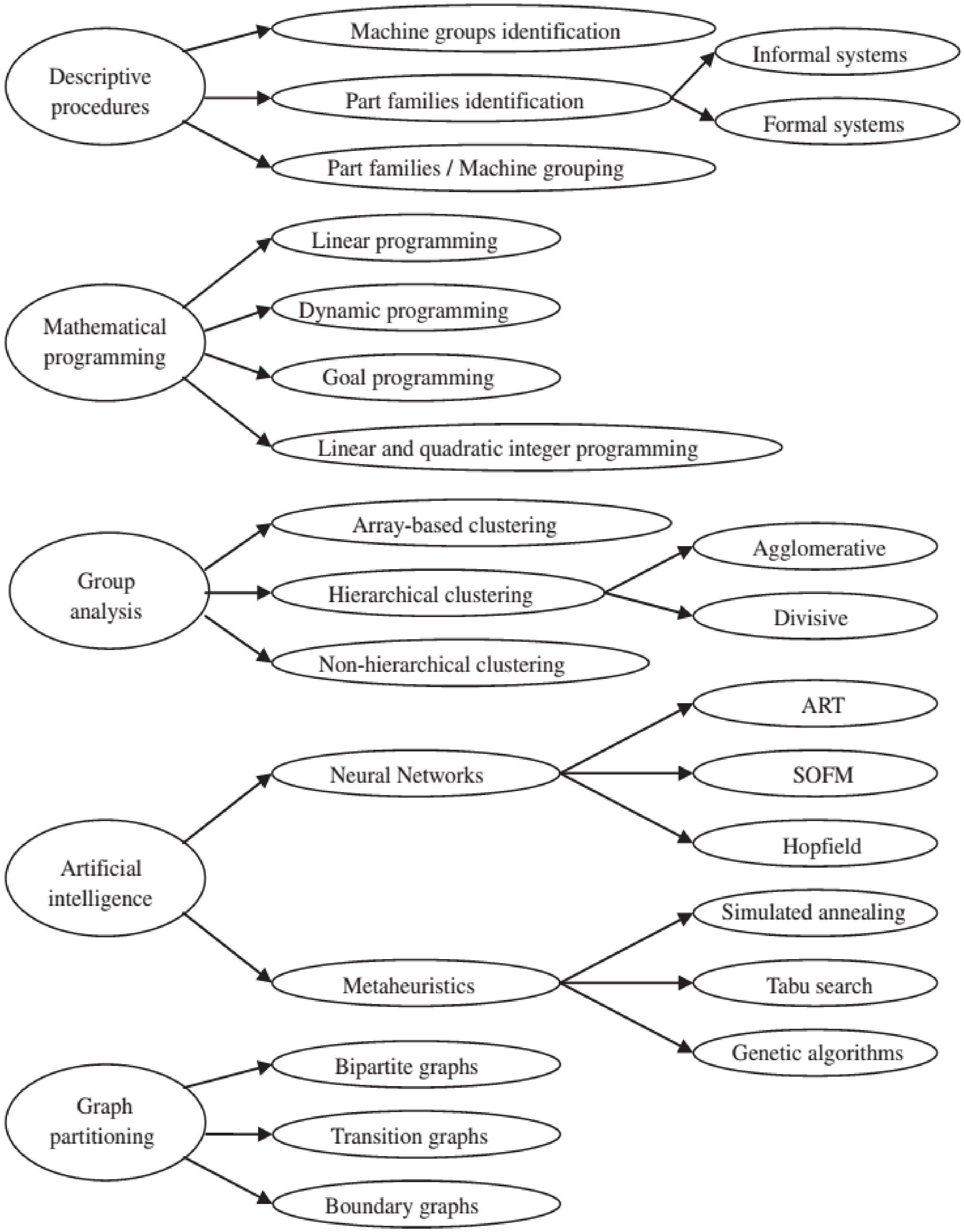


Figure: 2.1 Classification methods for the formation of cell and part families [5]

2.2 Literature Review

Similarity coefficient of parts play an important role in hierarchical clustering of part similarities among each other. Much of research is carried out for identification of part / product families and machine cells in different perspectives. Abdi and Labib [4] identified product family which were based on quantitative and qualitative aspects of products along with operational similarities. Galan et al. [5] adopted an approach based on product modularity, compatibility, commonality, reusability and product demand for product family formation. Kashkoush [6] used product assembly sequence tree, parts commonality in the product and its demand similarity coefficients for product family formation. Rakesh et al. [4] considered alternate process plan and applied jaccard similarity coefficient. Goyal et al., Choobineh et al., Ho et al., Askin and Zhou et al., Tam et al., and Irani and Huang et al. [8-11] used operation sequence based similarity coefficients to develop part families.

2.3 Techniques for Product/Part Family Formation

The process of designing matrices for similarity coefficients in RMSs / CMSs has to take into account the product / part requirement such as commonality, modularity, compatibility, demand and assembly sequence tree. Details of each technique is described below.

2.3.1 Similarity Coefficient Based on Commonality

Commonality for products measures level of common components shared by group of products whereas for a part it is the measure of number of common operations among a set of parts. Jaccard similarity coefficient is used in the calculation of commonality coefficient. Maximum value is '1' when all components or operations are similar and minimum value is 'zero' when no component is shared among products or no common operation of among parts.

$$J_{ij} = \frac{a}{a+b+c}\ ,\ J_{ij} \leq 1 \qquad (2.1)$$

Where

J_{ij} is Jaccard similarity coefficient between pair of products / parts i and j a is number of shared components / operations between i and j

b is number of components / operations that are in i but not in j

c number of components / operations that are in j but not in i.

2.3.2 Similarity Coefficient Based on Modularity

Degree to which a product is composed of independent modules is known as modularity of a product. Modularity can be obtained from bill of material representing the product including the components and sub-assemblies. Product modularity level and modularity similarity can be calculated by equations 2.2 & 2.3.

$$M_i = \frac{\psi_i}{\varphi_i} \quad , 0 \leq M_i \leq 1 \qquad (2.2)$$

$$S_{ij} = 1 - \left| M_i - M_j \right| \ , \quad 0 \leq S_{ij} \leq 1 \qquad (2.3)$$

Where

S_{ij} is modularity similarity coefficient

M_i & M_j are modularity levels of products i and j

ψ_i is shared component of product i

φ_i is total components of product i

2.3.3 Similarity Coefficient Based on Demand

Product / part demand factor will result in significant utilization of manufacturing system. In order to make a homogenous configuration of system, the system utilization need to be ensured to its utmost capacity. Therefore, parts demand requirements will adjust system according to capacity of system. Developed by Galan et al. [5] and can be calculated from following equation (2.4).

$$D_{ij} = 1 - \frac{\left| d_i - d_j \right|}{d_{max} - d_{min}} \ , \qquad 0 \leq D_{ij} \leq 1 \qquad (2.4)$$

Where

D_{ij} is demand similarity coefficient

d_i and d_j are demand of products i and j

d_{max} is maximum demand of a part among set of parts used for similarity

d_{min} is minimum demands of a part among set of parts used for similarity

2.3.4 Similarity Coefficient Based on Assembly Sequence

Product assembly sequence can be represented as binary tree, and can be used for product family formation developed by kashkosh et al. [6]. Robinson-Foulds (RF) distance is the most widely used metric for comparison of phylogenetic trees for similarity / dissimilarity. RF distance and assembly sequence similarity coefficient can be calculated by following equations.

$$RF(T1,T2) = \frac{1}{2}(|C1\backslash C2| + |C2\backslash C1|) \qquad (2.5)$$

$$RF_s = RF_{max} - RF \qquad (2.6)$$

$$RF_{max} = \frac{1}{2}(m1 - m2 - 2) \qquad (2.7)$$

$$RF_{sn} = \frac{RF_{max} - RF}{RF_{max}}, \quad 0 \leq RF_{sn} \leq 1 \qquad (2.8)$$

Where

C1 & C2 are set of tree T1 & T2

m1 and m2 are nodes of tree T1 &T2

RF_{sn} normalised value of RF similarity coefficient.

2.4 Techniques Based on Part Operation Sequence for Part Family Formation

Jaccard similarity coefficient caters for part operations commonality among set of parts but it does not follow part operation sequence according to precedence constraints. The sequence of machines for sequential processing of parts, known as part operation sequence, is mostly ignored by researchers while forming part families. Developed similarity coefficients are based on operation sequence and sequence of machines in a part flow process. LCS (longest common subsequence), edit distance, merger coefficient, compliant index and BMIM (bypass move and idle machines) similarity coefficients are developed between two operation sequence strings. Two operation sequences for manufacturing of part X and Y are taken to understand the methodology of comparing two operation strings by different techniques developed by authors in the literature. Operation sequences of parts X and Y are: -

Part X	(a	w	d	e	r	t	g	b)
Part Y	(n	d	t	w	g	f	h)	

Comparison of these two operation sequence for similarity / dissimilarity with the best exiting approaches based on operation sequence are discussed below.

2.4.1 Compliant Index Based Similarity Coefficient

Ho et al. [12] developed the approach by comparing in-sequence or by-pass moves of part flow path for both directions, i.e. forward and backward in operation sequence of part. Compliant indexes i.e. forward compliant index and backward compliant index are computed by the comparison of parts operation sequence strings. Similarity of operations in forward direction and backward direction are counted and compliant index similarity coefficient for part x can be determined by the following formula:

$$CO_{xy} = \frac{(CF_x + CB_x)}{2 * N_x} \tag{2.9}$$

Where

CO_{xy} is the operation sequence similarity of part x to be merge with part y

CF_x forward compliant index

CB_x backward compliant index

N_x is the number of operations in operation sequence of part x.

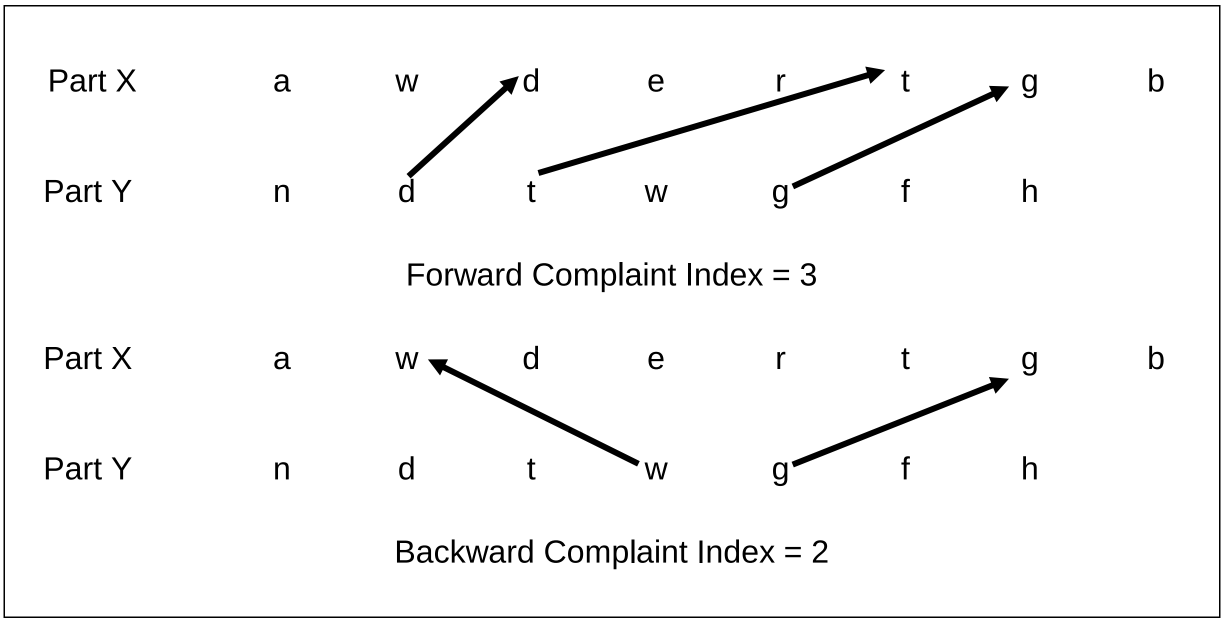


Figure: 2.2 Computation of complaint index

The complaint index of compared part sequence is determined for “in-sequence” or “by-pass” moves in relation to part flow path. Two complaint indexes i.e. forward and backward complaint index are calculated by comparing part operation sequence in both directions of flow path. Choose a part having maximum of operations between two parts operation sequences. The process for calculation of complaint indexes is illustrated in Figure 2.2.

Complaint index similarity coefficient using Equation for part X and part Y is 0.3125.

2.4.2 An LCS based Similarity Coefficient

Askin and Zhou [13] developed LCS (longest common subsequence) based similarity coefficient between operation sequence of parts. The similarity coefficient S_{xy} between operation sequence of part x and y is calculated as:

$$S_{xy} = max\left\{\frac{|LCS_{xy}|}{|x|}, \frac{|LCS_{xy}|}{|y|}\right\} \qquad (2.10)$$

Where

LCS_{xy} is the longest common subsequence between parts x and y.

$|x|$ and $|y|$ are number of operations for part X and part Y

LCS is determined by comparing two operation strings having operations which are common and in-sequence without violating operation precedence constraints. For the example parts X and Y, LCS is (d t g) shown with bold letters in Figure 2.3.

Part X	a	w	***d***	e	r	***t***	***g***	b
Part Y	n	***d***	***t***	w	***g***	f	h	

LCS_{xy} = d t g = 3

S_{xy} = 0.428

Figure: 2.3 Illustration of LCS

LCS based similarity coefficient by using Equation 2.10 is 0.428.

2.4.3 Merger Similarity Coefficient.

Irani and Huang [11] developed merger similarity coefficient based on LCS having substitutions, insertion and deletion of operations for required transformation of one sequence into another one. It is absorption of one operation sequence into another operation sequence. Merger distance md(x,y) is the minimum numbers of insertions and substitutions of operations to transform required operation sequence and interruption distance id(x,y) is the minimum number of non-ending deletions required for transformation. After identification of merger distance and interruption distance, merger coefficient mc(x,y) is calculated as:

$$mc_{(x,y)} = \begin{cases} max\left[1 - \dfrac{md_{(x,y)} + \dfrac{id_{(x,y)}}{|x|}}{|y|+1}\right] & If\ |x|\ > |y| \\ max\left[1 - \dfrac{md_{(x,y)} + \dfrac{id_{(x,y)}}{|y|}}{|x|+1}\right] & If\ |x|\ < |y| \\ max\left[1 - \dfrac{md_{(x,y)} + \dfrac{id_{(x,y)}}{|y|}}{|x|+1}\right], \left[1 - \dfrac{md_{(x,y)} + \dfrac{id_{(x,y)}}{|x|}}{|y|+1}\right] & If\ |x| = |y| \end{cases} \tag{2.11}$$

Where

$mc_{(x,y)}$ is merger coefficient

$md_{(x,y)}$ is merger distance (number of insertions and substitutions of operations)

$id_{(x,y)}$ is interruption distance (number of internal deletions of operations)

$|x|$ and $|y|$ are number of operations for part X and part Y

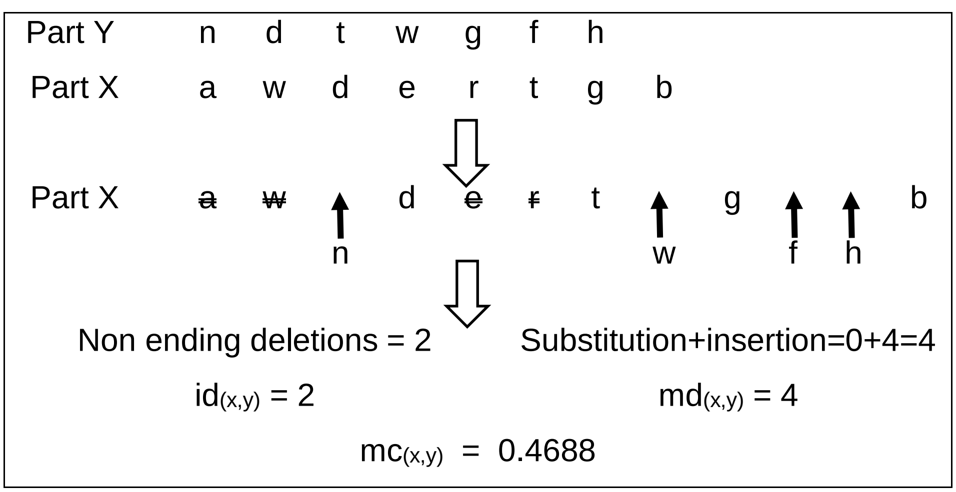


Figure: 2.4 Computation of merger coefficient

Interruption Distance and the Merger Distance are asymmetric, i.e. id(x,y) and md(x,y) may not equal to id(y,x) and md(y,x) respectively. For merger coefficient, take part having maximum number of operation to merge into other part operation sequence. Calculation of merger coefficient of example parts is shown in Figure 2.7. Insertion of operations is shown with arrow and deletion of operations is shown by striking of line on the concerned operations.

2.4.4 Modified Merger Similarity Coefficient

Huang [14] further modified merger coefficient by adding few terms. Calculation process of merger distance and interruption distance is same. Merger coefficient is calculated using following formula.

$$mc_{(x,y)}=\begin{cases} max\left[1-\dfrac{md_{xy}+\frac{id_{(y,x)}}{O_{max}}+\frac{|x|+|y|}{O_{max}^2}}{|y|},0\right] & If\ |x|\ >|y| \\ max\left[1-\dfrac{md_{xy}+\frac{id_{(y,x)}}{O_{max}}+\frac{|y|+|x|}{O_{max}^2}}{|x|},0\right] & If\ |x|\ <|y| \\ max\left[1-\dfrac{md_{xy}+\frac{id_{(y,x)}}{O_{max}}+\frac{|y|+|x|}{O_{max}^2}}{|x|},1-\dfrac{md_{xy}+\frac{id_{(y,x)}}{O_{max}}+\frac{|x|+|y|}{O_{max}^2}}{|y|},0\right] & If\ |x|=|y| \end{cases} \tag{2.12}$$

Where

$mc_{(x,y)}$ is merger coefficient

$md_{(x,y)}$ is merger distance (number of insertions and substitutions of operations)

$id_{(x,y)}$ is interruption distance (number of internal deletions of operations)

O_{max} is maximum number of operations for part X or part Y

Similarly, for modified merger coefficient, part with maximum number of operation is taken to be merge into other part. Illustration of computation of modified merger coefficient is shown in Figure 2.5.

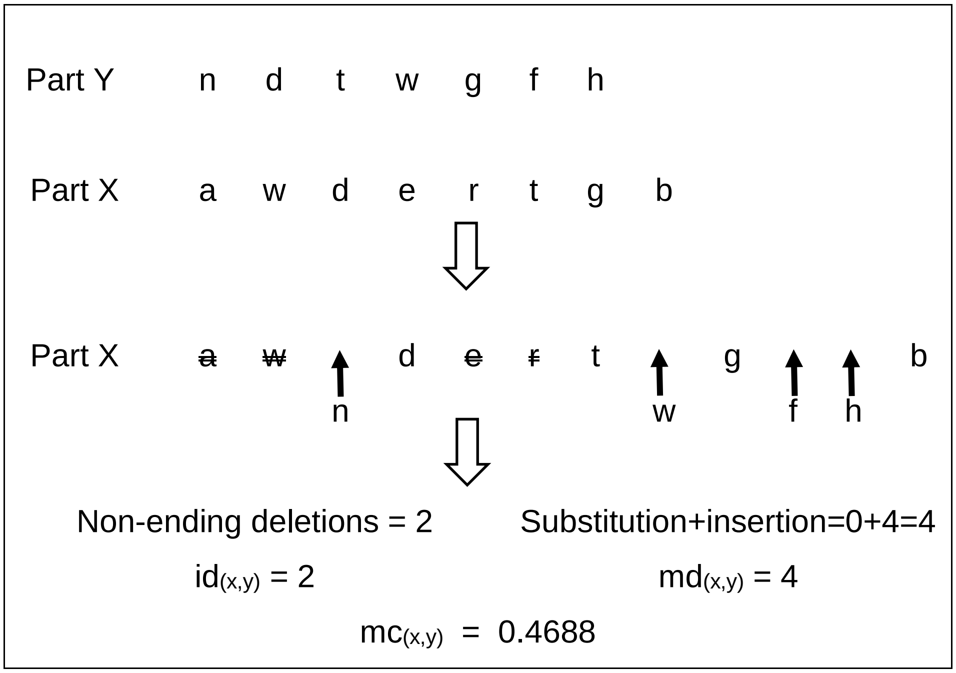


Figure: 2.5 Computation of modified merger coefficient

2.4.5 BMIM Similarity Coefficient.

Goyal [8] developed BMIM (by pass moves and idle machines) similarity coefficient based on LCS (longest common subsequence) and shortest common supersequence (SCS) between operation sequence x and y. By-pass moves and idle machines during manufacturing of part is important factor for utilization of the system. Two operation strings are compared and the similarity coefficient is based on bypass move and idle machines during manufacturing of parts. After computing by pass moves (BPM), idle machines (IM) and total moves (TM) during processing of each part, BMIM similarity coefficient can be calculated as:

$$S_{xy} = 1 - \left\{ \left[\frac{BPM_x}{2 * |TM_x|} + \frac{BPM_y}{2 * |TM_y|} \right] + \left[\frac{IM_x}{2 * |SCS_{xy}|} + \frac{IM_y}{2 * |SCS_{xy}|} \right] \right\} \qquad (2.13)$$

Where

BPM_x is bypass moves during manufacturing of par X

BPM_y is bypass moves during manufacturing of par Y

IM_x is idle machines during manufacturing of par X

IM_y is idle machines during manufacturing of par Y

TM_x is total moves during manufacturing of par X

TM_y is total moves during manufacturing of par Y

SCS_{xy} is shortest common supersequence for manufacturing the parts X and Y

During bypass moves machines also remains idle. LCS_{xy} is common operations between two compared parts without violating the operation precedence. SCS_{xy} is sequence of machines such as to manufacture both compared parts. Computation of BMIM similarity coefficient of two parts X and Y is shown in Figure 2.6.

Part X	a	w	d	e	r	t	g	b				
Part Y	n	d	t	w	g	f	h					
LCS_{xy}	d	t	g	=	3		SCS_{xy}		=	12		
SCS_{xy}	a	w	n	d	e	r	t	w	g	b	f	h
Part X	a	w	$\boxed{n}$	d	e	r	t	$\boxed{w}$	g	b	f	h
Part Y	a	w	n	d	$\boxed{e}$	$\boxed{r}$	t	w	g	b	f	h

Bypass Moves

Idle Machines

BPM_x = 2 IM_x = 4 TM_x = 11

BPM_y = 3 IM_y = 5 TM_y = 11

S_{xy} = 0.3977

Figure: 2.6 Computation of BMIM coefficient

2.5 Cluster Analysis

Cluster analysis is form of grouping showing the degree of similarity among different part groups. Clustering procedure have three main techniques which are (1) array-based clustering (2) hierarchical clustering and (3) non-hierarchical clustering as shown in Figure 2.1.

Hierarchical clustering is used in this study for grouping of sample parts. Hierarchical clustering techniques divide the incidence matrix into broad cells again and again till further partitioning of obtaining groups be not possible. Dendograms i.e. inverted tree structure is the representation of hierarchical clusters. Dendograms illustrate the different grouping based on the similarity of parts within a family as shown in Figure 2.7. Two part families have 100 % similarity which are {4,6} and {3,7}. Five part families having 60 % similarity coefficient among parts are {1}, {2,8,3,7}, {4,6}, {5}, and {9} and three families having 24 % similarity coefficient are {1}, {2,8,3,7,4,6,5}, and {9}. Set Merging Algorithm [17], Single Linkage Clustering Algorithm (SLC) [18], Linear Cell Clustering Algorithm (LCC) [19], Complete Linkage Clustering Algorithm (CLC) and the Average Linkage Clustering Algorithm (ALC) [21] are most widely used techniques.

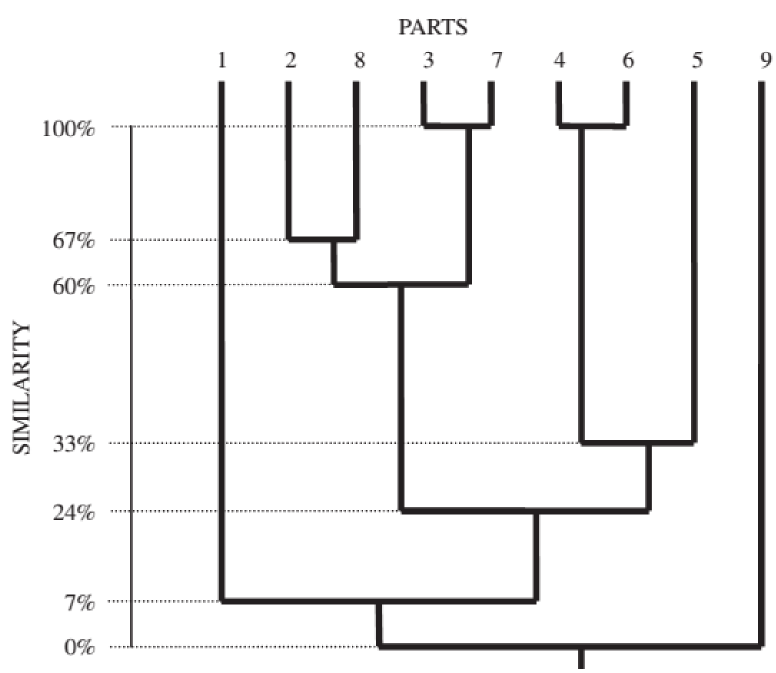


Figure: 2.7 Example of dendogram

2.6 Summary

In this chapter, the method of pasts/products family formation on different similarity basis were discussed. Jaccard commonality matrix is based on common numbers of parts for products and common number of operations for a part similarity, modularity matrix focuses on composition of independent modules within products, demand matrix depend upon part / product demand for system utilization and product assembly sequence tree similarity coefficient is based on Robinson Fould distance between binary trees of products.

Similarity coefficient based on part operation sequence for part family formation by different techniques such as LCS, merger coefficient complaint index and BMIM were highlighted. Two operation strings were compared and similarity index obtained by using above mentioned techniques.

For cluster analysis, i.e. degree of similarity among different part groups, hierarchical clustering method is proposed. Hierarchical clustering technique divide the groups in the form of dendrograms i.e. inverted tree structure for representation of different group based on similarity of parts within a family.

CHAPTER 3

SETUP SEQUENCE BASED PROPOSED METHODOLOGY

Operation sequence based similarity coefficient method is used for calculation of similarity coefficients for part family formation as discussed in previous chapter. Whereas proposed methodology for part family formation is based on setup sequencing similarity coefficient which also includes operation sequence. The methodology will focus on different phases of setup sequence and development of similarity coefficient i.e. BMIMS (bypass moves and idle machines in setup) similarity coefficient based on setup sequence and associated part groups. Flow chart of methodology is shown in Figure 3.1.

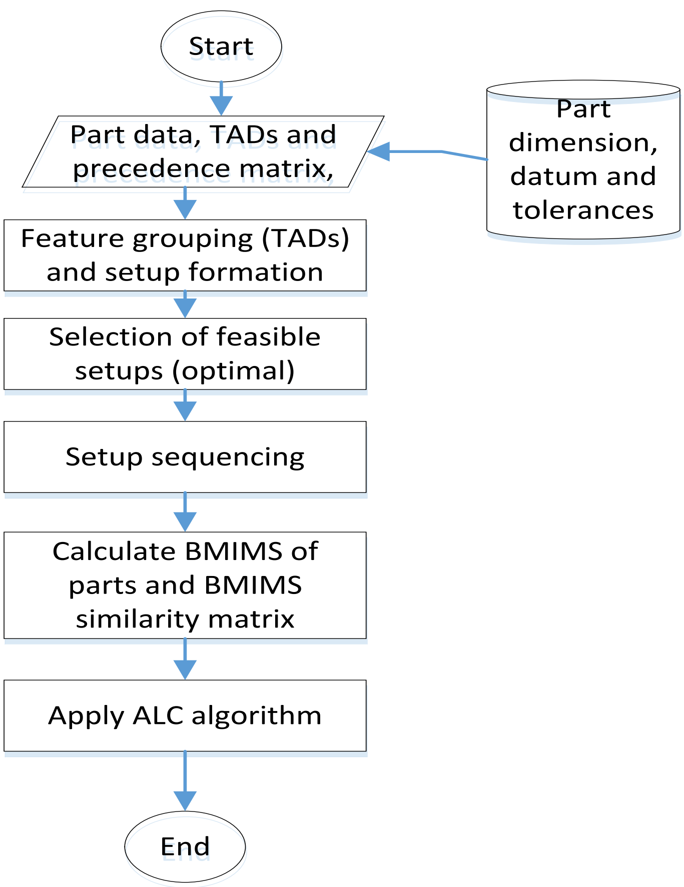


Figure: 3.1 Flow chart of proposed methodology

An important activity for part manufacturing is process planning. Conversion of raw stock into finished product through the design information to systematic manufacturing steps of the part is mapped by process planning. It bridges the practical gaps between design and manufacturing processes being a post-design and pre-manufacturing activity. Integration of design parameters and manufacturing phases is essential for improvements of manufacturing quality cost and time. This factor is addressed by process planning which brings together design and manufacturing aspects as shown in Figure 3.2. Process planning in manufacturing are of two types of i.e. machining process planning and assembly process planning. Setup sequence planning, part of machining process planning is the focus of study.

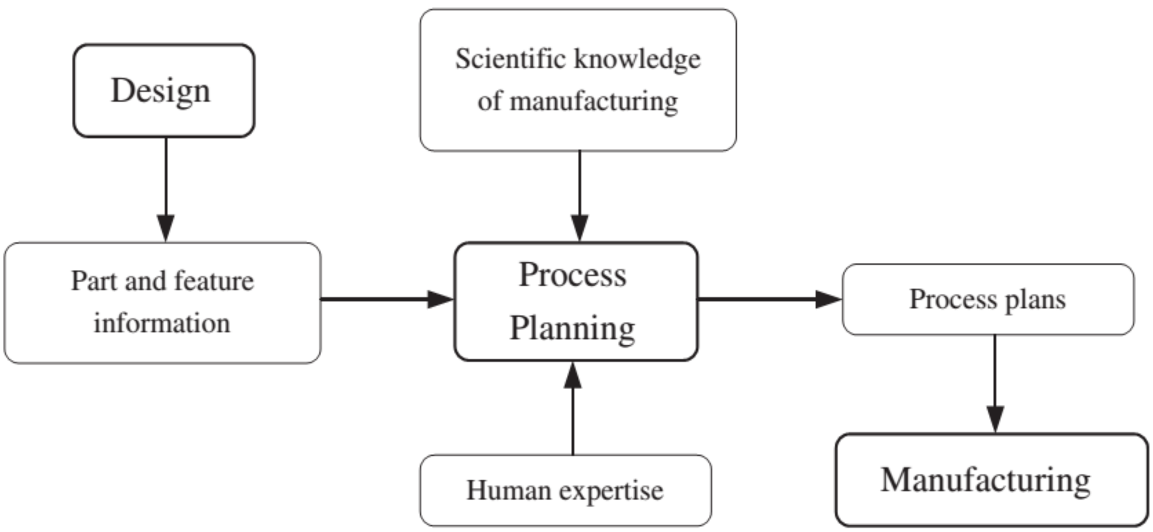


Figure: 3.2 Schematic flow of process planning

3.1 Phases of Setup Planning

Part orientations and fixtures placements in particular position during manufacturing process are essential parameters for machining. Setup planning an intermedia step of process planning caters for such machining issues of orientation and positioning. When the changing of part position and orientation, a new setup for subsequent features operations is considered. A feature or set of features can be machined in a setup without repositioning the part. Figure 3.3 shows the framework of an ideal setup planning. Various phases of setup planning include feature groups, number of setups, selection of datum, operation sequence within a setup and setup sequence.

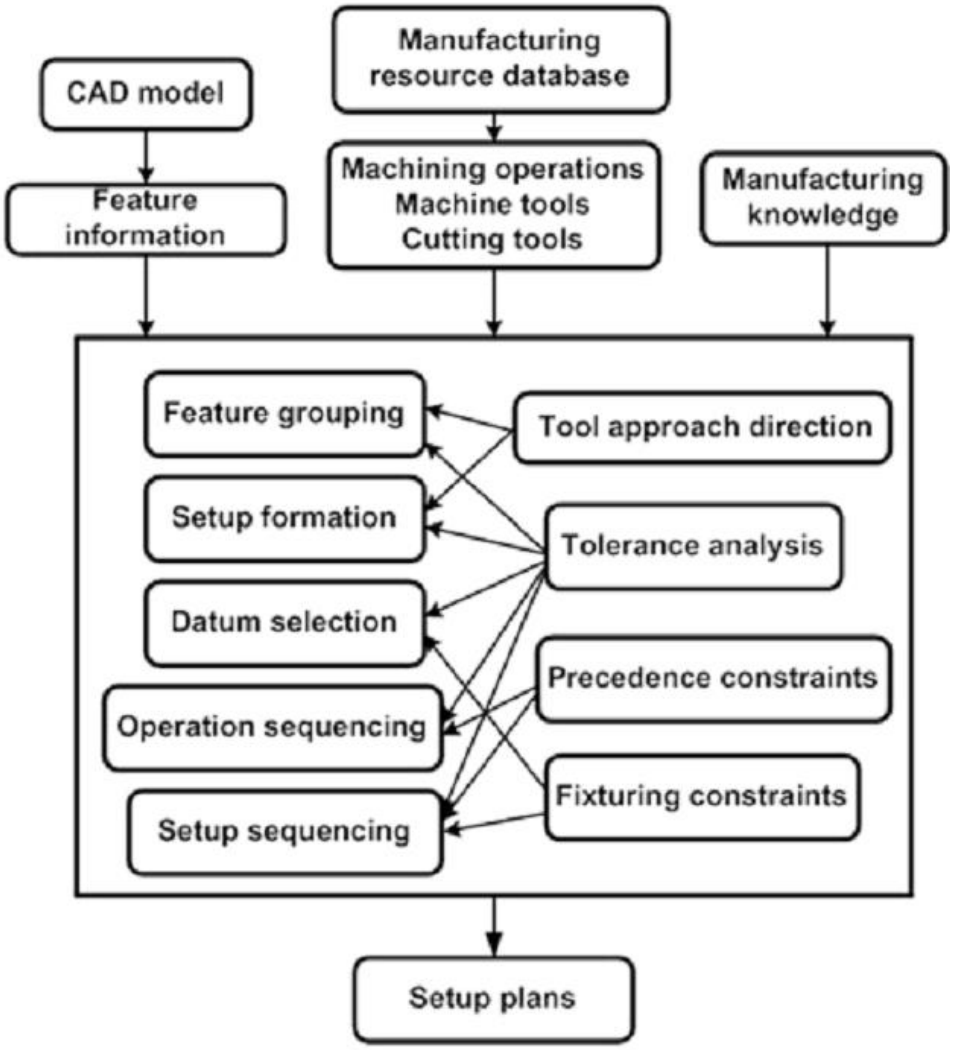


Figure: 3.3 A setup planning system [15]

3.1.1 Feature Grouping

Part containing the machining features represents the geometric specifications of a part. Machining of features in a setup, without setup change or repositioning of part, are grouped together and known as feature grouping. Machining the maximum of features in a minimum setups ensure better tolerance during manufacturing [15]. Feature grouping is based on TADs of feature, feature geometry & precedence and topological interaction relation among features. Primarily grouping is based on TADs of features. Figure 3.4

shows the tool approach direction relative to different features. TAD feature group is formed on basis of features having common TAD, whereas features having multiple TADs are assigned to different TAD feature groups. Maximum of features machining in a single setup, tolerances and setup fixtures are factors to assign single TAD for a feature having multiple TADs.

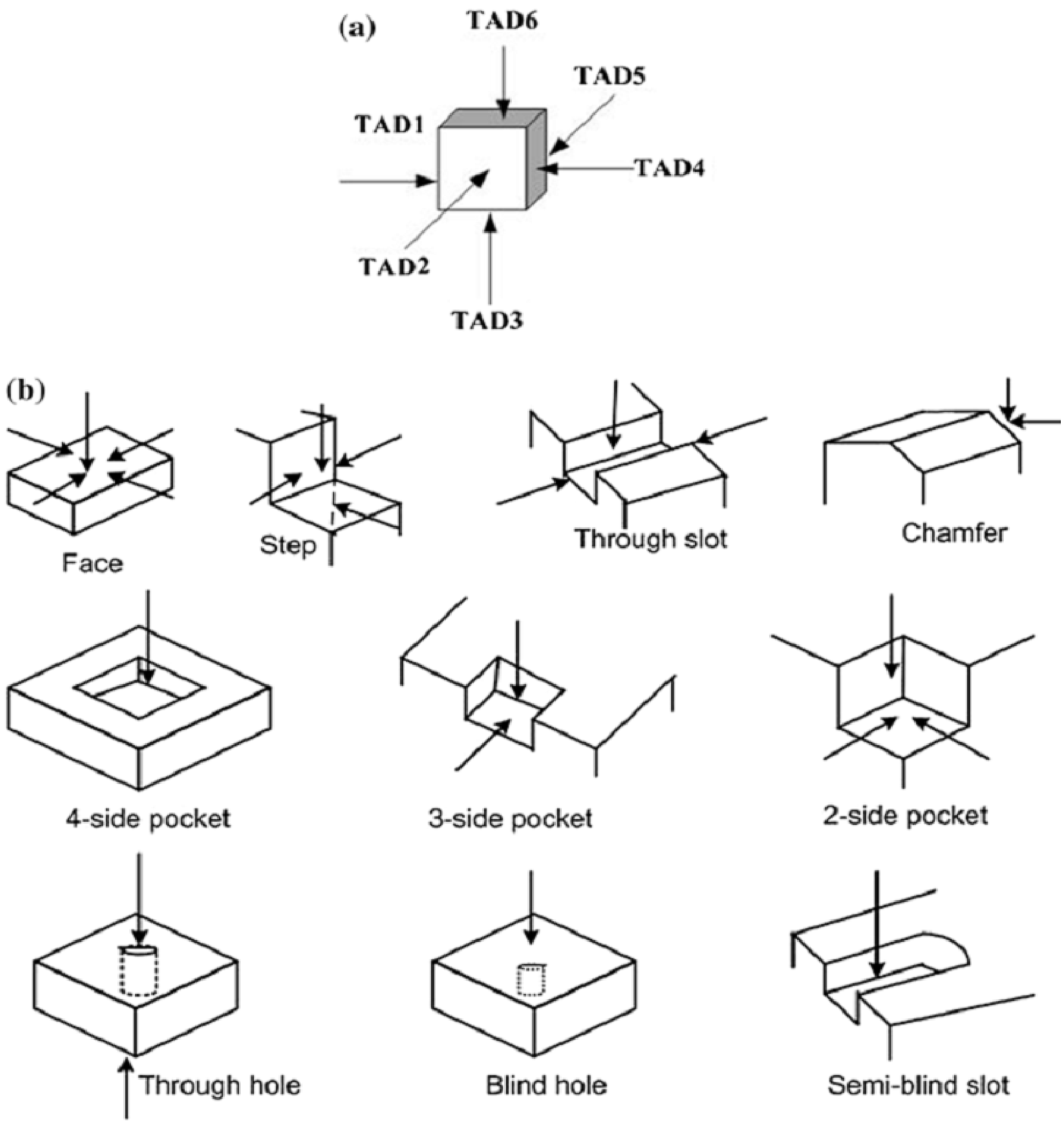


Figure: 3.4 TADs and workpieces. (a) Six available TAD for a prismatic part. (b) Different features with their TADs [15]

In order to explain the feature grouping method, an example part having four features is taken shown in Figure 3.5 and its operation data is shown in table 3.1. All six faces of prismatic block are rough machined. P1 is planner surface obtained by milling operation and TAD for this operation is from all directions less TAD3. Through hole A1 has TAD3 and TAD6, A2 hole has TAD2 and TAD5. Chamfering operation can only be performed from TAD6 direction. Precedence diagram is shown in Fig 3.6.

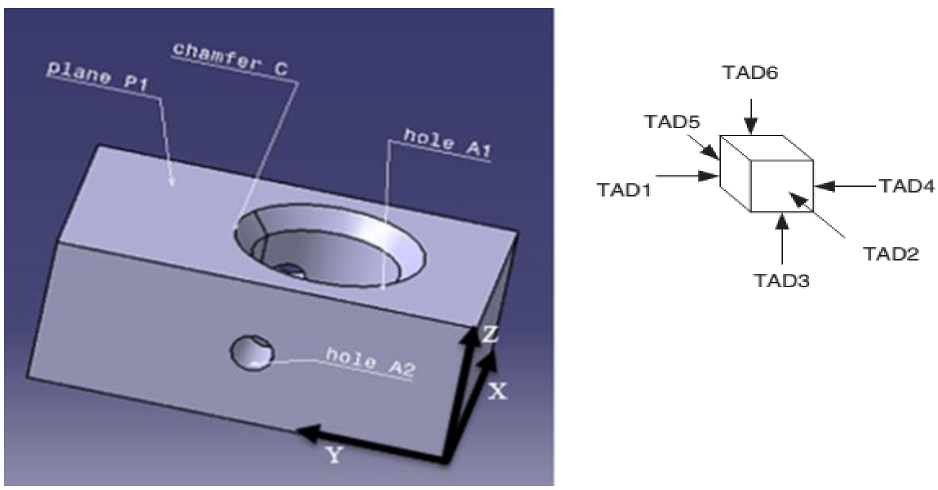


Figure: 3.5 Prismatic part with features

Table: 3-1 Operational data of prismatic part

Feature	Description	Op	Op No	TAD
P1	Planner Surface	M	1	TAD1, TAD2, TAD4, TAD5, TAD6
A1	Through Hole	D	2	TAD3, TAD6
		R	3	TAD3, TAD6
		B	4	TAD3, TAD6
A2	Through Hole	D	5	TAD2, TAD5
		R	6	TAD2, TAD5
C	Chamfer	C	7	TAD6

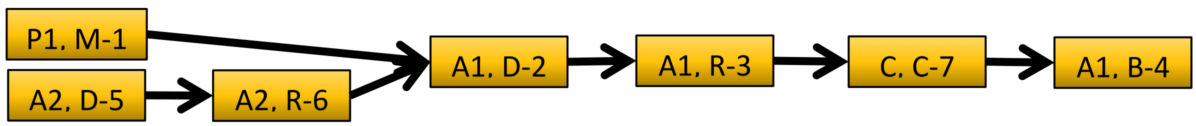


Figure: 3.6 Precedence diagram of example part

Gathering processes of part and all TADs feed axis in the form equation for finding common feed axis direction or tool approach directions.

Process Equation =

$$[(D5)\ \Lambda\ M\ (P1)\ \Lambda\ M^2\ (R6)]\ W\ [(P1)\ \Lambda\ M\ (D5)\ \Lambda\ M^2\ (R6\ ]\ W\ [(D5)\ \Lambda\ M\ (R6)\ \Lambda\ M^2\ (P1)]$$

$$M^3\ [(D2)\ \Lambda\ M\ (R3)\ \Lambda\ M^2\ (C7)\ M^3\ (B4)]$$

Where, M = Machining precedence, Λ = And, W = or

Feed Equation =

$$[(2W5)\ \Lambda\ M\ (1W2W4W5W6)\ \Lambda\ M^2\ (2W5)]\ W\ [(1W2W4W5W6)\ \Lambda\ M\ (2W5)\ \Lambda\ M^2\ (2W5)\ ]$$

$$W\ [(2W5)\ \Lambda\ M\ (2W5)\ \Lambda\ M^2\ (1W2W4W5W6)]M^3\ [(3W6)\ \Lambda\ M\ (3W6)\ \Lambda\ M^2\ (6)\ M^3\ (3W6)]$$

Gathering feed equation

$$\left.\begin{array}{l} [(2W5)\ \Lambda\ M\ (1W2W4W5W6)\ \Lambda\ M^2\ (2W5)] \\ [(1W2W4W5W6)\ \Lambda\ M\ (2W5)\ \Lambda\ M^2 (2W5)] \\ [(2W5)\ \Lambda\ M\ (2W5)\ \Lambda\ M^2\ (1W2W4W5W6)] \end{array}\right\} M^3\ [(3W6)\ \Lambda\ M\ (3W6)\ \Lambda\ M^2\ (6)\ M^3\ (3W6)]$$

Feed Equation $=[(2W5)\ \Lambda\ M\ (2W5)\ \Lambda\ M^2\ (2W5W4)]M^3\ [(6)\ \Lambda\ M\ (6)\ \Lambda\ M^2\ (6)\ M^3\ (6)]$

Two direction of accessibility (2W5) Λ M (6) i.e. TAD2 or TAD5 and TAD6 are chosen as common TADs to process the example part.

3.1.2 Setup Formation

Common TADs features are grouped together for setup formation. Importance is given to machine capability to access direction for machining a feature. Total number of setups depend upon machine capability with reference to machine tool feed direction. For above example part the number of setups is three depending upon precedence constraints as shown in Table 3.2. setup 2 consists of two operations whereas setup 3 contain four operations.

3.1.3 Selection of Datum

Properly identified datum is important for achieving the specified accuracy / tolerance of the feature. It acts as a theoretically exact point, line, area, surface or axis which is used during machining processes as an origin for dimension measurement. Datum features form datum planes i.e. primary, secondary and tertiary datum planes which are perpendicular to each other as shown in Figure 3.7. For manufacturing accuracy, proper selection of datum is essential.

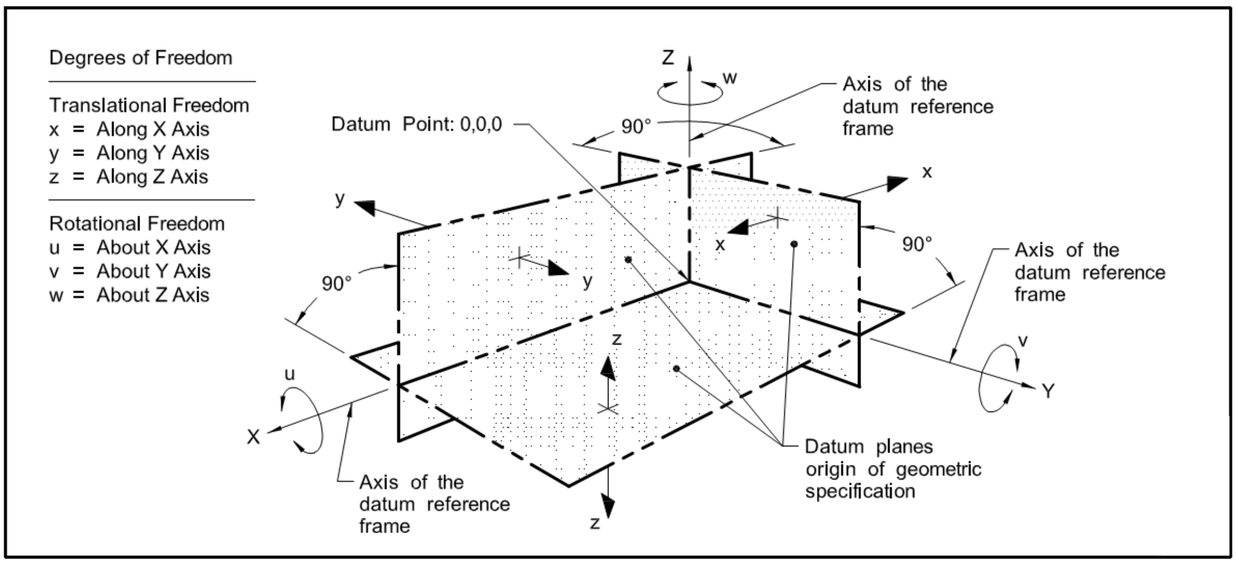


Figure: 3.7 Datum reference frame [15]

3.1.4 Setup Grouping

Setup grouping is based on number of features which are machined in same setups [20]. Machining operation sequencing within the setup depends upon precedence constraints, machining constraints and good manufacturing practices. Minimum tool change is an important criterion for machining operation sequencing and can be achieved by grouping similar operations together such as group drilling operations without violating precedence constraints. Setup grouping is shown in Table 3.2, which are setup 1 (operation 1), setup 2 (operations 5 & 6) and setup 3 (operations 2, 3, 7 & 4).

Table: 3-2 Setup formation of prismatic part

Setup	**Setup 1**	**Setup 2**		**Setup 3**			
Op ID	1	5	6	2	3	7	4
OP	M	D	R	D	B	C	R
TAD	TAD 6	TAD 2 or TAD 5		TAD 6			

3.1.5 Machining Operation Sequencing Within a Setup

Each setup has number of features to be machined are grouped. For example, drilling to make a hole or milling operation to make a plane surface. Feature operations are sequenced as per cutting tool chart such as for feature A1 of example part, three operations are required i.e. drilling, reaming and boring. Boring operation cannot be done before drilling and similarly reaming cannot be done after boring. So, operation sequencing is based on precedence and cutting tool chart. Setup 3 contain four operations which are drilling, reaming, chamfering and boring as chamfering is done before boring.

3.1.5.1 Generation of Machining Precedence Constraints

Feature operations are having precedence relationship as per cutting tool chart as discussed above. Similarly, precedence relationship among features are also be respected. Precedence relation among features are based on feature topological interactions, tolerance relationships, feature accessibility, machining tool interactions, clamping and fixturing interaction, reference relations and good manufacturing constraints. Figure 3.8 shows precedence relationship of different features among each other. Precedence relationship of different parts of Figure 3.10 have different interaction constraints. 3.8 (a) and (b) depicts a fixturing interaction constraint and for this drilling of hole should precede the chamfer. 3.8 (c) shows datum reference constraint and first datum of surface A then bottom face. 3.8 (h) shows slot precedence over boss. 3.8 (j) is example of machining precedence. 3.8 (i) shows good manufacture practice. 3.8 (n) is example of machining of a groove and a chamfer which must be completed prior to that of the adjacent thread.

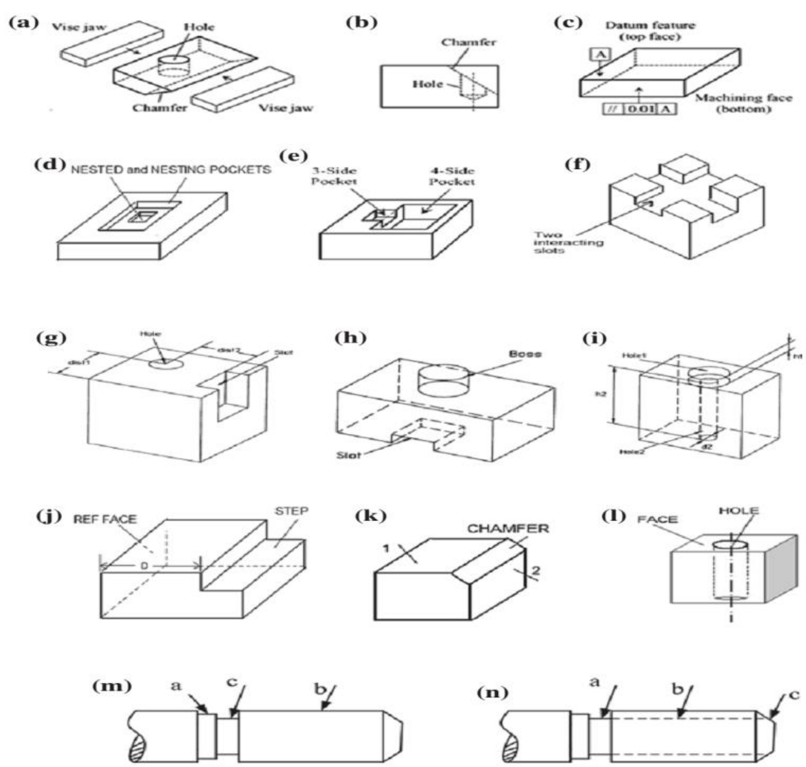


Figure: 3.8 Different precedence relationship [15]

3.1.5.2 Good Manufacturing Practice

Machining operations precedence of a feature and machining operations precedence relations among features are evolved from decades of manufacturing practices. For example, drilling of hole A2 being smaller diameter of example part will be done before A1 hole having larger diameter. Therefore, decision of precedence relations of features depends upon the factors like material properties, cutting parameters, tool accessibility, etc.

3.1.6 Setup Sequencing

Setup sequencing is done in a similar way as the sequencing machining operations within the setups. Precedence relations among features of different setups are the prime criterion for setup sequencing. Setup with greater number of features should be considered at last (without violating precedence constraints). If done earlier, it may raise issues like instability of part or less clamping area for remaining setups. In a same manner, features having larger dimensions or sizes preferably be machined last to avoid above mentioned problems.

Keeping in view the precedence constraints and good manufacturing practice, number of setups obtained for example part are three and setup sequence is {(1), (5,6), (2,3,7,4)} and corresponding TADs are {(TAD6), (TAD2 or TAD5), (TAD6)}.

In a similar manner grouping of features, setups and machining operation sequences within each setup and setup sequencing is done for all parts.

3.2 Research Scope and Assumptions

Scope of research is to develop a method for finding the similarities between parts to assist speedy manufacturing to avoid frequent changes of machines setups. The proposed methodology is based on part setup sequencing and developing BMIMS similarity coefficient. Assumptions of auto tool changer with each machine, milling operation on milling machines only and each setup require a separate machine to perform operations are taken into consideration for proposed methodology. Flow Chart for proposed methodology is shown in figure 3.9.

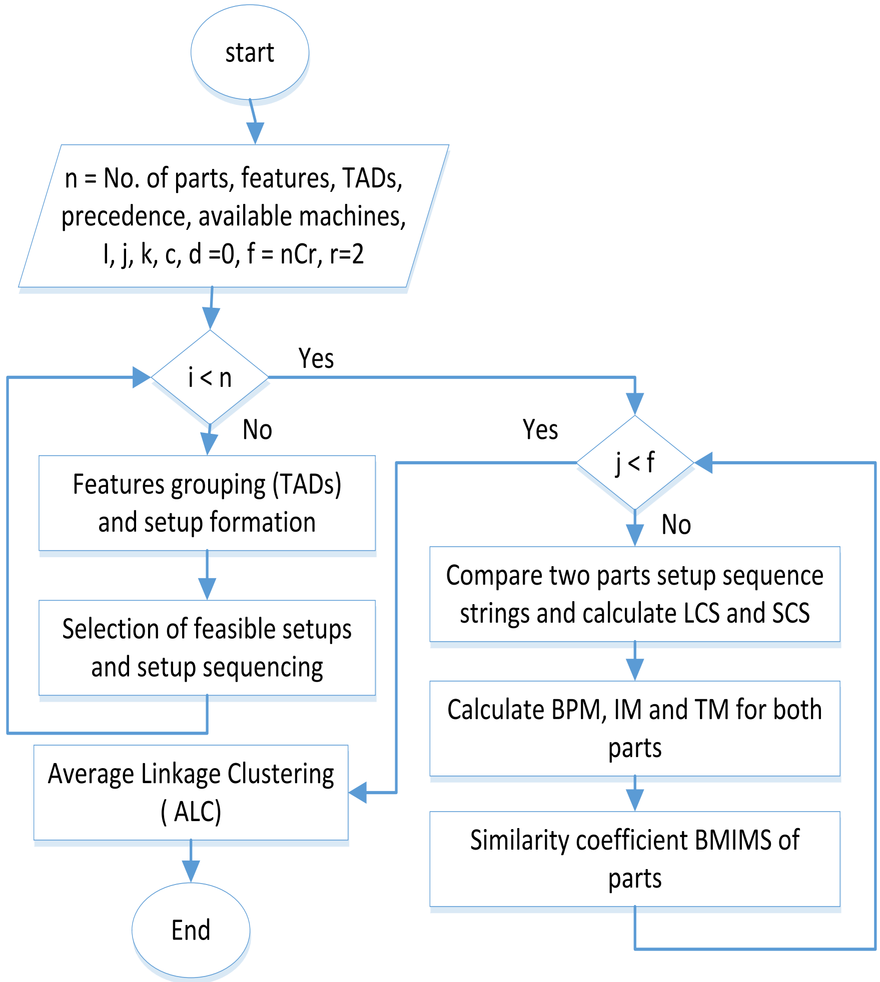


Figure: 3.9 Flow Chart for proposed methodology

3.3 Development of BMIMS (By Pass Moves and Idle Machines in Setups) Symmetry Coefficient

Operations sequence based similarity coefficients has been used in cellular manufacturing, whereas so far no similarity coefficient is developed based on setups sequence. Setup sequencing symmetry will ensure smooth flow of material as well as achievement of better dimensional tolerances. Maximum of dimensional tolerance errors are outcome of repeatedly changing of setups. Completion of machining in minimum number of setups will ensure reduction of tolerance errors. This will also ensure time reduction factor as maximum time is consumed for the preparation of proper setup (clamping and fixtures) as compared to tool changing.

Methodology for finding have uses similar parameters as of Goyal [8] BMIM similarity coefficient but having changes of setup sequence instead of operation sequence. BMIM symmetry coefficient is calculated for two parts operation sequence whereas BMIMS similarity coefficient is based on two parts setup sequence. List of longest common setups in both setup sequence is used for finding the LCS, following the precedence constraints. Setup similarity of two different parts will consider similar types of operations being performed in each setup. Similar operations do not require following the exact operation sequence in both setups but operations will be performed with tool change options.

3.3.1 Identification of LCS and SCS

In order to find out similarity coefficient between two parts setup sequences, first step is to find maximum number of common setups following precedence constraints known as LCS (longest common subsequence). The shortest common supersequence (SCS) is the shortest possible length of a sequence that can accommodate all setups sequence without violating precedence constraints. If compared two setup sequences, then SCS will accommodate all machines to manufacture both parts with its precedence. It can be obtained from LCS of both setup sequence. Many combinations of SCS of same length can be obtained using same LCS while following precedence constraints. SCS which gives minimum bypass moves and minimum idle machines in setup sequence is to be determined. SCS can be calculated using following equation.

$$SCS_{xy} = |x| + |y| - LCS_{xy} \qquad (3.1)$$

where $|x|$ & $|y|$ are number of part setups

3.3.2 Mathematical Model for Determining BMIMS Similarity

SCS can be obtained by appending LCS and left out operations of LCS. Left out operations of LCS are appended to obtain SCS are divided into two categories. First one to append left out operations in between LCS and second one to append left out operations before or after the LCS. The mathematical model is formulated to find SCS with minimum number of bypass moves and idle machines to compute BMIMS similarity coefficient.

In order to find out similarity of setups with reference to two part setups, ratio of tools required and operations for each setup is added in main equation for calculation of similarity coefficient. This ratio factor will determine the similarity of two part setups with each other. In case of same setup sequence for two parts, the difference of tools required and operations ratios for each setup will determine the similarity coefficient for said parts. The developed similarity coefficient BMIMS value become same to similarity coefficient BMIM, when it is considered that all operations in the sequence are having separate setups. The ratio of tools required and operations become one and average of setup also become one and whole equation become Goyal equation.

The model parameters are:

x, y	Setup sequence of part x and part y
LCS_{xy}	Longest common subsequence between setup sequences x and y
SCS_{xy}	Shortest common supersequence between setup sequences x and y
$NOBL_x$	Number of setups of setup sequence x, appended before LCS_{xy} to form SCS_{xy}
$NOAL_x$	Number of setups of setup sequence x, appended after LCS_{xy} to form SCS_{xy}
NOIL	Number of setups of setup sequence x, appended in between LCS_{xy} to form SCS_{xy}
ξ_x	Number of bypass moves before LCS_{xy} while producing part x
φ_x	Number of bypass moves after LCS_{xy} while producing part x
TR_{xi}	**Tool required in ith setup of part x where i=1, 2, 3…n**
OP_{xi}	**Operations in ith setup of part x**
TR_{yj}	**Tool required in jth setup of part y where j=1, 2, 3…m**

Equations (3.2) and (3.3) are used to find minimum bypass moves before LCS while producing part x while following SCS.

$$\xi_x = \begin{cases} NOBL_y & If\ (NOBL_y \le NOBL_x) \\ 0, & otherwise \end{cases} \tag{3.2}$$

$$\varphi_x = \begin{cases} NOAL_y & If\ (NOAL_y \le NOAL_x) \\ 0, & otherwise \end{cases} \tag{3.3}$$

Similarly, ξ_y and φ_y can be calculated using above equations. For exact number of bypass moves for part x and part y following Equations 3.4 and 3.5 are used.

$$BPM_x = NOIL_y + \xi_x + \varphi_x \tag{3.4}$$

$$BPM_y = NOIL_x + \xi_y + \varphi_y \tag{3.5}$$

Total moves of material handling while producing part x by using bypass moves equation and number of part x setups and can be computed as.

$$TM_x = BPM_x + |x| + 1 \tag{3.6}$$

Similarly, total moves for part y cab be calculated using Equation 3.7.

$$TM_y = BPM_y + |y| + 1 \tag{3.7}$$

Idle machines are number machine which remain idle while producing part x and can calculated by Equation (3.8) using SCS and number of setups of part x. Similarly, idle machines for part y is also calculated by Equation (3.9).

$$IM_x = |SCS_{xy}| - |x| \tag{3.8}$$

$$IM_y = |SCS_{xy}| - |y| \tag{3.9}$$

BMIMS similarity coefficient is computed by Equation (3.10). Exact numbers of bypass move and idle machines while producing both parts, total moves, SCS and part tool ratios of all setups are used calculation of BMIMS similarity coefficient.

$$S_{xy} = 1 - \left\{ \begin{array}{c} \frac{1}{2*|x|} \sum_{i=1}^{n} \frac{|TR_{xi}|}{|OP_{xi}|} + \frac{1}{2*|y|} \sum_{j=1}^{m} \frac{|TR_{yj}|}{|OP_{yj}|} \left[\frac{BPM_y}{|TM_y|} + \frac{IM_y}{|SCS_{xy}|} \right] + \\ \left[\left| \frac{1}{|x|} \sum_{i=1}^{n} \frac{|TR_{xi}|}{|OP_{xi}|} - \frac{1}{|y|} \sum_{j=1}^{m} \frac{|TR_{yj}|}{OP_{yj}} \right| \right] \end{array} \right\} \tag{3.10}$$

The range of developed BMIMS similarity coefficient is from zero to one i.e. $0 \leq S_{xy} \leq 1$. The similarity coefficient has half percentage i.e. 50% contribution from each setup sequence for bypass moves, idle machines, tool and operation ratios for both part x and part y in deriving the BMIMS similarity coefficient.

3.3.3 Illustration for computing the BMIMS Similarity Coefficient

For illustration of computation of two parts X and Y are taken with setup {(1,2), (3,3,4,4), (3,4,7,7)} and {(1,2), (1,2), (3,4,3,4,3,4,8), (8,8,8)} respectively. LCS_{xy} is {(1,2), (3,3,4,4)} of length three. SCS_{xy} can be calculated from Equation (3.1) which is in this case is 5.

Part		**Setup1**	**Setup2**	**Setup3**	**Setup4**
X	Op	M	D,D,R,R	B,B,T,T	
	Op ID	1,2	3,3,4,4	3,4,7,7	
Y	Op	M,M	M,M	B,R,B,R,B,R,F	F,F,F
	Op ID	1,2	1,2	3,4,3,4,3,4,8	8,8,8
	LCS	1,2	3,3,4,4	**SCS** 5	
X	1,2	1,2	3,4,3,4,3,4,8	3,4,7,7	8,8,8
Y	1,2	1,2	3,4,3,4,3,4,8	$\boxed{3,4,7,7}$	8,8,8

S_{xy} = 0.6639

Figure: 3.10 Computational Illustration of BMIMS

3.4 Hierarchical Clustering

After calculating the BMIMS similarity coefficient between pairs of parts for set of parts. An agglomerative hierarchical clustering algorithm i.e. average linkage clustering method developed by Seifoddini [21], is used to build a dendrogram. The symmetric square matrix is generated by using inputs of BMIMS of pairs in following Equation.

$$S_{ij} = \frac{\sum_{m \in i} \sum_{n \in j} S_{mn}}{N_i . N_j} \qquad 3.11$$

Where

S_{ij} = Similarity between any pair of family i and j (new family)

S_{mn}= Similarity between any pair of family m and n

N_i = Number of parts in family i

N_j = Number of parts in family j

When parts are merged and similarity are formed to make a family through algorithm, the similarity between newly formed families be recalculated by updating matrix by deletion of rows and columns. The process is repeated till all parts are grouped into a family.

3.5 Summary

Different methods for part family formation based on operation sequence similarity coefficients have already been developed, whereas proposed methodology is basing on setup sequencing similarity coefficient for part family formation. Phases of setup sequence includes feature grouping, setup formation, datum selection operation sequence and setup sequencing. Feature grouping based on TADs of features and common TADs feature grouping make a setup. Setup grouping and machining sequence within a setup and setup group sequencing is the last step of phases of setup sequencing.

Development of BMIMS similarity coefficient for part family formation involves setup sequencing and tool change options within a setup to complete the machining of the part. The range of developed BMIMS is from zero to one. After calculating BMIMS similarity coefficient between pair of parts, average linkage clustering (ALC) method is applied to build a dendogram.

CHAPTER 4

APPLICATION AND ANALYSIS OF PROPOSED METHODOLOGY

In this chapter, the proposed methodology is applied on four parts i.e. CAI, CDV, ANC-090 and ANC-101, to find out how much similarity they have among each other (machining process similarity). Case study involves developing of phases of setups of parts and further computation of BMIMS similarity coefficient. Precedence matrix of each part is generated keeping in view its precedence relations of features and operations as developed by Baqai [20].

4.1 Input Operational Data

Operational data of four parts features along with respective TADs and parts are shown in table 4.1-4.4 and figures 4.1-4.4 below.

Table: 4-1 Operational data of part CAI

Feature	Description	Operation			TAD
		Op	ID	No	
PL 100	Plane Surface	M	1	1	-Z, +X, -X,
		M	2	2	+Y, -Y
CY 103	Hole	D	3	3	-Z
		R	4	4	-Z
CY 104	Hole	D	3	5	-Z
		R	4	6	-Z
CY 105	Through Hole	D	3	7	+Z
		R	4	8	+Z
CY 107	Threaded Hole	T	7	9	+Z
CY 108	Threaded Hole	T	7	10	+Z

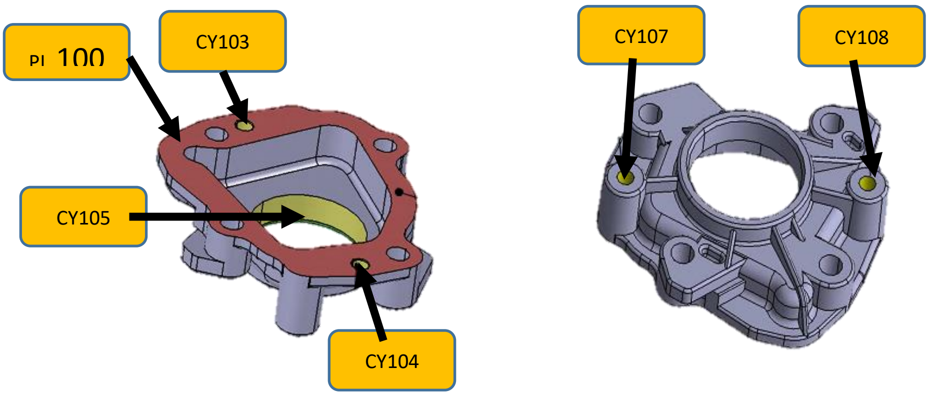


Figure: 4.1 Part CAI

Table: 4-2 Operational data of part CDV

Feature	Description	Operation			TAD
		Op	**ID**	**No**	
PL 100	Plane Surface	M	1	11	-Z, +X, -X, +Y, -Y
		M	2	12	-Z, +X, -X, +Y, -Y
PL 101	Plane Surface	M	1	13	-Z, +Z, -X, +Y, -Y
		M	2	14	-Z, +Z, -X, +Y, -Y
CY 102	Through Hole	D	3	15	+Z, -Z
		R	4	16	+Z, -Z
CY 103	Hole	D	3	17	-Z
		R	4	18	-Z
CY 104	Hole	D	3	19	-Z
		R	4	20	-Z
FL 106	Fillet	F	8	21	-Z
FL 108	Fillet	F	8	22	-X
FL 109	Fillet	F	8	23	-X
FL 110	Fillet	F	8	24	-X
F9	A Step	M	1	36	-Z, -X

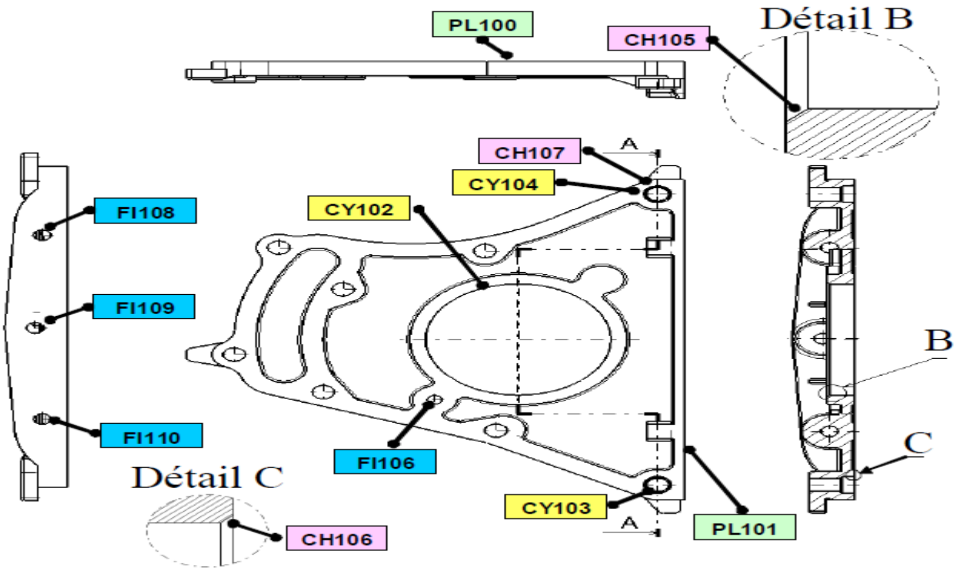


Figure: 4.2 Part CDV

Table: 4-3 Operational data of part ANC-090

Feature	Description	Operation			TAD
		Op	ID	No	
F1	Planner Surface	M	1	25	+Z
F2		M	1	26	-Z
F3	4 Holes replicated	D	3	27	+Z, -Z
F4	A Step	M	1	28	-Z, +X
F5	A Protrusion-rib	M	1	29	-Z, +Y
F6	A Protrusion	M	1	30	+Z, -Y
F7	Compound Hole	D	3	31	-Z
		R	4	32	-Z
		B	5	33	-Z
F8	6 Holes replicated	D	3	34	-Z
		T	7	35	-Z
F9	A Step	M	1	36	-Z, -X

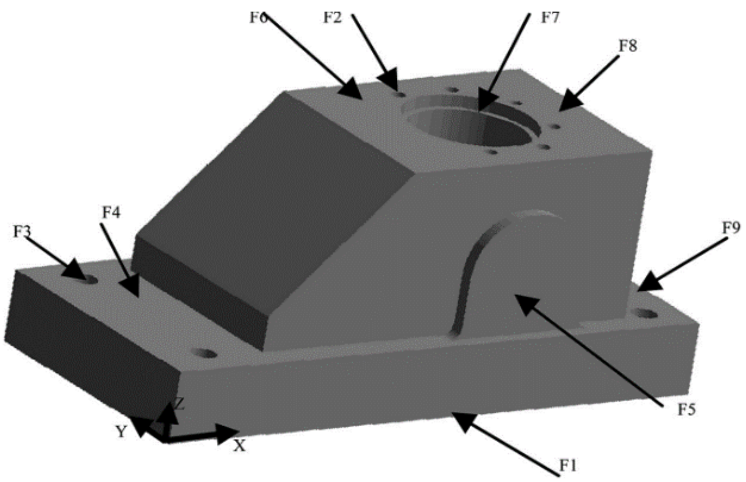


Figure: 4.3 Part ANC-090

Table: 4-4 Operational data of part ANC-101

Feature	Description	Operation			TAD
		Op	ID	No	
F1	Planner Surface	M	1	37	+Z
F2	Planner Surface	M	1	38	-Z
F3	4 Holes replicated	D	3	39	+Z, -Z
F4	A Step	M	1	40	-Z, +X
F5	A Protrusion-rib	M	1	41	-Z, +Y
F6	A Protrusion	M	1	42	+Z, -Y
F7	Compound Hole	D	3	43	-Z
		R	4	44	-Z
		B	5	45	-Z
F8	9 Holes replicated	D	3	46	-Z
		T	7	47	-Z
F9	A Step	M	1	48	-Z, -X
F10	2 Pockets	M	1	49	+X
F11	A Boss	M		50	-a
F12	A Compound Hole	D	3	51	-a
		R	4	52	-a
		B	5	53	-a
F13	A Pocket	M	1	54	-X
F14	A Compound Hole	R	4	55	+X
		B	5	56	+X

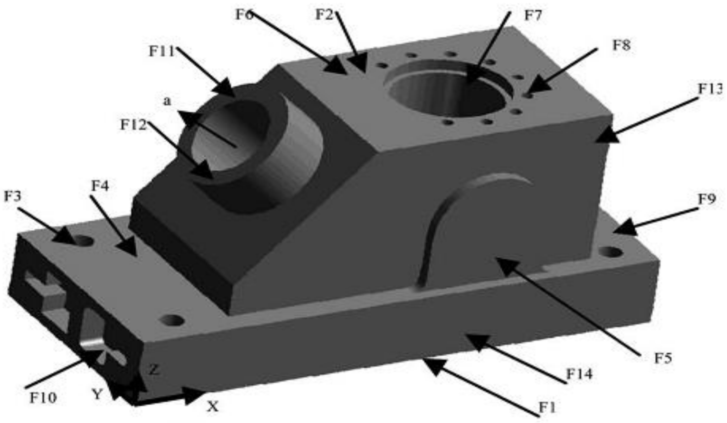


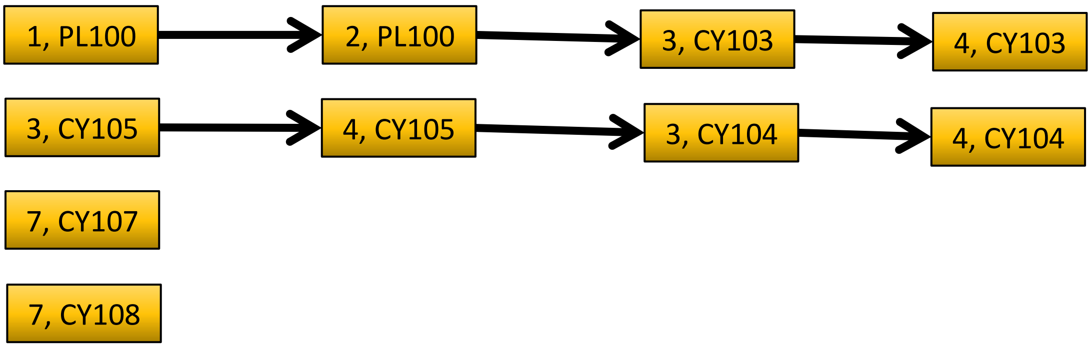
Figure: 4.4 Part ANC-101

4.2 Proposed Methodology Application

Proposed methodology is applied on four parts. Details of two parts i.e. part ANC and part CDV has been illustrated for computation of BMIMS similarity coefficient.

4.2.1 Setup Formation of Part CAI

Precedence diagrams of part ANC, associated setup formation and setup sequencing is shown in Figure 4.5. Operation ID is used along features for part setup and its sequencing and done according to example part in chapter 3.



Setup	**Setup 1**		**Setup 2**				**Setup 3**			
Op ID	1	2	3	3	4	4	3	4	7	7
OP	M	M	D	D	R	R	D	R	T	T
TAD	-Z		-Z				+Z			

4.2.2 Setup Formation of Part CDV

Precedence diagrams of part ANC, associated setup formation and setup sequencing is shown in Figure 4.6.

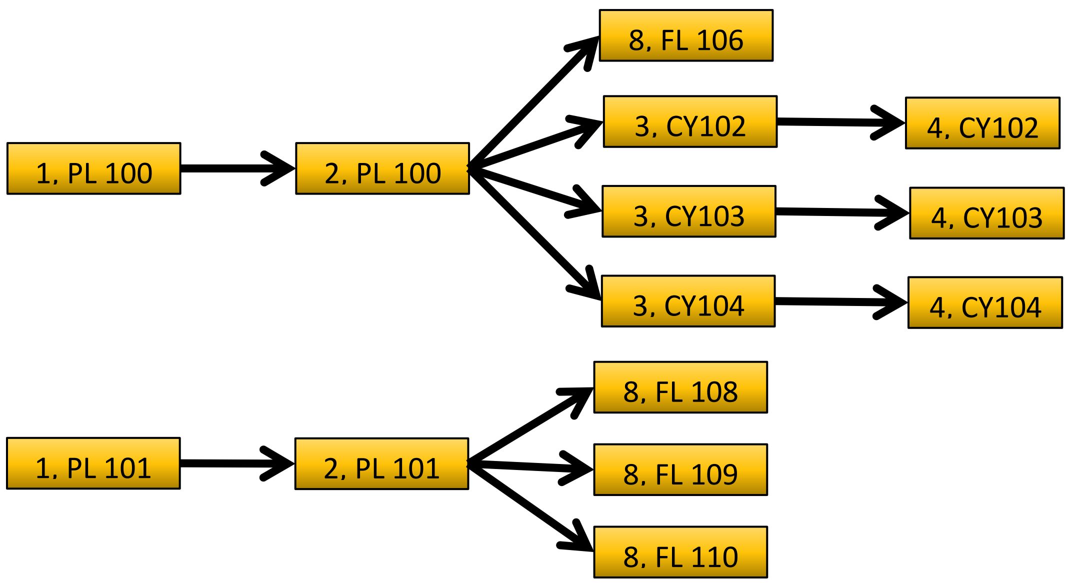


Figure: 4.5 Precedence diagram and setup formation of part CAI

Setup	**Setup 1**		**Setup 2**		**Setup 3**							**Setup 4**		
Op ID	1	2	1	2	3	4	3	4	3	4	8	8	8	8
OP	M	M	M	M	D	R	D	R	D	R	F	F	F	F
TAD	-Z		-X		-Z							-X		

Figure: 4.6 Precedence diagram and setup formation of part CDV

4.2.3 BMIMS Similarity Coefficient Computation

Setup sequencing of part CAI and part CDV have been developed through precedence diagrams. For computation of BMIMS similarity coefficient, Equations developed in chapter 3 will be used.

Part CAI 1 2 3 3 4 4 3 4 7 7

Part CDV 1 2 1 2 3 4 3 4 3 4 8 8 8 8

LCS between these two parts is (1 2) and (3 3 4 4 or 3 4 3 4 3 4 8) i.e. two part setups and SCS can be calculated by using Equation 3.1.

$$SCS = X + Y - LCS = 3 + 4 - 2 = 5$$

SCS is the arrangement of machines in such a way that both parts can be manufactured with minimum of bypass move and idle machines. For above parts SCS will be as following.

Part CAI		1 2		1 2		3 ~~4~~ 3 4 ~~3~~ 4 ~~8~~		3 4 7 7		8 8 8

Part CDV		1 2		1 2		3 4 3 4 3 4 8		3 4 7 7		8 8 8

For manufacturing of part CAI setup 1 i.e. operation (1 2) and setup 5 i.e. (8 8 8) will be idle machines and for setup 3 operations with double strike (~~4~~ ~~3~~ ~~8~~) will not be performed. Similarly, for part CDV, setup 4 i.e. (3 4 7 7) be idle and at the same time it will be bypassed. So, all parameters which has been developed in chapter 3 are shown in Table 4.5: -

Table: 4-7 Calculation Illustration of part CAI and CDV

Part CAI	**Part CDV**
$SCS_{xy} = 5$	$SCS_{xy} = 5$
$BPM_x = 0$	$BPM_y = 1$
$IM_x = 2$	$IM_y = 1$
$TM_x = 4$	$TM_y = 6$
$TR_{x1}/OP_{x1} = 2/2 = 1$ $TR_{x2}/OP_{x2} = 2/4 = 0.5$ $TR_{x3}/OP_{x3} = 3/4 = 0.75$	$TR_{y1}/OP_{y1} = 2/2 = 1$ $TR_{y2}/OP_{y2} = 2/2 = 1$ $TR_{y3}/OP_{y3} = 3/7 = 0.43$ $TR_{y4}/OP_{y4} = 1/3 = 0.33$

Substituting all values in Equation 3.10

$$S_{xy} = 1 - \left\{ \frac{1}{2*|x|} \sum_{i=1}^{n} \frac{|TR_{xi}|}{|OP_{xi}|} \left[\frac{BPM_x}{|TM_x|} + \frac{IM_x}{|SCS_{xy}|} \right] + \frac{1}{2*|y|} \sum_{j=1}^{m} \frac{|TR_{yj}|}{|OP_{yj}|} \left[\frac{BPM_y}{|TM_y|} + \frac{IM_y}{|SCS_{xy}|} \right] + \left[\left| \frac{1}{|x|} \sum_{i=1}^{n} \frac{|TR_{xi}|}{|OP_{xi}|} - \frac{1}{|y|} \sum_{j=1}^{m} \frac{|TR_{yj}|}{OP_{yj}} \right| \right] \right\}$$

$$S_{xy} = 1 - \left\{ \frac{1}{2*|3|} \left[\frac{2}{2} + \frac{2}{4} + \frac{3}{4} \right] \left[0 + \frac{1}{5} \right] + \frac{1}{2*|4|} \left[\frac{2}{2} + \frac{2}{2} + \frac{3}{7} + \frac{1}{3} \right] \left[\frac{1}{6} + \frac{1}{5} \right] + \left[\left| \frac{1}{|3|} \left[\frac{2}{2} + \frac{2}{4} + \frac{3}{4} \right] - \frac{1}{|4|} \left[\frac{2}{2} + \frac{2}{2} + \frac{3}{7} + \frac{1}{3} \right] \right| \right] \right\}$$

$$S_{xy} = 0.6639$$

4.3 Results

BMIMS similarity for all four parts have been calculated and similarity matrix for a group of four parts is shown in Table 4.6.

Table: 4-8 BMIMS similarity matrix for four parts under investigation

Parts	**A-CAI**	**B-CDV**	**C-ANC090**	**D-ANC101**
A-CAI	-	0.6639	0.6203	0.5174
B-CDV		-	0.6539	0.5571
C-ANC090			-	0.7276
D-ANC101				-

4.4 Hierarchical Clustering

Average linkage clustering (ALC) is applied for classification of parts for BMIMS similarity index [18]. ALC methodology groups higher similarity coefficients between parts and can be calculated with following formula 3.11. Where S_{ij} similarity coefficient and N_i & N_j are parts in family i and j and S_{mn} is similarity coefficient of part m and n. Parts are labelled as A, B, C and D for part ANC, part CDV, part ANC-090 and part ANC-101 respectively.

$$S_{ij} = \frac{\sum_{m \in i} \sum_{n \in j} S_{mn}}{N_i . N_j}$$

To obtain the dendogram, the method is repeated till grouping of all parts into a family. As per BMIMS dendogram shown in Figure 4.7, the similarity of part ANC-090 and part ANC-101 is 73 % and for part CAI and part CDV is 66 %. For all four parts the similarity is 59%. Explanation of Hierarchical Clustering for four parts is as under: -

Parts	**B-CDV**	**C-ANC090**	**D-ANC101**
A-CAI	0.6639	0.6203	0.5174
B-CDV	-	0.6539	0.5571
C-ANC090		-	0.7276

$$S_{A,CD} = \frac{S_{AC} + S_{AD}}{1 * 2} = \frac{0.6203 + 0.5174}{2} = 0.56885$$

$$S_{B,CD} = \frac{S_{BC} + S_{BD}}{1 * 2} = \frac{0.6539 + 0.5571}{2} = 0.6055$$

Parts	**B**	**CD**
A	0.6639	0.56885
B	-	0.6055

$$S_{AB,CD} = \frac{S_{AC} + S_{AD} + S_{BC} + S_{BD}}{2 * 2} = \frac{0.6203 + 0.5174 + 0.6539 + 0.5571}{4}$$
$$= 0.58718$$

Parts	**CD**
AB	0.58718

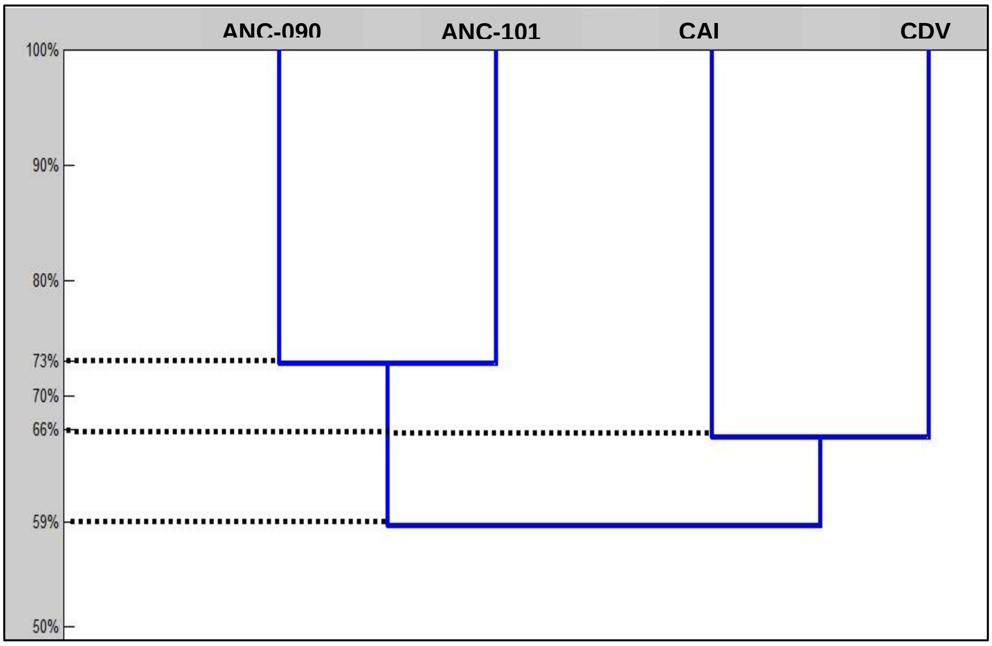


Figure: 4.9. Dendogram for BMIMS

4.5 Analysis

All previously discussed developed similarity coefficients are based on operation sequence whereas BMIMS similarity coefficient is based on setup sequence and have been used for comparing of results of current similarity index. The previously discussed work in literature review do not taken into account setup sequencing, as they are based on operation sequencing.

4.5.1 Existing Approaches and BMIMS Similarity Coefficient

For comparison of result, similarity index of each method for four parts are calculated and results shown in Table 4.9. The existing similarity coefficients have limitations which are discussed in detail by Goyal while comparing with BMIM similarity coefficient [8]. Results of Table 4.9 also shows Drawbacks / limitation of developed approaches for four parts. Limitations of different similarity coefficients highlighted in are shown in bold and underlined in the Table 4.9.

Table: 4.9 Similarity coefficients of different developed techniques

Parts	Complaint Index 1993	LCS 1998	Merger Coefficient 2000	Merger Coefficient 2003	BMIM Coefficient 2013	BMIMS Coefficient 2016
A-B	0.65	**0.6**	0.7208	0.6908	0.4975	0.6639
B-C	0.454	0.5	0.5219	0.4813	0.473	0.6539
C-D	0.917	**1**	**1**	**0.9983**	0.8	0.7276
A-C	**0.5**	**0.6**	0.6288	0.5903	0.5521	0.620
A-D	0.55	**0.6**	0.7045	0.6725	0.3871	0.5174
B-D	**0.5**	0.57	0.5833	0.5525	0.5046	0.5571

Complaint index similarity coefficient is same i.e. 0.5 for parts (CAI&ANC-090) and (CDV&ANC-101). All four have different operations sequences and cannot have same value. Similarly, LCS similarity coefficient for parts groups (CAI&CDV), (CAI&ANC-090) and (CAI&ANC-101) have same value of 0.6, which also shows limitation of the approach.

Merger coefficient and modified merger coefficient have shown almost 100 % similarity between parts ANC-090 and ANC-101. Although parts are similar to some extent but 100% similarity is not possible as part ANC-101 have more operations than part ANC-090. Results of BMIM and BMIMS have variations but no two results are same. Figure 4.10 shows clustering trends of different similarity coefficients.

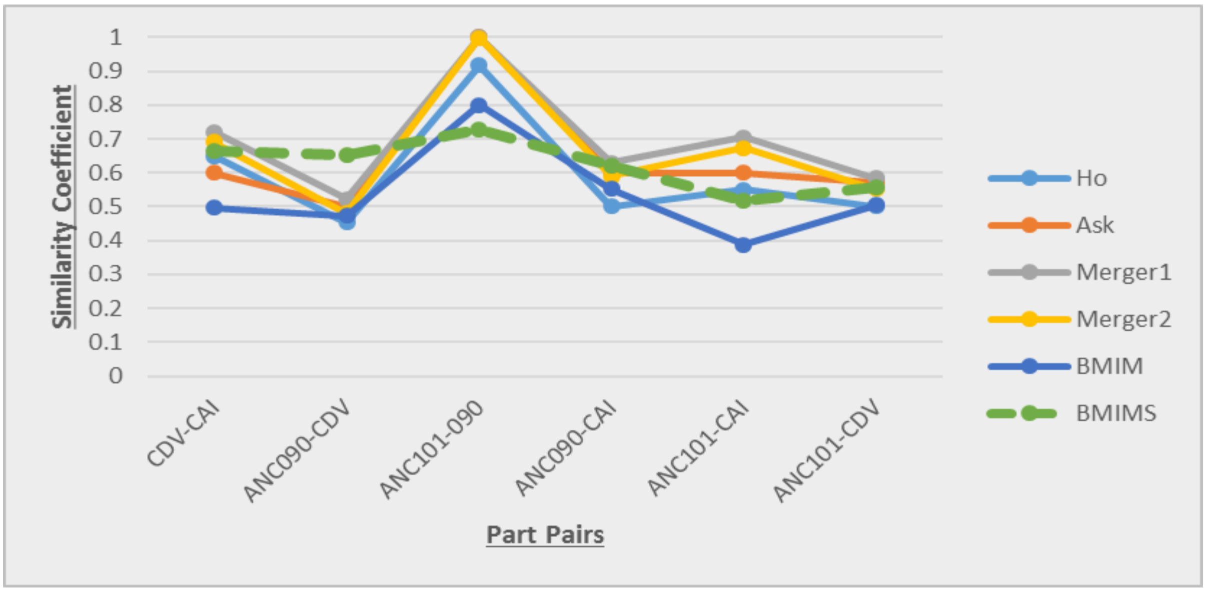


Figure: 4.10 Graphical representation of similarity coefficients

4.5.2 Comparison of BMIM and BMIMS Similarity Coefficient

Comparing the results of BMIM and BMIMS, shows that BMIMS results have been improved gradually almost for all parts. Practically, if multiple operations can be performed in a setup by changing tools instead of single operation, then result would definitely be improved and the same improvement of BMIMS results is evident. Only for parts ANC-101 and ANC-090 value is slightly on lower side, it is because of difference in precedence matrix of both parts, which effected the setup formation and overall result of similarity coefficient.

BMIMS similarity coefficient of four parts can have same value as of BMIM similarity coefficient if all operation sequence of parts is assumed as independent setup for each operation (not setup sequence). Take example of two parts i.e. part CAI and part CDV and it is assumed that all parts operations have independent setups. It means that each setup has one operation and one tool is required for manufacturing the part.

Part CAI 1 2 3 3 4 4 3 4 7 7

Part CDV 1 2 1 2 3 4 3 4 3 4 8 8 8 8

Part CAI 1 2 1 2 3 3 4 3 4 4 3 4 7 7 8 8 8 8

Part CDV 1 2 1 2 3 3 4 3 4 4 3 4 7 7 8 8 8 8

The computation of BMIMS similarity coefficient using Equation 3.10 is as under: -

$$S_{xy} = 1 - \left\{ \frac{1}{2*|x|} \sum_{i=1}^{n} \frac{|TR_{xi}|}{|OP_{xi}|} \left[\frac{BPM_x}{|TM_x|} + \frac{IM_x}{|SCS_{xy}|} \right] + \frac{1}{2*|y|} \sum_{j=1}^{m} \frac{|TR_{yj}|}{|OP_{yj}|} \left[\frac{BPM_y}{|TM_y|} + \frac{IM_y}{|SCS_{xy}|} \right] + \left[\left| \frac{1}{|x|} \sum_{i=1}^{n} \frac{|TR_{xi}|}{|OP_{xi}|} - \frac{1}{|y|} \sum_{j=1}^{m} \frac{|TR_{yj}|}{OP_{yj}} \right| \right] \right\}$$

$$S_{xy} = 1 - \left\{ \frac{1}{2*|10|} \left[\frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} \right] \left[\frac{2}{13} + \frac{8}{18} \right] \right.$$
$$+ \frac{1}{2*|14|} \left[\frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} \right.$$
$$\left. + \frac{1}{1} \right] \left[\frac{4}{19} + \frac{4}{18} \right]$$
$$+ \left[\left| \frac{1}{|10|} \left[\frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} \right] \right. \right.$$
$$\left. \left. \left. - \frac{1}{|14|} \left[\frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} \right] \right| \right] \right\}$$

$$S_{xy} = 1 - \left\{ \frac{1}{2*|10|} [10] \left[\frac{2}{13} + \frac{8}{18} \right] + \frac{1}{2*|14|} [14] \left[\frac{4}{19} + \frac{4}{18} \right] + \left[\left| \frac{1}{|10|} [10] - \frac{1}{|14|} [14] \right| \right] \right\}$$

$$S_{xy} = 0.4975$$

For computation of BMIM similarity coefficient using Equation 2.13 is as under: -

Part CAI 1 2 3 3 4 4 3 4 7 7

Part CDV 1 2 1 2 3 4 3 4 3 4 8 8 8 8

Part CAI 1 2 1 2 3 3 4 3 4 4 3 4 7 7 8 8 8 8

Part CDV 1 2 1 2 3 3 4 3 4 4 3 4 7 7 8 8 8 8

Part CAI

SCS_{xy} = 18

BPM_x = 2

IM_x = 8

TM_x = 13

Part CDV

SCS_{xy} = 18

BPM_y = 4

IM_y = 4

TM_y = 19

$$S_{xy} = 1 - \left\{ \left[\frac{BPM_x}{2*|TM_x|} + \frac{BPM_y}{2*|TM_y|} \right] + \left[\frac{IM_x}{2*|SCS_{xy}|} + \frac{IM_y}{2*|SCS_{xy}|} \right] \right\}$$

$$S_{xy} = 1 - \left\{ \left[\frac{2}{2*|13|} + \frac{4}{2*|19|} \right] + \left[\frac{8}{2*|18|} + \frac{4}{2*|18|} \right] \right\}$$

$$S_{xy} = 0.4975$$

BMIMS and BMIM similarity coefficient results are same as shown above. This shows that when parts setup sequence has independent setups then BMIMS similarity coefficient result will match BMIM similarity coefficient. As per BMIMS dendogram shown in figure 4.9, the similarity of all four parts for grouping is 59%. Whereas the grouping percentage of BMIM similarity index for four parts is 48% as shown in Figure 4.11. This also shows improvement of results of BMIMS similarity coefficient for grouping of part families.

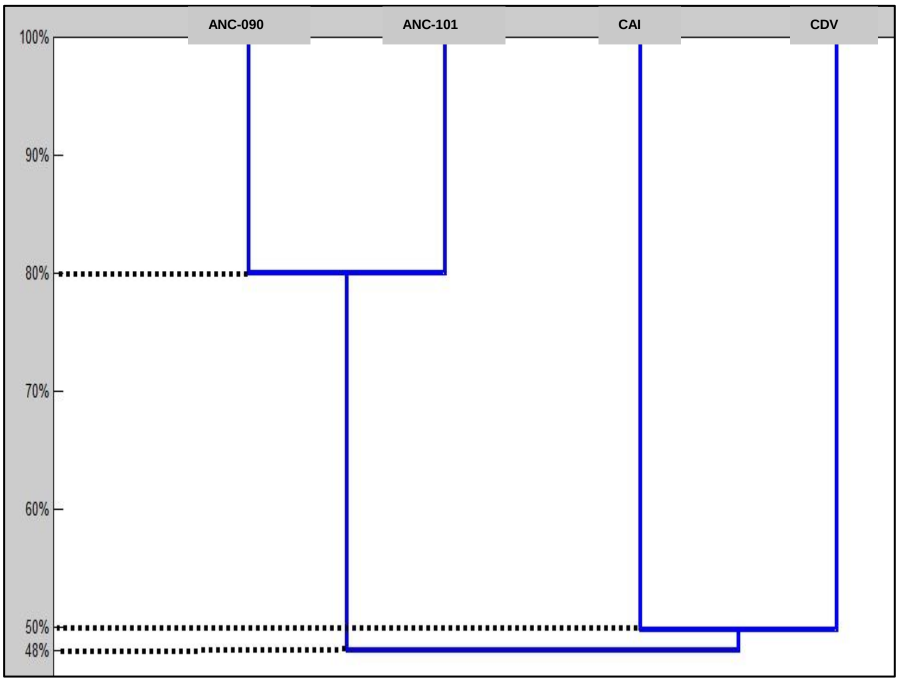


Figure: 4.11 Dendogram for BMIM

4.6 Summary

In this chapter, the proposed methodology has been applied on four part i.e. CAI, CDV, ANC-090 and ANC-101 to find out their similarities among each other. Setup sequencing based similarity coefficient i.e. BMIMS has been calculated for each pair of parts. In order to make family grouping of parts, ALC algorithm has also been applied.

For analysis of the results, BMIMS similarity coefficients are compared with already existing developed approaches which are based on operation sequence for part family formation. BMIMS and BMIM similarity coefficients are also compared and part families which are obtained through dendogram are same for both similarity coefficients.

CHAPTER 5

CONCLUSION AND FUTURE RECOMMENDATIONS

Production of a part consists of a sequence of operations which transforms the material to form the desired shape. In RMS, parts are grouped into part families and requiring a system configuration and to produce another part family system is reconfigured and so on. Therefore, effectiveness of RMS depends upon the best set of part families which will further effect production efficiency and economy. Different methodologies, used for part family formation are highlighted in this literature and among these main emphasis is given to part operation sequence similarity coefficients technique. Selection of proper setups for part production resulting in lesser setups, thus improving accuracy, tolerances and improving part similarity index for part family formation.

The proposed methodology is based on setup sequencing similarity coefficient for part family formation in which part operation sequence is also focused for each setup. Three main steps involve for part family formation are addressed in this thesis which are (1) identification of part setup sequence, (2) application of BMIMS similarity index for pairs of parts and (3) application of ALC algorithm for dendogram formation for part families

The main purpose of setup sequence based similarity coefficient between parts is to classify them so as to smooth flow of material while producing parts on a common plant layout. Phases of setup sequencing similarity coefficient for part family formation includes feature grouping, setup formation, datum selection operation sequence and setup sequencing. Feature grouping based on TADs of features and common TADs feature grouping make a setup. Setup grouping and machining sequence within a setup and setup group sequencing is the last step of phases of setup sequencing.

Development of BMIMS similarity coefficient for part family formation involves setup sequencing and tool change options within a setup to complete the machining of the part. The range of developed BMIMS is from zero to one. BMIMS similarity coefficient is based on setup sequence, LCS, SCS, Bypass moves and Idle machines for each pair of part setup sequences.

After calculating BMIMS similarity coefficient between pair of parts, average linkage clustering (ALC) method is applied to build a dendogram for part family formation.

BMIMS similarity coefficient is an improved technique for part family formation. It can further be improved by considering additional factors which are not included in this research which are as under: -

- Considering more aspects of manufacturing similarities for part family formation such as material of various parts
- Integration of manufacturing operation time
- Considering machining tolerances in developing of part family for improvement of manufacturing quality
- Extending research for multi axes machines and its influences on part family formation

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CERTIFICATE OF COMPLETENESS

It is hereby certified that the dissertation submitted by Muhammad Ali, Reg No. NUST201464680MCEME35114F, titled: **Framework for Part Families Associated with Setup Sequence Based similarity in Cellular / Reconfigurable Manufacturing System** has been checked/reviewed and its contents are complete in all respects.

Supervisor's Name: Dr. Sajid Ullah Butt

Signature: ______________

Date: ______________