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Part Family Formation Based on Operation Sequence in RMS

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Abstract - **Reconfigurable Manufacturing Systems (RMSs) are recognized as next generation manufacturing systems capable of producing customized parts along with the benefits of mass production. The prime focus of design and operation of an RMS is based around a part family. Initially RMS configuration is designed to produce the variety existing within a part family and is subsequently reconfigured to produce the next part family and so on. Thus, the most important issue in RMS design and operation is part family formation. Though, several methods were developed in past for part family formation in context cellular manufacturing systems but for RMS the part family formation algorithms are relatively few. In this work an extended methodology is being proposed for part family for RMS. The methodology adopted for grouping is based on the operation order. The similarity coefficient between any two parts is calculated using stepping passes and idle machines (SPIM). The proposed methodology is explained with the help of a numerical example.**

Keywords – RMS, Part Family, Operation Sequence.

1. INTRODUCTION

The last few decades have witnessed the intense global competition, shortened product life cycles, ever increasing product variety demands, difficulty in forecasting the demand accurately and rapid development of manufacturing technology [Phanden, 2013, 2012a, 2012b, 2011a, 2011b]. A cost effective response to global competition and aggressive market requires a new manufacturing approach that must combine the benefits of DML (high throughput) and FMS (flexibility) [Mehrabi et al., 2000]. Along with the benefits of DML and FMS, the manufacturing system must be equipped to respond to the changes timely and efficiently. These benefits can be achieved if the system is designed according to two the following principles [Koren et al., 1999, Goyal et al., 2013a, 2013b, 2012a]:

- Design the system around the part family to enable customization
- Design the system and its machines for adjustable structure to enable scalability

Koren et al. [1999] defines RMS as "*a system designed at the outset for rapid change in structure, as well as in hardware and software components, in order to quickly adjust production capacity and functionality within a part family*". A RMS must possess several key characteristics that help in designing the system to achieve the desired goals. These characteristics are scalability, convertibility, diagnosability, modularity, integrability, and customization. These characteristics enable rapid responsiveness of the system and help in achieving 'exactly the capacity and functionality as and when needed' [Goyal et al., 2012b, 2012c, 2012d, 2011a]. Customization aims at designing a manufacturing system around a part family. Convertibility is the capability of a system to adjust production functionality, or change the system from one product to another within a part family. A part family corresponding to one distinct configuration of the RMS which can be economically reconfigured into other configurations to cater many new part families. New products can be easily incorporated within existing part families or new families can be generated if parts are effectively grouped into families [Abdi, 2012].

Formation of part family requires a decision criterion or a philosophy or a basis by which these parts can be easily grouped into distinct families [Galan et al, 2007]. Researchers have developed various grouping philosophies in the part family formation for cellular manufacturing system. In context of RMSs, any part family methodology must account for the reconfiguration aspect as well, because of which an altogether a different approach is required for part family formation. Galan et al. [2007] proposed a methodology based on key attributes of products viz. modularity, commonality, compatibility, reusability and product demand for grouping products. Abdi [2012] proposed an analytical network process (ANP) model using decisive factors such as manufacturing and market requirements, manufacturing cost and the process of reconfiguration. Gupta et al. [2013] developed a two-phase approach where parts are first grouped into families and then families are sequenced, computing the required machines and modules configuration for each family. One of the pioneering work on part family formation was carried out by Goyal et al [2013c] in which a novel operation sequence based BMIM (bypassing moves and idle machines) similarity coefficient were being developed using longest common subsequence (LCS) and the minimum number of bypassing moves and the quantity of idle machines. The present work is an extension of the work done by

Goyal et al [2013c]. in which the methodology has been modified to get new similarities values. The developed methodology is explained in the following sections.

2. LITERATURE REVIEW

Numerous methods are available in literature for part family formation in cellular manufacturing systems but only some limited number of studies has so far has been addressed for part-machine grouping while considering operation sequences. Some of the pertinent techniques for part family formation are as follows

Selvam and Balasubramanian [1985] developed a heuristic procedure for addressing a sequence-dependent clustering problem for part family formation. Paydar and Sahebjamania [2009] proposed linear mathematical programming model for cell formation problem using operation sequence. Choobineh [1988] presented a similarity measure which uses the manufacturing operations and their sequences in the first stage. Following this, the machine cells are formed in the second stage. This method also requires the entire part-machine incidence matrix to be stored in memory. It also entails a part-by-part similarity coefficient method, and relies on other, traditional clustering methods, like the single linkage method, for actual clustering. Vakharia and Wemmerlöv [2007] developed a heuristic procedure for cell formation based on commonality in material flow, the mathematical representation of which is as follows:

$$S_{pq} = 0.5 \times \left[\left\{ \frac{\sum_{i \in C_{pq}} M_{ip}}{\sum_{i=1}^{m} M_{ip}} \right\} + \left\{ \frac{\sum_{i \in C_{pq}} M_{iq}}{\sum_{i=1}^{m} M_{iq}} \right\} \right] \quad (1)$$

Where $i=1,...,m$ is the machine type index; A_{ip}=1 , If machine type i is required for part p; else= 0; and C_{pq} is the set of machine types required for p and q in the same sequence.

Instead of similarity, dissimilarity coefficient was proposed by Tam [1990] based on operation commonality and Levenshtein distance measure. Similarity between two sequences is measured as the minimum number of operations required in converting one part sequence to the other. The clustering of coefficients may results in unnecessary machine duplication thus increasing the material handling efforts. Ho et al. [1993] proposed an operation sequence similarity coefficient based on the number of operations in the sequence of a product that are either in-sequence or by-passing with the sequence of flow in both the forward and backward directions. This similarity coefficient is defined as the sums of both compliant indices divided by twice the number of operations in the product. Similarity coefficient for product p can be determined by the following formula:

$$C_{pq} = \frac{FCI + BCI}{2 \times N} \quad (2)$$

Where C_{pq} is the coefficient of part p to be merged with part q, FCI is the forward compliant index, BCI is the backward compliant index, and N is the number of operations in the operation sequence of part p. While finding the similarity coefficient, the part p is assumed with the minimum number of operations in its operation sequence out of both the parts; the value of C_{pq} lies between zero and 1. This similarity coefficient is designed for the multiple product flow line, may also be used for part family formation. Askin and Zhou [1998] presented a similarity coefficient based on the LJOS between parts for designing flow-line manufacturing cells. They constructed a tree of all the possible subsequence of operations common in operation sequences of both the parts. Further, the concept of non-dominated matches has been applied to reduce the size of the tree. The similarity coefficient S_{pq} between two operation sequences p and q is defined as:

$$S_{pq} = \max \left\{ \frac{|LCS|}{|p|}, \frac{|LCS|}{|q|} \right\} \quad (3)$$

Where, LCS is the longest common subsequence between p and q, and $|p|$ is the number of operations in sequence p Irani and Huang [2000] developed merger similarity coefficient based on LCS to find the minimum number of string operations required to transform one sequence into other. Huang [2003] further modified the above merger similarity coefficient considering differences in length of operation sequence p and q. Kang and Wemmerlöv [1993] proposed the similarity coefficient:

$$S_{pq} = \alpha \frac{C_{pq}}{|p|} + (1-\alpha)\frac{C_{pq}}{|q|} \tag{4}$$

Where, $C_{pq}=max_l\{C_{pq}(l)\}>0$
α= a constant between 0 and 1
The problem with this coefficient is that α is chosen subjectively. Moreover, no procedure was specified for findingC_{pq}.

3. METHODOLOGY

The methodology is based on finding out the Lengthiest Joint Operation Sequence (LJOS), Shortest Common Super-sequence (SCS) of operation sequences *p*, and *q*. LJOS and SCS are used to find out stepping moves and idle machines. Stepping moves and idle machines affects the material flow and machine utilization. The SMIM similarity coefficient can be calculated using equation (12). A weight is considered to incorporate the effects of operation sequences. The details of which are as follows;

3.1 Lengthiest Joint Operation Sequence

Lengthiest Joint Operation Sequence is a special case of edit distances [Crochemore & Rytter, 1997]. LJOS is the maximal common ordered subsequence of sequences *p* and *q*. Common ordered subsequence, means a subsequence with the same operations and precedence relationships as in both original sequences *p* and *q*. Maier [1978] proved that finding the LJOS and SCS for a general set of n-sequences are NP-complete problems. Using Dynamic programming, length of LJOS can be recursively found. LJOS can be extracted by backtracking. Recursion for the length LJOS is given as;

$$c[i,j] = \begin{cases} 0 & if\,(i=0, j=0) \\ c[i-1, j-1]+1 & if\,(i,j>0\;\&\; p=q) \\ \max(c[i,j-1], c[i-1,j] & if\,(i,j>0\;\&\; p\neq q) \end{cases} \tag{5}$$

3.2 Shortest Composite Super-sequence

Shortest composite/common super-sequence (SCS) is a shortest sequence that contains the original operation sequences *p* and *q* as subsequence
The length of SCS between two operation sequences *p* and *q* may be obtained after finding the LJOS using:

$$SCS = |p| + |q| - |LJOS| \tag{6}$$

The number of idle machines depends only on the length of SCS, which remains unaltered for all the possible alternative arrangements of the SCS.

3.3 Mathematical Model of SMIM Similarity

While calculating LJOS for *p* and *q* some of operation are left out from both of operation sequences. When SCS is formed these left out operations are appended by three means viz. added before, after and in between the LJOS. Orders by which these operations are added affect material flow. Operations that are added before and after LJOS affect stepping moves. The following mathematical formulation is adopted to find the minimum no of stepping moves (SM) and idle machine to compute the SMIM similarity coefficient.
The notations used are as follows:

LJOS	Longest common subsequence between operation sequences *p* and *q*
SCS	Shortest common super-sequence between operation sequence *p* and *q*
BL_p	Number of operations of operation sequence appended before *LJOS* to form *SCS*
AL_p	Number of operations of operation sequence *p* appended after *LJOS* to form *SCS*
IL_p	Number of operations of operation sequence *p* appended in between *LJOS* to form *SCS*

a_p Number of stepping moves required before the start of *LJOS* while producing part with operation sequence *p* on *SCS*

b_p Number of stepping moves required after the end of *LJOS* while producing part with operation sequence *p* on *SCS*

Procedure for calculations for operation sequence *p* is given. Following Equations are used to find a_p and b_p

$$a_p = \begin{cases} BL_{q,} & if\,(BL_q \leq BL_p) \\ 0 & Otherwise \end{cases} \quad (7)$$

$$b_p = \begin{cases} AL_q & if\left(AL_q \leq AL_p\right) \\ 0 & Otherwise \end{cases} \quad (8)$$

Minimum number of stepping moves while producing the part having operation sequence *p* and *q* on a *SCS* can be calculated using equations given below:

$$SM_p = IL_p + a_p + b_p \quad (9)$$

Total number of material handling movements while processing part *p* and *q*, using stepping moves can be obtained as:

$$T_p = SM_p + |p| + 1 \quad (10)$$

The number of idle machines in any layout while producing the part is an effective measure of utilization of resources. The number of idle machines while producing the part with operation sequence *p* and *q* on the SCS of operation sequences *p* and *q* is computed using,

$$I_p = |SCS| - |p| \quad (11)$$

Similarly a_q, b_q SM_q,T_q,I_q can be calculated for operation sequence *q*.

The SMIM (stepping moves and idle machines) similarity coefficient is computed as:

$$S_{pq} = 1 - k \times \left\{ \left[\frac{SM_p}{|T_p|} + \frac{SM_q}{|T_p|} \right] + \left[\frac{I_p}{|SCS|} + \frac{I_q}{|SCS|} \right] \right\} \quad (12)$$

Where, *k* is weight considering the effects of lengths of operation sequences and can be given as

$$k = \frac{|LJOS|}{|SCS|} \quad (13)$$

4. Numerical Example

As an example sample values obtained for part number 1 & 2 from Table 1 are as follows
p = a,d,h,i , |p|=4; q = a,d,g,d,h,g, |q|=6; LJOS = a,d,h, |LJOS|=3; SCS = a,d,g,d,h,i,g, |SCS|=7
BL_p=0, BL_q=0; AL_p=0,AL_q=1; b_p=1,b_q=1;a_p=0,a_p=0; IL_p=0,IL_q=2; SM_p=3,SM_q=1; T_p=8,T_q=8
k=0.43, $\mathbf{S_{pq}=0.541}$

4. RESULTS AND DISCUSSION

The SMIM approach is exemplified by an example of 19 parts [Huang, 2003]. Table 1 presents the 19 parts along with their operation sequences. A MATLAB code has been developed for the calculation of SMIM similarity coefficient and generation of dendrogram. Table 2 compiles the SMIM similarity coefficient values for the sample data that ranges from 0 to 1. Average linkage hierarchical clustering (ALC) algorithm has been applied for the part family formation as it neither suffered from the chaining effect nor lost the benefits of similarity among parts. The dendrogram of the sample of the sample data is presented in Figure 1. The selection of product families can be made through cutting the dendrogram at the desired threshold level.

Table 1 Operation considered

sequence of parts

Part no.	Operation sequence	Part no.	Operation sequence
1	*a,d,h,i*	11	*f*
2	*a,d,g,d,h,g*	12	*k,g,l*
3	*a,b,d,g,h,i*	13	*k,l*
4	*a,d,g,i*	14	*k,g,j*
5	*a,f,j,g,i*	15	*a,g,k,j,k,l*
6	*f,j,g,h,i*	16	*a,g,k,j,k,l*
7	*f,d,h,i*	17	*k,g,l*
8	*c,e,b,f,d,h,i*	18	*f,g,j*
9	*c,e,f,d,h,i*	19	*l*
10	*d,g,d,h*		

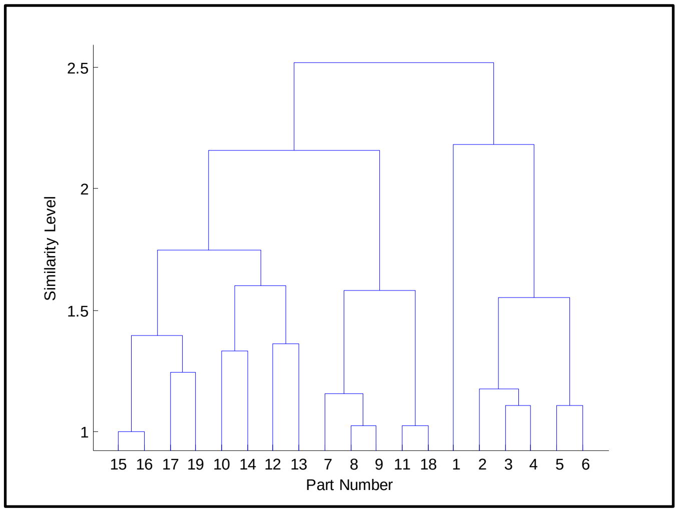

Figure 1: Dandogram based on similarity values so obtained

Table 2: SMIM similarity coefficients of sample parts

Part #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	-	0.54	0.6	0.56	0.62	0.72	0.56	0.72	0.7	0.68	0	0	0	0	0.87	0.87	0	0	0
2		-	0.5	0.59	0.69	0.67	0.65	0.77	0.74	0.78	0	0.82	0	0.82	0.77	0.77	0.82	0.82	0
3			-	0.59	0.56	0.68	0.63	0.61	0.68	0.7	0	0.86	0	0.86	0.77	0.77	0.86	0.86	0
4				-	0.54	0.62	0.59	0.75	0.72	0.72	0	0.78	0	0.78	0.76	0.76	0.78	0.78	0
5					-	0.68	0.64	0.74	0.7	0.85	0.84	0.81	0	0.79	0.67	0.67	0.81	0.73	0
6						-	0.54	0.66	0.63	0.72	0.84	0.84	0	0.85	0.87	0.87	0.84	0.73	0
7							-	0.76	0.78	0.68	0.81	0	0	0	0	0	0	0.81	0
8								-	0.77	0.78	0.88	0	0	0	0	0	0	0.88	0
9									-	0.76	0.86	0	0	0	0	0	0	0.86	0
10										-	0	0.78	0	0.78	0.85	0.85	0.78	0.78	0
11											-	0	0	0	0	0	0	0.78	0
12												-	0.61	0.55	0.66	0.66	1	0.71	0.78
13													-	0.76	0.64	0.64	0.61	0	0.75
14														-	0.76	0.76	0.55	0.55	0
15															-	1	0.62	0.66	0.86
16																-	0.62	0.66	0.86
17																	-	0.71	0.78
18																		-	0
19																			-

5. CONCLUSIONS

A stepping moves and idle machines based methodology have been presented for part family formation. Since efficiency and economy of RMS is depends upon the grouping of part. Considering material flow smoothness and idleness of machines makes this approach more practical and realistic, leading improvement in the system performance measures e.g. Machine utilization, throughput rate and transporter utilization. The developed approach is free from inappropriate ties in the clustering threshold values due to inaccurately assigning the same similarity values to different part groups on. In this work only operation sequence is considered as basis. Further research may include operation time, alternative operation sequence, and production volume. Multi objective optimization for part family formation can also be attempted in the future.

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