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Design of Cellular Manufacturing System by Using New Similarity Coefficient Algorithm to Reduce Total Traveling Time

[1]M. Shunmugasundaram and [2]V. Anbumalar
[1]Vickram College of Engineering, Sivagangai, India
[2]Velammal College of Engineering and Technology, Madurai, India

Abstract: Machine cell formation and part family classification are the most important steps in cellular manufacturing system. Cell Formation (CF) is a complicated process and there are numerous approaches for this purpose such as Array based clustering, agglomerative clustering, mathematical programming, graph partitioning and Nontraditional methods. A new similarity coefficient algorithm is proposed to form the machine cell and part families identification. This Proposed algorithm is tested by using standard problems and compared with other CF method results. The quality of the algorithm is measured by using Grouping efficiency and Grouping efficacy which are most widely used measures the superiority of Cellular Manufacturing Systems (CMS). The proposed algorithm is used to form a manufacturing cells in a power press industry to reducing total travelling time.

Key words: Cell formation, power press industry, Proposed algorithm, CF method, India

INTRODUCTION

Group Technology (GT) is a manufacturing technique which has positive attention in the batch-type production. CMS is one of the important methods of GT in manufacturing the parts. In the design of CMS cells, similar parts are grouped in to families and linked machines in to cells so that one or more part families can be processed within a machine cell. Group the Part in to part families and machines in to machine cell is considered as CF problem. CMS has been considered as an alternative method for conventional batch-type manufacturing where several parts are manufactured sporadically in small lot sizes. The volume of a particular part may be or may not be enough to efficiently use the machine cell (Miltenburg and Zhang, 1991).

CF is a complex process and there are several approaches for this purpose viz., array based clustering, agglomerative clustering, Mathematical programming, Graph partitioning and Nontraditional methods. Similarity coefficient is one of the agglomerative clustering methods is used in the formation of machine cell. A number of researchers or investigators have used various types of similarity and dissimilarity coefficients for determining part families. Rerouting is feasible in CMS, because the machines are capable of doing more than one operation. When a part is rerouted, it impacts the cell performance and also most of the suggested approaches in the literature developed a similarity coefficient based on mathematical equation and calculation; however, during the machine failure these methods tend to ignore alternative routes.

Jaccard similarity coefficient was first used in CF problem by McAuley (1972). Kusiak and chow (1987) has considered alternate process plans and formulated a p-median model to form cells and this concept improves the quality of process (part) families, machine cells and formulated an integer programming model. A multi-period linear programming model to determine the minimum cost loading plan of manufacturing cells and optimum work force for each cell over the planning horizon, which is used in batch production environment, was proposed by Choobineh (1984). Grouping the machines and parts simultaneously based on the tooling requisites of the parts, tools available on the machines and the processing times. The capableness between two machines in processing a set of parts was calculated by using similarity index (Gunaringh and Lashkari, 1991).

Tam (1990) presented a similarity coefficient based on the process sequences similarity of machines and its use for parts grouping is discussed. It also explained that such a coefficient, increased with an advanced clustering algorithm, can improve production by identifying part families that allow machines to intersperse between identical operations of different parts. Seifoddini (1990) suggested identifying the part families and machine cells based on the manufacturing data by using similarity coefficient. Process sequence of parts, pair-wise average manufacturing volume and unit operation time were also

Corresponding Author: M. Shunmugasundaram, Vickram College of Engineering, Sivagangai, India

considered as new manufacture parameters. Alternate process routings of parts were considered to determine the similarity coefficient between machines was proposed by Gupta (1993).

Kamrani and Parsaei (1993) has proposed a dissimilarity measure to form machine cells based on design and manufacturing attributes of parts in a computer integrated production environment. KAMCELL software package was developed. It can be used as a tool for model development and analysis. The process sequences and process times during the assignment process based similarity coefficient was proposed (Moussa and Kamel, 1995). Garbie *et al.* (2005) developed a sub similarity coefficient between the new part and existing manufacturing cells. The first sub similarity coefficient is between the currently manufactured part family and new part. The second sub similarity between the existing machine cell associated with that part family andthe same new part. The result of above said method shows that production cells can become agile systems.Machine utilization and flexibility in the cells based similarity coefficientwas developed to adapt a new part in to CMS. It also considered cell utilization, parts flexibility (system flexibility) and similarity of this part with existing manufacturing cells (Garbie *et al.*, 2005).

Yin and Yasuda (2006) discussed and gave an overview of different similarity coefficients were developed up to date for used to solve the CF problem. From this study, the similarity coefficients based methods are more flexible than other machine cell formation methods; this study tries to explain the reason explicitly. Yin and Yasuda (2005) compared the different similarity coefficients proposed in various papers. For this comparative study, two hundred and fourteen numerical problems were used. The goodness of the proposed machine cell formation solutions were measured by using nine performance measures. The proposed CF solutions are more discriminable. A similarity coefficient based on the number of alternate routings during machine failure and demand changes for multiple periods to design manufacturing cells was developed (Jeon *et al.*, 1998).

Wu and Suzuki (2015) develops a new methodology for a machine CF problem. In first phase, an operation sequence and the number of repeated operations are considered to propose an improved similarity coefficient. In second phase, the following operational aspects:

- Alternative routing
- Machine capacity
- Part demand
- Operation time
- Lot splitting were considered to develop a new decomposed mathematical model

The result of the literature survey indicates that, there were many similarity coefficient methods are used to machine CF and part family classification. Similarity coefficient based cell formation techniques are more exible and easy to implement (Yin and Yasuda, 2006). In this study a new similarity coefficient is proposed to form machine cells for produce the part families. The proposed similarity coefficient is used to identify a machine cells and part families for power press industry by using machine component occurrence matrix.

MATERIALS AND METHODS

Problem definition: The different types of automobile component are manufactured in the power press industry. Job shop arrangement is used to produce those parts. The industry faced some problems like congested in flow and bottlenecks. The industry plans to produce some of automobile parts in a separate plant and hence, the industry wants to form the machine cells to produce that automobile parts. To intend a new algorithm for design the manufacturing cell. To design a manufacturing cell layout for the power press industry by using the proposed algorithm. To compare the performance of the Cellular Manufacturing System (CMS) with the Traditional Manufacturing System (TMS) in terms of total traveling time.

Notations:

- M = No of Machines
- NSC_{ij} = similarity coefficient between machines i and j
- X_{ij} = Number of parts visiting to both machines i and j
- i= 1 to M-1
  j= 1to M
- P= No of Parts
- NSC_{pq} = similarity coefficient between machines p and q
- X_{pq} = Number of parts visiting to both machines p and q
- p= 1 to P-1
- q= 1to P
- η = Grouping Efficiency
- τ = Grouping Efficacy
- ω = Weighted Co-efficient (0.5)
- o = Number of ones in the matrix
- e = Number of exceptional elements
- v = Number of voids
- TMT= Total Material Handling Time
- TPT= Total Processing Time

Table 1: Machine-Parts instance matrix

Part/ Machine	1	2	3	4	5	6	7
1	0	1	0	1	1	1	0
2	1	0	1	0	0	0	0
3	1	0	1	0	0	1	1
4	0	1	0	1	0	1	0
5	1	0	0	0	1	0	1

Table 2: Similarity coefficient between machines

Machine/Machine	1	2	3	4	5
1	0	0	0.25	0.75	0.25
2	--	0	1	0	0.5
3	--	--	0	0.25	0.5
4	--	--	--	0	0
5	--	--	--	--	0

- TTT= Total Traveling Time
- RTMT= Reduction of Material Handling Time
- RTTT= Reduction in Total Traveling Time

New similarity coefficient algorithm: In this study new similarity coefficient algorithm is proposed to form machine cells. This proposed algorithm is experienced by using standard problems and compared with other method results.

Algorithm: Step 1: Calculate the similarity coefficient between machines (rows) by using Eq. 1:

$$NSC_{ij} = \frac{X_{ij}}{X_i}$$

Step 2: Show the calculated similarity coefficients in a similarity matrix. The similarity matrix is symmetric; the upper triangular portion is enough to form the machine cell.

Step 3: Find the largest similarity coefficient from the similarity matrix. The two machine that form the initial cluster based on that largest similarity coefficient.

Step 4: In the same manner, locate the remaining coefficient from the similarity matrix and group the associated machines together.

Step 5: Repeat steps 3 and 4 until all machines are clustered together in to groups.

Step 6: Calculate the similarity coefficient between parts (column) by using Eq. 2:

$$NSC_{pq} = \frac{X_{pq}}{X_p}$$

Step 7: Show the calculated similarity coefficients in a similarity matrix. The similarity matrix is symmetric; the upper triangular portion is enough to identify the part family.

Table 3: Rearranged matrix after applying Similarity coefficient for row

Part/Machine	1	2	3	4	5	6	7
1	0	1	0	1	1	1	0
4	0	1	0	1	0	1	0
2	1	0	1	0	0	0	0
3	1	0	1	0	0	1	1
5	1	0	0	0	1	0	1

Table 4: Similarity coefficient between parts

Part/Part	1	2	3	4	5	6	7
1	0	0	0.67	0	0.33	0.33	0.67
2	--	0	0	1	0.5	1	0
3	--	--	0	0	0	0.5	0.5
4	--	--	--	0	0.5	1	0
5	--	--	--	--	0	0.5	0.5
6	--	--	--	--	--	0	0.33
7	--	--	--	--	--	--	0

Step 8: Find the largest similarity coefficient from the similarity matrix. The two machine that form the initial cluster based on that largest similarity coefficient.

Step 9: In the same manner, locate the remaining coefficient from the similarity matrix and group the associated parts together to form part family.

Step 10: Repeat steps 8 and 9 until all parts are clustered together in to part family.

Illustrated example: The proposed approach is going to explain by using data set with the size (5×7) from literature has been selected (King and Nakornchai, 1982) which is a machine part occurrence matrix with (zero-one) entries. Where the entry one refers to that specific part need to operate on specific machine while zero otherwise. This matrix consists of 5 machines to manufacturing 7 parts with different process sequences. The incidence matrix between machines and parts is presented in Table 1.

Calculate the similarity coefficient between machines (rows) using the formula, $NSC_{ij}= x_{ij}/x_i$ is used calculated coefficients of above matrix. Only the upper triangular portion is necessary to cluster the machines. Similarity coefficients are shown in Table 2.

Find the largest similarity coefficient from the similarity matrix. The two machine that form the initial cluster based on that largest similarity coefficient. In the same manner, locate the remaining coefficient from the similarity matrix and group the associated machines together. Repeat steps until all machines are clustered together in to two groups. Rearranged matrix after applying similarity coefficient is shown in Table 3.

Now, calculate the similarity coefficient between parts (column) using the formula, $NSC_{pq}= x_{pq}/x_p$ is used calculated coefficients of above matrix. Only the upper triangular portion is necessary to cluster the parts. Similarity coefficients are shown in Table 4.

Find the largest similarity coefficient from the similarity matrix. The two machine that form the initial cluster based on that largest similarity coefficient.. In the same manner, locate the remaining coefficient from the similarity matrix and group the associated machines

Table 5: Result of new similarity coefficient

Part/machine	1	3	7	2	4	6	5
1	0	0	0	1	1	1	1
4	0	0	0	1	1	1	0
2	1	1	0	0	0	0	0
3	1	1	1	0	0	1	0
5	1	0	1	0	0	0	1

together. Repeat steps until all parts are clustered together in to two groups. Rearranged machine part occurrence matrix is shown in Table 5.

Performance measures: There is a need to develop performance measure or criteria to compare the quality of the solutions obtain by different algorithms. This study two performance measure have been used to find the quality of the solution.

Exceptional elements (e): The numbers of positive entries in the outside of the manufacturing cell of the final machine part occurrence matrix is called as eexceptional elements.

Voids (v): Number of zero's which are located inside the manufacturing cell of the final machine part occurrence matrix are called voids.

Grouping efficiency (η): Grouping Efficiency is quality measures in cellular manufacturing system. It was developed by Chandrasekharan and Rajagopalan (1986a, b). It is used to evaluate the final cell obtained by different CF algorithms. The quality of solution depends on number of ones outside the cell and number of zero's inside the cell. Grouping efficiency is calculated as a weighted average of the two efficiencies η_1 and η_2.
Where:

$$\eta_1 = (o-e)/(o-e+v)$$

$$\eta_2 = (MP-o-v)/(MP-o-v+e)$$

Grouping efficacy (τ): The grouping efficacy is used to measure the effectiveness of the proposed cell. It was proposed by Murugan and Selladurai (2007) Kumar and Chandrasekaran (1990). The size of the matrix is not affected the grouping efficacy. It is only depending upon the exceptional elements and voids of the cell.

$$\tau = (1-\varphi)/(1+\varphi)$$

Where:

$$\varphi = e/o$$

$$\varphi = e/o$$

RESULTS AND DISCUSSION

The quality of proposed algorithm is compared with a set of 16 problems were selected from the literature, which is used in many comparative studies. Comparisons of the above said method with other CF methods are shown in the Table 6 and 7. The grouping efficiency and efficacy values of proposed method are improved or equal in all instances. From Table 6 and 7, it is stated that the proposed method produces same (maximum value for those problems) efficiency and efficacy value in10 instances where as in 6 instances it outperforms other established techniques. It shows that the performance of the proposed technique against best CF methods of literature which clearly depicts that equal or improved performance over the other techniques.

Case study: The process sequence of automobile components is collected from industry namely SUNPRESSING (P) LTD, F-2&3 SIDCO Industrial Estate, K. Pudur, Madurai-07, India. It is a subcontracting company for Ashok Leyland, TAFE, TVS, BRIDGE STONE, NISSON etc. It is an automotive components manufacturing company. Job shop layout is used in the above said industry to produce automobile parts. This industry has different types of press tools, lathe, welding machines, grinding machines and powder coating machines. Sixty different types of parts were manufactured in this industry.

Out of that 16 parts were selected to manufacture in separate plant which is processed through 5-10 steps before it is finished. Machines are used to produce the parts are listed in Table 8.

The components sequence is collected and Machine component Occurrence Matrix (MOIM) is prepared with binary data and shown in Table 9. The proposed algorithm is applied in the Machine component Matrix. The result of the real time MOIM was shown in Table 10.

Table 6: Grouping efficiency of different methods

Source	ZODIAC	GRAPHICS	correlation analysis	ART1	Principal Component Analysis (PCA)	self-organizing map	GA	NEW SLC
(Chan and Milner, 1982)	96	96	--	--	--	--	--	96.00
(King and Nakornchai, 1982)	85.62	85.62	--	--	--	--	--	85.62
(Asktn and Subramantan, 1987)	82.54	82.54	--	--	--	--	--	83.73**
(Mosier and Taube, 1985)	85.29	85.29	--	--	--	--	--	85.29
(Yang and Yang, 2008)	--	--	--	100	--	--	--	100.00
(Hachicha *et al*., 2008)	--	--	86.9	--	--	--	--	87.82**
(Chandrasekharan and Rajagopalan, 1989)	95.83	95.83	--	--	--	--	--	95.83
(Chen and Cheng, 1995)	--	--	--	83.11	--	--	--	83.94**
(Hachicha *et al*., 2008)	--	--	--	--	86.08	--	--	86.08
(Pradhan and Mishra, 2015)	--	--	--	--	--	96.29	--	96.29
(Hachicho *et al*., 2008)	86.08	86.08	--	--	--	--	--	86.08
(Yang and Yang, 2008)	--	--	--	97.66	--	--	--	97.66
(Yang and Yang, 2008)	--	--	--	90.68	--	--	--	90.68
(Chandrasekharan and Rajagopalan, 1989)	100	100	--	--	--	--	100	100.00
(Waghodekar and Sahu, 1984)	72.2	74.51	--	--	--	--	62.5	81.25**
(Kusiak and Chow, 1987)	65.01	76.81	--	--	--	--	50	78.59**

Table 7: Grouping efficacy of different methods

Source	ZODIAC	GRAPHICS	correlation analysis	ART1	Principal Component Analysis (PCA)	Self-organizing map	GA	NEW SLC
(Chan and Milner, 1982)	92.00	92.00	--	--	--	--	--	92.00
(King and Nakornchai, 1982)	73.68	73.68	--	--	--	--	--	73.68
(Asktn and Subramantan, 1987)	64.36	64.36	--	--	--	--	--	66.67**
(Mosier and Taube, 1985)	70.59	70.59	--	--	--	--	--	70.59
(Yang and Yang, 2008)	--	--	--	100	--	--	--	100.00
(Hachicha *et al*., 2008)	--	--	71.28	--	--	--	--	73.12**
(Chandrasekharan and Rajagopalan, 1989)	85.24	85.24	--	--	--	--	--	85.25**
(Chen and Cheng, 1995)	--	--	--	63.08	--	--	--	63.24**
(Hachicha *et al*., 2008)	--	--	--	--	70.37	--	--	70.37
(Tribikram and Satya, 2015)	--	--	--	--	--	90.00	--	90.00
(Hachicha *et al*., 2008)	70.37	70.37	--	--	--	--	--	70.37
(Yang and Yang, 2008)	--	--	--	87.10	--	--	--	87.10
(Yang and Yang, 2008)	--	--	--	00.00	--	--	--	100.00
(Chandrasekharan and Rajagopalan, 1989)	100.00	100.00	--	--	--	--	100	100.00
(Waghodekar and Sahu, 1984)	56.52	60.85	--	--	--	--	62.5	63.50**
(Kusiak and Chow, 1987)	39.13	53.12	--	--	--	--	50	57.58**

** Proposed method showing higher efficacy

Table 8: Details of machines and parts

Machines	Descriptions	Parts	Descriptions
M1	Hydraulic Press 80 Tonnes	P1	Assembly support foot throttle
M2	Hydraulic Press 150 Tonnes	P2	Green cap molding
M3	Hydraulic press 50 Tonnes	P3	Taper packing
M4	Hydraulic Press 10 Tonnes	P4	Packing Plate
M5	Hydraulic Press 30 tonnes	P5	BOY00631Foot rest
M6	Hydraulic press 100 Tonne	P6	Fuel Box PlateB9Y00301
M7	Hydraulic Press 350 Tonnes	P7	Fuel Tank Plate
M8	Hydraulic Press 250Tonnes	P8	Do cross member
M9	Hydraulic Press 40 Tonnes	P9	F4205214Brake Pedal
M10	Pneumatic Press 50 tonnes	P10	CAP modeling bracket
M11	Pneumatic Press 500 Tonnes	P11	Box flitching
M12	Hydraulic Press 110 Tonnes	P12	TVS4411Bar2 Wheel cup
M13	Pneumatic Press 1100 Tonnes	P13	AL Component F 8027114
M14	Hydraulic Press 20 Tonnes	P14	Tafe cap 2CUP M02
M15	Hydraulic Press 160 Tonnes	P15	Bracket cap mounting
M16	Pneumatic Press 80 Tonnes	P16	Cap mounting bracket

Table 9: Machine Component Occurrence Matrix (MOIM)

Parts/machine	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0	1	0	1	0	0	1	0	0	0	1	1	1	0	0	0
2	0	1	0	1	1	0	0	0	0	0	1	1	1	0	0	0
3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4	0	1	0	1	1	0	1	0	1	0	1	1	0	0	0	0

Table 9: Continue

Parts/machine	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
5	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0
6	0	1	0	1	1	0	1	0	1	0	1	0	1	0	0	0
7	0	0	1	1	0	0	0	0	0	1	1	0	0	0	0	0
8	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0
9	1	0	0	0	0	0	0	0	1	0	1	1	0	1	0	0
10	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
12	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0
13	1	0	1	0	0	1	0	1	0	1	0	0	0	1	1	1
14	1	0	1	0	0	1	0	0	0	1	0	0	1	1	1	1
15	1	0	1	0	0	1	0	0	0	1	0	0	0	0	1	0
16	1	0	1	0	0	1	0	1	0	1	0	0	0	1	0	1

Table 10: Cell formation result by using new similarity coefficient

Parts / Machines	3	6	10	1	14	16	8	15	13	11	9	7	4	5	2	12
13	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
16	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
14	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0
15	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0
7	1	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0
4	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
6	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0
12	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
9	0	0	0	1	1	0	0	0	0	1	1	0	0	0	0	1
2	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	1
8	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1
1	0	0	0	0	0	0	0	0	1	0	0	1	1	0	1	1
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
10	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1
3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
5	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0

Table 11: Comparison between Cellular Manufacturing System (CMS) with Traditional Manufacturing System (TMS)

PART NO.	TMS			CMS				
	TPT MIN	TMT MIN	TTT MIN	TPT MIN	TMT MIN	TTT MIN	% OF RTMT	% OF RTTT
1	15	25.2	40.2	15	15.5	30.5	38.49	24.13
2	12	10.48	22.48	12	6.23	18.23	40.55	18.91
3	17.5	14.21	31.71	17.5	10.42	27.92	26.67	11.95
4	9.4	6.9	16.3	9.4	5.8	15.2	15.94	6.75
5	7	9.5	16.5	7	5.92	12.92	37.68	21.70
6	13	16.5	29.5	13	10.28	23.28	37.69	21.08
7	5.5	8.2	13.7	5.5	6.15	11.65	25	14.96
8	2.08	14.3	16.38	2.08	11.08	13.16	22.52	19.66
9	4.5	17.2	21.7	4.5	12.49	16.99	27.38	21.71
10	18.04	15.47	33.51	18.04	10.37	28.41	32.97	15.22
11	6.72	13.8	20.52	6.72	9.85	16.57	28.62	19.25
12	13.67	16.28	29.95	13.67	12.17	25.84	25.25	13.72
13	20.04	18.64	38.68	20.04	14.62	34.66	21.57	10.39
14	9.77	15.52	25.29	9.77	13.41	23.18	13.59	8.34
15	16.08	17.28	33.36	16.08	12.82	28.9	25.81	13.37
16	14.42	16.35	30.77	14.42	10.62	25.04	35.05	18.62

CONCLUSION

The proposed New Similarity Coefficient algorithm is simple, easy to implement and understand. The result of the proposed algorithm is proportionate to the CF problems which is taken from literature. This similarity coefficient yields good or better results than some available algorithms for standard problems. Therefore, this method is one of the promising methods in CMS and it is also applied to real time problem. The proposed algorithm gives 76.86% of grouping efficiency and 70.66% of grouping efficacy of the case study.

The proposed Cellular Manufacturing System (CMS) and Traditional Manufacturing System (TMS) are compared based on total travelling time and total material movement. Table 11 shows that, the proposed CMS is reduced total material handling time in 28.42% and total traveling time in 16.35%. This gives to a quick response than the TMS. Proposed cellular manufacturing system reduce the material handling time, the total traveling time and improved accuracy in the production, which gives good customer satisfaction and more competitive business capability.

In this research, only operation sequence is considered as basis. Further research may include operation time, alternative process routings and volume of the parts. Multi objective optimization can also be attempted for part family formation in future.

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