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Framework for Part Family Formation Based on Setup Similarity

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Abstract

Post industrial revolution led to the emergence of Reconfigurable Manufacturing Systems as result of increasing market and manufacturing demands. Shorter product life-cycle, competitive pricing, diverse needs and highly customized designs with more flexibility, efficiency and reactivity redefined the manufacturing paradigms. Products as well as parts exhibiting close similarity in features generally followed similar manufacturing patterns and thus were suggested to be grouped together in part families and configurations. Optimizing the setup changes to the minimum possible number is the ultimate target in several part productions. This research focuses on formulation of approach to develop an optimized arrangement of product to form family. The methodology depends on coefficients of similarity using intelligent sequencing of setup, group-based machining features and identification of datum. It considers the product setup sequence based BMIMS coefficient of similarity derived by incorporating concepts of LCS and SCS. The prime objective is to enhance the production performance of Cellular/Reconfigurable Manufacturing.

Keywords: Reconfigurable Manufacturing Systems (RMS); Longest Common Subsequence (LCS); Bypass Moves and Idle Machines in Setup (BMIMS); Shortest Common Super-Sequence (SCS)

Introduction

Reconfigurable Management Systems (RMS) is an open ended system that allows flexible customization rather than replacement to improve, upgrade or reconfigure a particular part family. The objective of an RMS is to provide the functionality and capacity on need-to-need basis. This makes RMS a configuration that is either dedicated or flexible, or in between. Research conducted so far has resulted in providing different perspectives for the identification of part/product families and machine cells. In context to hierarchical clustering of part similarities among each other, similarity coefficient of parts holds an important role. Quantitative and qualitative aspects of products along with operational similarities form the basis of product family identification [1]. For product family formation, Galan took into account an approach based on product modularity, compatibility, commonality, reusability and product demand [2]. Kashkoush and HodaElMaraghy employed concept of product assembly sequence tree, parts commonality and demand similarity coefficients for product family formation [3]. On the other hand, Rakesh et al. adopted an alternate process plan and applied Jaccard similarity coefficient [4]. The authors used similarity coefficient based on operation sequence to develop part families [5-9]. Goyal et al. has considered not only operation sequence but also developed BMIM similarity coefficients which determines minimum bypass movement and idle machines during part flow [5]. In order to take the advantage of minimum setups for maximum of operations to achieve better accuracy and tolerance, BMIMS similarity coefficient has been developed. BMIMS similarity coefficient uses tool change option for completion of maximum operations in a setup to avoid frequent changes of setups.

Part Operation Sequence Based Techniques

For part family formation, there are some constraints. For instance, Jaccard similarity coefficient does not follow part operation sequence according to precedence constraints however it does cater for part operations commonality. Examples of similarity coefficients developed between two operation sequence strings include:

- LCS (longest common subsequence)
- Merger coefficient
- Compliant Index
- BMIM

Summary of developed techniques for part family formation are shown in Table 1.

Proposed Methodology Based on Setup Sequence

The methodology proposed for part family formation involves setup sequencing similarity coefficient including operation sequence. The focus will be on setup sequences and associated part groups using BMIMS similarity coefficient to form different phases of setup sequence and similarity coefficient. Flow chart of proposed methodology is shown in Figure 1.

Development of BMIMS symmetry coefficient

To ensure achievement of better dimensional tolerances and smooth material flow setup sequencing symmetry is the technique applied in this research. Another aspect catered is the time reduction factor, which is the outcome of utilizing minimum number of setups and hence avoiding dimensional tolerance errors resulting from repeatedly changing setups.

BMIMS is calculated using similar parameters as of Goyal BMIM similarity coefficient [5]. However, instead of two-part operation sequence a two-part setup sequence is used. Incompliance with the precedence constraints, LCS is found using the list of longest common setups in both setup sequences. Similar type of operations dictates the

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Author	Operation Sequence	Techniques for part family formation
Kashkoush and HodaElMaraghy [3]	Compliant index	$CO_{AB}=\frac{(CF_A+CB_A)}{2*N_A}$
Askin and Zhou [9]	LCS	$SAB=max\left\{\frac{\lvert LCS_{AB}\rvert}{\lvert A\rvert},\frac{\lvert LCS_{AB}\rvert}{\lvert B\rvert}\right\}$
Irani and Huang [8]	Merger similarity coefficient	$mc_{(A,B)}=max\left[1-\frac{md_{(A,B)}+\frac{id_{(A,B)}}{\lvert A\rvert}}{\lvert B\rvert+1}\right] \quad If\ \lvert A\rvert>\lvert B\rvert$
Huang [8]	Modified Merger similarity coefficient	$mc_{(A,B)}=max\left[1-\frac{md_{AB}+\frac{id_{(B,A)}}{O_{max}}+\frac{\lvert A\rvert+\lvert B\rvert}{O_{max}^2}}{\lvert B\rvert},0\right] \quad If\ \lvert A\rvert>\lvert B\rvert$
Goyal et al. [5]	BMIM	$S_{AB}=1-\left\{\left[\frac{BPM_A}{2*\lvert TM_A\rvert}+\frac{BPM_B}{2*\lvert TM_B\rvert}\right]+\frac{IM_A}{2*\lvert SCS_{AB}\rvert}+\frac{IM_B}{2*\lvert SCS_{AB}\rvert}\right\}$

Table 1: Developed techniques based on Operation Sequence.

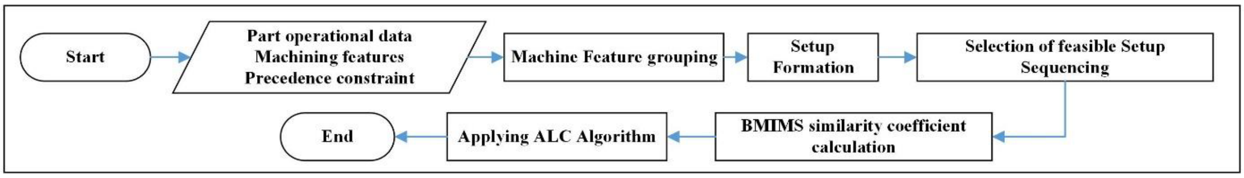


Figure 1: Flow chart of proposed methodology.

setup similarity of two different parts and it does not require the exact operation sequence be followed in both setups. However, tool change options can be used to perform the operations.

Finding of LCS and SCS

Askin and Zhou subsequence formulation is used to calculate the longest common subsequence. For example, consider two operation sequences X={a d e g h} and Y={d f e g k m}. {d e}, {e g} and {d e g} are some of the sub-sequences constructed from the two sequences X and Y [9]. Thus, the LCS of X and Y is the longest common subsequence from all the possible constructed sub-sequences i.e., {d e g} is the LCS of X and Y. Finding the LCS between two operation sequence is not the one followed by Wagner and later given by Goyal. The algorithm developed has the following features.

- LCS_string presents the list of operation in LCS satisfying the precedence constraints.
- LCS_length gives the cardinality of LCS_string i.e., the length or the number of operations in the longest common subsequence.

Shortest Common Super-Sequence (SCS)

SCS is obtained from the LCS using the two given sequences. However, in the present work, the SCS gives minimum bypass moves and the minimum number of idle machines selected for further calculation of similarity. The length of SCS (cardinality_SCS) between two operation sequences X and Y may be obtained as:

cardinality_SCS=cardinality_*X*+cardinality_*Y* – cardinality_*LCS*

BMIMS similarity mathematical model

For SCS, operations left out of LCS are appended. There are two categories to obtain SCS.

- Append left out operations in between LCS.
- Append left out operations before or after the LCS.

Addition of tools ratio required and operation for each setup are added in the main equation to find out similarity of setups with reference to two-part setups. For same setup sequence for two parts, the similarity coefficient is calculated using the difference in tools required and operations ratios for each setup. The BMIMS similarity coefficient developed as a result will be similar to Goyal BMIM similarity coefficient. However, the only constraint is that all operations in the sequence have separate setups.

The mathematical model parameters are:

- u, v Setup sequences of part U and part V
- LCS_{uv} Longest Common Subsequence for setup part U and part V
- SCS_{uv} Shortest Common Super-Sequence for setup parts U and V
- NBL_u Number of setups for U, appended before LCS_{uv} to form SCS_{uv}
- NAL_u Number of setups for U, appended after LCS_{uv} to form SCS_{uv}
- NIL_u Number of setups for U, appended in between LCS_{uv} to form SCS_{uv}
- ξ_u Bypass moves before LCS_{uv} while producing part U
- φ_u Bypass moves after LCS_{uv} while producing part U
- TR_{ui} Tool required in ith setup of part U where i=1, 2, 3…n
- OP_{ui} Operations in ith setup of part U

- TR_{vj} Tool required in jth setup of part V where j=1, 2, 3…m.

The following equations are used to find bypass moves, idle machines, material handling moves and finally similarity coefficient of BMIMS. Equations (1) and (2) are used for calculating minimum bypass moves before LCS while producing part U.

$$\xi u = \begin{cases} NBLv & If\left(NBLv \le NBLu\right) \\ 0, & otherwise \end{cases} \quad (1)$$

$$\varphi_u = \begin{cases} NALv & If\left(NALv \le NALu\right) \\ 0, & otherwise \end{cases} \quad (2)$$

Similarly, ξ_v and φ_v can be calculated accordingly. To calculate exact number of bypass moves for part

U and part V, equations 3 and 4 are used.

$$BPM_u = NILv + \xi_u + \varphi_u \quad (3)$$

$$BPM_v = NIL_u + \xi_v + \varphi_v \quad (4)$$

Total moves while producing part U can be computed as.

$$TMu = BPM_u + |u| + 1 \quad (5)$$

Similarly, for part V can be calculated as follows:

$$TM_v = BPM_v + |v| + 1 \quad (6)$$

Idle Machines (ID) are machines that remain idle while producing part U or part V and can calculated using equations (7) and (8) respectively.

$$IM_u = |SCS_{uv}| - |u| \quad (7)$$

$$IM_v = |SCS_{uv}| - |v| \quad (8)$$

BMIMS coefficient of similarity is computed as below:

$$Suv = 1 - \left\{ \frac{1}{2*|u|} \sum_{i=1}^{n} \frac{|TR_{ui}|}{|OP_{ui}|} \left[\frac{BPM_u}{|TM_u|} + \frac{IM_u}{|SCS_{uv}|} \right] + \frac{1}{2*|v|} \sum_{j=1}^{m} \frac{|TR_{vi}|}{|OP_{vi}|} \left[\frac{BPM_v}{|TM_v|} + \frac{IM_v}{|SCS_{uv}|} \right] + \left[\left| \frac{1}{|u|} \sum_{j=1}^{n} \frac{|TRui|}{|OPui|} - \frac{1}{|v|} \sum_{j=1}^{m} \frac{|TRvj|}{|OPvj|} \right| \right] \right\}$$

Range $0 \le S_{uv} \le 1$.

Case Study

For illustration of the developed approach, four parts i.e. CAI, CDV, ANC-090 and ANC-101 are considered to find out how much similarity do they have among each other (machining process similarity). Parts features along with respective machining feature and parts are shown in Table 2. Setup sequence and operations sequence within each setup are generated through precedence matrix for each part [10].

The longest common subsequence for parts CAI and CDV is (1 2 3 3 4 3 4). Table 3 shows the illustration of LCS calculation of the parts under consideration.

Figure 2 shows the associated setup formation and setup sequencing for part CAI and CDV. Computational illustration of similarity coefficient i.e., BMIMS for Part CAI and part CDV is shown in Figure 3.

PART CAI

Setup	Setup1	Setup2	Setup3
Op ID	1 2	3 3 4 4 3 4	7 7
Machining	M M	D D R R D R	T T

PART CDV

Setup	Setup1	Setup2	Setup3
Op ID	1 2 1 2	3 4 3 4 3 4	8 8 8 8
Machining	M M M M	D R D R D R	F F F F

Figure 2: Setup Formation of Part CAI & CDV.

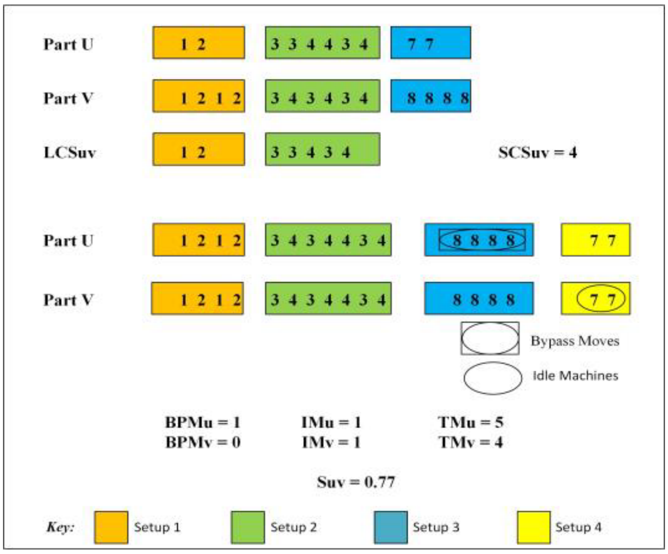
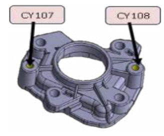
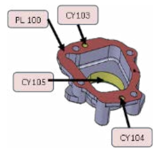


Figure 3: Computation of BMIMS.

PART CAI

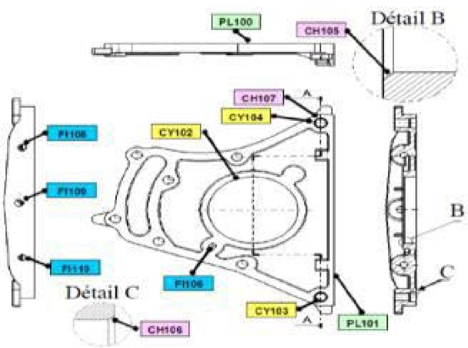
Feature	Description	Operation			Machining Feature
		ID	No	TAD	
PL 100	Plane Surface	1	1	-Z, +X, -X, +Y, -Y	M
		2	2		M
CY 103	Hole	3	3	-Z	D
		4	4	-Z	R
CY 104	Hole	3	5	-Z	D
		4	6	-Z	R
CY 105	Through Hole	3	7	+Z	D
		4	8	+Z	R
CY 107	Threaded Hole	7	9	+Z	T
CY 108	Threaded Hole	7	10	+Z	T





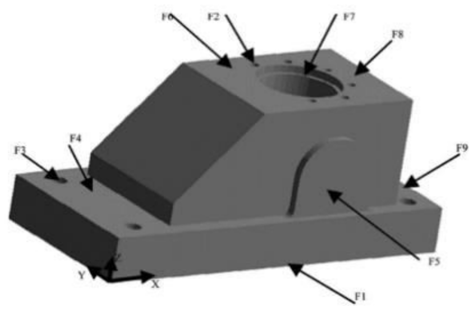
PART CDV

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



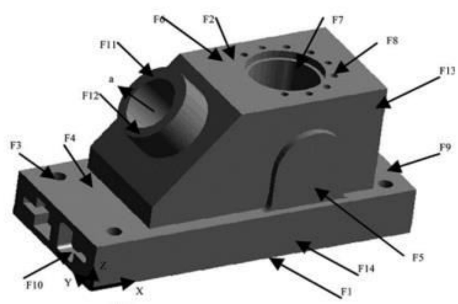
PART ANC-090

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



PART ANC-101

Feature	Description	Operation			Machining Feature
		ID	No	TAD	
F1	Planner Surface	1	37	+Z	M
F2	Planner Surface	1	38	-Z	M
F3	4 Holes replicated	3	39	+Z, -Z	D
F4	A Step	1	40	-Z, +X	M
F5	A Protrusion-rib	1	41	-Z, +Y	M
F6	A Protrusion	1	42	+Z, -Y	M
F7	Compound Hole	3	43	-Z	D
		4	44	-Z	R
		5	45	-Z	B



F8	9 Holes replicated	3	46	-Z	D	
		7	47	-Z	T	
F9	A Step	1	48	-Z, -X	M	
F10	2 Pockets	1	49	+X	M	
F11	A Compound Hole	3	50	-a	D	
		4	51	-a	R	
		5	52	-a	B	
F12	A Pocket	1	53	-X	M	
F13	A Compound Hole	4	54	+X	R	
		5	55	+X	**B**	

Table 2: Operational data for parts.

				Part CDV													
				1	2	1	2	3	4	3	4	3	4	8	8	8	8
			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Part CAI	1		0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	2		0	1	2	2	2	2	2	2	2	2	2	2	2	2	2
	3		0	1	2	2	2	3	3	3	3	3	3	3	3	3	3
	3		0	1	2	2	2	3	3	4	4	4	4	4	4	4	4
	4		0	1	2	2	2	3	4	4	5	5	5	5	5	5	5
	4		0	1	2	2	2	3	4	4	5	5	6	6	6	6	6
	3		0	1	2	2	2	3	4	5	5	6	6	6	6	6	6
	4		0	1	2	2	2	3	4	5	6	6	7	7	7	7	7
	7		0	1	2	2	2	3	4	5	6	6	7	7	7	7	7
	7		0	1	2	2	2	3	4	5	6	6	7	7	7	7	7
Key				LCS			Path followed by SCS										

Table 3: LCS calculation of parts CAI and CDV.

Parts	Complaint Index	LCS	Merger Coefficient	Modified Coefficient	BMIM	BMIMS
Year	1993	1998	2000	2003	2013	2018
A-B	0.65	<u>0.6</u>	0.7208	0.6908	0.4975	0.77
B-C	0.454	0.5	0.5219	0.4813	0.473	0.52
C-D	0.917	1	1	<u>0.9983</u>	0.8	0.85
A-C	<u>0.5</u>	<u>0.6</u>	0.6288	0.5903	0.5521	0.69
A-D	0.55	<u>0.6</u>	0.7045	0.6725	0.3871	0.62
B-D	0.5	0.57	0.5833	0.5525	0.5046	0.67

Table 4: Different similarity coefficient.

Result and Analysis

The algorithm of BMIMS similarity coefficient prove to be useful in identifying part families' similarities, which is based on the concept of applying LCS and SCS for setup sequence. Previously developed similarity coefficients have been used for comparing of results of current similarity index. The previously discussed work in literature review has not been taken into account setup sequencing, as they are based on operation sequencing. For comparison of result, similarity index of each method for four parts are calculated and results shown in Table 4 below.

The major aspects of the calculations are discussed below:

- For parts (CAI & ANC-090) and (CDV & ANC-101) compliant index similarity is 0.5.
- The limitation of the approach is clear from LCS similarity coefficient value (0.6) for parts groups (CAI & CDV), (CAI & ANC-090) and (CAI & ANC-101).
- Merger coefficient 2000 and Modified merger coefficient 2003 shows that parts ANC-090 and ANC-101 have 100% similarity which in fact is not possible due to difference in number of operations with ANC-101 to be on greater side.

Comparing the results of BMIM and BMIMS, it is evident that by utilizing tool changer performing multiple operations instead of single operation the results are more improved and optimized. However, the only diversion is prominent in CDV and ANC-090 parts in which the value is a bit low. This is due to the effect of setup formation as a difference exists in precedence matrix of both parts. Figure 4 shows the comparison between different similarity coefficients. In order for four parts to have BMIMS value same as BMIM, all operation sequence of parts is assumed to be independent setup for each operation. For instance, in manufacturing two parts CAI and CDV can have the same value if there are one operation and one tool for each setup. Average linkage clustering (ALC) has been applied for classification of parts for BMIMS similarity index [11]. ALC methodology groups higher similarity coefficients between parts. To obtain the dendrogram, the method is repeated till grouping of all parts into a family. As per BMIMS dendrogram shown in Figure 5, it can be seen that part ANC-090 and part ANC-101 have 85% similarity whereas parts CAI and part CDV have 77%. Similarity for all parts is 62%.

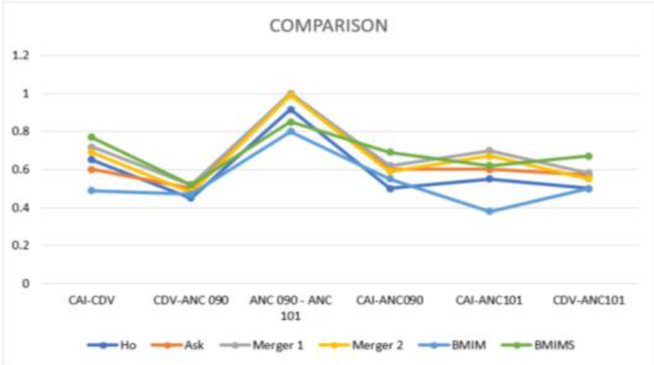


Figure 4: Comparison of different similarity coefficients.

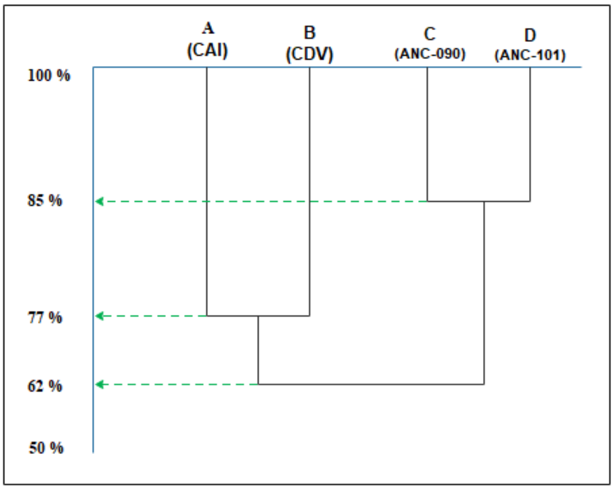


Figure 5: Dendrogram for BMIMS.

Conclusion

The improved methodology presented in this research has shown that proper selection of part families in Reconfigurable Manufacturing Systems plays an important role in enhancing the production efficiency and economy. The selection translates into improved accuracy, tolerance and part similarity index; thus, resulting in less setups required for part production. Another outcome of the research is the calculation of setup sequence based BMIMS similarity coefficient derived by incorporating concepts of LCS and SCS. The results of improvement are shown to validate assumptions and proposed method is compared with previous researches to support the hypothesis. Future work recommendations include the integration of operation time and machining tolerances in developing of part family for improvement of manufacturing quality.

References

1. Abdi MR, Labib AW (2004) Grouping and selecting products: The design key of Reconfigurable Manufacturing Systems (RMSs). Int J Prod Res 42: 521-46.
2. Galan R, Racero J, Eguia I, Garcia JM (2007) A systematic approach for product families formation in Reconfigurable Manufacturing Systems. Robot Comput Integr Manuf 23: 489-502.
3. Kashkoush M, Hoda El Maraghy (2014) Product family formation for reconfigurable assembly systems. CIRP 17: 302-307.
4. Rakesh K, Jain P, Mehta N (2010) A framework for simultaneous recognition of part families and operation groups for driving a reconfigurable manufacturing system. APEM Journal 5: 45-58.
5. Goyal KK, Jain P, Jain M (2013) A comprehensive approach to operation sequence similarity-based part family formation in the reconfigurable manufacturing system. Int J Prod Res 51: 1762-1776.
6. Choobineh F (1988) A framework for the design of cellular manufacturing systems. Int J Prod Res 26: 1161-1172.
7. Tam KY (1990) An operation sequence-based similarity coefficient for part families formations. Journal of Manufacturing Systems 9: 55-68.
8. Irani SA, Huang H (2000) Custom design of facility layouts for multiproduct facilities using layout modules. IEEE Trans Robot Autom 16: 59-267.
9. Askin RG, Zhou M (1998) Formation of independent flow-line cells based on operation requirements and machine capabilities. IEEE Trans 30: 319-329.
10. Baqai A (2010) Co-design of machining processes and kinematic configurations of a reconfigurable product system.
11. Seifoddini H, Wolfe PM (1986) Application of the similarity coefficient method in group technology. IIE Trans 18: 271-277.