Journal of Technology Research (JTR)
Volume 2, Issue 1, (2024), pp 039-046, ISSN 3005-639X

Use of Rank Order Clustering Algorithm for Part-Machine Grouping in Cellular Manufacturing

Jamal Ben Sasi[1*], Mohammed N. Traina[2], Saleh Amaitik[1].

[1]Misurata University, Misurata, Libya.

[2]College of Industrial Technology, Misurata, Libya.

*Corresponding author email: Jamal.bensasi@eng.misuratau.edu.ly

Received: 01-05-2024 | Accepted: 25-05-2024 | Available online: 15-06-2024 | DOI:10.26629/jtr.2024.05

ABSTRACT

The Rank Order Clustering (ROC) algorithm, developed by J.R. King, has undergone significant advancements over the last five decades and is widely utilized in diverse fields, including manufacturing, for the grouping of machines and parts. This study investigates the utilization of the ROC algorithm in cellular manufacturing systems (CMS) to optimize the creation of machine cells and part families, with the objective of enhancing production efficiency. The research presents a comprehensive analysis employing a binary part-machine matrix and utilizes Microsoft Excel for data manipulation. By iteratively rearranging rows and columns based on binary values, the ROC algorithm effectively clusters machines and parts into intersecting machine cells and non-intersecting part families. A case study involving a 16×10 binary part-machine matrix demonstrates the practical implementation of the ROC algorithm. The findings indicate that while the ROC algorithm provides a structured approach to cell formation, its effectiveness may vary. This research highlights the potential of the ROC algorithm in improving manufacturing layout optimization and process management, thereby it paving the way for further advancements in manufacturing systems.

Keywords: Cellular Manufacturing System (CMS), Clustering Algorithm, Group Technology (GT), Rank-Order Clustering (ROC), Parts - Machines, Matrix.

استخدام خوارزمية التصنيف بالترتيب الرتبي لتجميع الأجزاء والآلات في التصنيع الخلوي

جمال بن ناجي[1]، محمد نجيب طرينة[2]، صالح محمد معيتيق[3]

[1] جامعة مصراتة، مصراتة، ليبيا

[2]كلية التقنية الصناعية، مصراتة، ليبيا

ملخـــــــص البحـــــــث

خضعت خوارزمية تجميع ترتيب الرتب (ROC)، التي طورها جيه آر كينج J.R (King. (، لتطورات كبيرة على مدى العقود الخمسة الماضية، ويتم استخدامها الن على نطاق واسع في مجالات متنوعة، بما في ذلك التصنيع، لتجميع اللات والأجزاء. تبحث هذه الدراسة في استخدام خوارزمية ROC في أنظمة التصنيع الخلوية (CMS) لتحسين إنشاء خلايا اللة وعائلات الأجزاء، بهدف تعزيز كفاءة الإنتاج. يقدم البحث تحليلًا شاملًا يستخدم مصفوفة ثنائية الأجزاء ويستخدم برنامج **Excel Microsoft** لمعالجة البيانات. من خلال إعادة ترتيب الصفوف والأعمدة بشكل متكرر بناءً على القيم الثنائية،

تقوم خوارزمية ROC بتجميع اللات والأجزاء بشكل فعال في خلايا آلة متقاطعة وعائلات أجزاء غير متقاطعة. توضح دراسة الحالة التي تتضمن مصفوفة جزء اللة الثنائية 10*16 التنفيذ العملي لخوارزمية. ROC تشير النتائج إلى أنه على الرغم من أن خوارزمية ROC توفر نهجًا منظمًا لتكوين الخلايا، إلا أن فعاليتها قد تختلف. يسلط هذا البحث الضوء على إمكانات خوارزمية ROC في تحسين تخطيط التصنيع وإدارة العمليات، وبالتالي تمهيد الطريق لمزيد من التقدم في أنظمة التصنيع

الكلمات الدالة: نظام التصنيع الخلوي، تكنولوجيا المجموعات، خوارزمية التصنيف بالترتيب، خوارزميات التجميع، مصفوفة الأجزاء– الآلات.

1. INTRODUCTION

Most Over fifty years the ROC *technique* has matured with its implementation in many domains. J.R. King, first introduced the notion of ROC in the domain of manufacturing for clustering machines into machine cells simultaneous formation of part families that need to be assigned to one of the machine clusters. Ideally each part and its part family have a unique assignment when it comes to assigning to one and only one cell while getting completely processed inside the assigned machine cell. A machine cell is constituted of all those machines that are part of the machine cell. However, this historic ROC algorithmic method has since been applied in various domains–image processing.[1]

This research work is an extension of the well-known rank order clustering algorithm for group technology problems. The present method uses the ROC algorithm for obtaining a set of intersecting machine cells and non-intersecting part families.

Generally, the cell formation problems are represented in a matrix namely "machine-part incident matrix". Its elements are either 0 or 1. Parts are arranged in rows and machines are in columns in the incidence matrix.[2]

Clustering is terminated when all the surviving cells are non-intersecting or when a single group is formed. In the latter case, the number of cells is determined on the basis of a suitable decision criterion is identified at the appropriate hierarchical level in the clustering process. The manufacturing industries are looking to enhance the operation presents in the production lines for obtaining the optimal management of production rates. The performance of the production directly depends on the installed machine in the line of production. If the machine is presented in the production lines not entirely predictable and reliable, it will arise in the analysis of the maintainability and reliability to deliver optimal strategies.[2] GT, is a processing philosophy based on the principle that similar products should be processed similarly.[2] The basic idea of GT, is to decompose a manufacturing system into subsystems. It reduces production lead time, work-in process, labor, tooling, rework,scrap material, set-up time, delivery time, and paperwork. The idea behind GT, is to improve efficiency by exploiting similarities. The application of GT influences time, power of operation, work in processing (WIP), inventory, material handling, job satisfaction, fixture, set up time, required space, quality, finished product and labor cost. This concept has been successfully employed in cellular manufacturing in which parts with similar processing requirements are identified and grouped into part families, and then machines with different processing capacities are placed within a cell [2] . The main objective of the research is to offer optimal creation, of how to obtain a set of intersecting machine cells and non-intersecting part families in Product flow for cellular manufacturing by using ROC algorithm.

1.1 An Overview about Rank Order Clustering Algorithm

At present, the world is hugely competitive; therefore, manufacturing firms face pressure to satisfy ever-changing customer necessities rapidly. In the current, the survival of the company in the business environment is difficult due to highly competitive [3]. ROC algorithm is also called as production flow algorithm is used to create cells to accommodate part numbers to specific machines. Although in manufacturing, machines are capable of running different part numbers, it is important to route them to create a specific flow of part numbers through assigned machines. This also improves productivity and eliminates cross line flow. ROC algorithm functions as follows:

a. The clustering algorithm: [1]

Step 1: Create an n*m matrix bij (binary number for part and machine). Where, m is machines, and n is parts.

Step2: For each row of i compute, Σn bij*2n-j

Step 3: Rearrange the rows in descending order based on the computed numbers.

Step4: For each column of j compute, Σm bij*2m-j

Step 5: Rearrange the columns in descending order based on the computed numbers.

Step 6: Repeat step 1 until there is no change observed in step 3 and 5.

Step 7: Stop.

This algorithm works well in an ideal manufacturing environment where all the products have the same value and all machines run exactly the same. In the real world it is highly unlikely where the entire product has the same weight or all machines behave exactly in a similar manner. [4]

In a ROC algorithm, rather than specifying a constant value for the number of clusters, a distance threshold is considered, which determines the number of clusters in a certain dataset. Selecting the threshold C for determining the number of clusters in a dataset is one of the most difficult issues in data clustering. In practice, it cannot be assumed that the actual number of clusters is predetermined, so this algorithm is evaluated in several effective values of C and the best result is reported. [5]

GT, is an important technique in the planning of manufacture that allows the advantages of flow production organization to be obtained in what otherwise would be jobbing or batch manufacture. The approach is to arrange separate machine groups with appropriate internal group layout to suit the production of specific component families, formed in accordance with the similarity of operations that are to be performed on them. The most important reason for manufacturing cells to be established is to reduce throughput time. The MLT of a part is defined as follows: [6]

MLT = Set-up Time +Processing Time + Material Handling Time+ Waiting Time, Total MLT, is the total manufacturing lead time needed to finish all of the operations on all of the parts. The MLT can be reduced by reducing these individual times, as explained below. The set-up time reduction is realized by automatic tool changing devices and/or by bringing similar parts together that are processed by the same machine, exploiting their similarities

in design and manufacture. The processing time reduction is realized by improving machine speeds and/or routing parts to machines having shorter processing times for those parts if alternative machining is possible. The material handling time reduction is realized by improving material handling devices and/or bringing machines together that process the same parts. The first aspects of all of the aforementioned reductions are under the responsibilities of mechanical and/or electrical engineers, while industrial (production) engineers are responsible for the second aspects. Waiting time is a variable dependent on set-up, processing, and material handling times, and therefore cannot be set independently. Consequently, the waiting time reduction can only be realized by altering production/process planning decisions, e.g. using different scheduling rules, and it is the responsibility of industrial (production) engineers. The importance of the waiting time reduction is not only that it can reduce the MLT but also that it reduces WIP.

1.2 Literature Review

There are many studies that have dealt within this subject area, and the following is a summary of some of these studies:

Amruthnath and Gupta (2016) introduced a methodology that incorporates real-time manufacturing data into the creation of product flow for cellular manufacturing based on weight. Their modified rank order clustering (MROC) method improved upon the traditional ROC algorithm by creating load-balanced cells and minimizing bottlenecks, demonstrating robustness and efficiency in cell formation [1]

King (1980) compared three methods single linkage cluster analysis, bond energy, and ROC—in the context of machine-component matrix regrouping for production flow analysis. King's study highlighted the distinct advantages of the ROC method, particularly its ease in handling exceptional elements and bottleneck machines, which are common challenges in practical manufacturing scenarios [7].

Padmakar (2012) investigated the impact of cellular manufacturing techniques on an existing plant layout with a focus on reducing material handling costs. By adopting an improved layout through cellular manufacturing, Padmakar achieved a 22.81% reduction in material handling costs. This optimization not only saved resources but also enhanced the number of movements per day and other process activities, ultimately reducing cycle time and increasing overall productivity.[8]

Kumara and Singhb (2020) conducted a study that applied the ROC algorithm in conjunction with imperialist competitive optimization for cost and reliability, availability, and maintainability (RAM) analysis across different industrial sectors. Their findings indicated that the combined approach yielded significant improvements in the formation of manufacturing cells, addressing cost and RAM considerations effectively. [3]

Selim and Al-Ahmari (2010) explored the integration of genetic algorithms with ROC to enhance cell formation in CMS. Their hybrid approach provided a more flexible and efficient means of addressing the complexities involved in machine-part grouping, demonstrating superior performance in comparison to traditional methods. [6]

Raj and Singh (2021) proposed a novel approach combining ROC with machine learning techniques for predictive maintenance in CMS. By leveraging historical data and predictive algorithms, their method aimed to anticipate machine failures and optimize cell formation dynamically, thus enhancing the reliability and efficiency of manufacturing processes.

These studies collectively underscore the versatility and effectiveness of the ROC algorithm and its variations in addressing the challenges of cell formation in cellular manufacturing systems. The ongoing advancements and hybrid approaches continue to push the boundaries of optimization in manufacturing layouts, contributing to significant improvements in productivity, cost efficiency, and overall operational performance.

2. MATERIALS AND METHODS

This the methodology used in this paper is an analysis of data related to the research topic. Hereby, Microsoft Excel Program was applied to the data given. Clustering Algorithm is adopted in this research work as the solution methodology, which is theoretically and mathematically simple practiced.

GT, is used in CMS. Groups of parts and machines are organized into different cells where manufacturing and production takes place. Among the various methods of cell formation, ROC algorithm is chosen in this research work, which illustrated limited and Satisfactory results.

2.1 Case Study

A matrix with the size (16×10), which is a binary part- machine matrix with (zero- one) entries. Where the entry one refers to the specific part required to do an operation on a specific machine while zero otherwise. It is composed of 16 types of parts and 10 types of machines with different process plans. For this matrix, the number of cells occupied by the number (1) equals 38 cells. The incidence matrix between machines and parts is presented in Table 1. In our case, there are 16 parts (labeled 01 to 16) & 10 machines (labeled 1 to 10). so, the part- machine incidence matrix is as shown in Table 1.

Table 1. Initial part-machine incidence matrix.

Step 0 (origin Matrix)										
	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
P1		1	1							1
P2				1	1					
P3		1	1			1				
P4	1				1					
P5			1			1				1
P6		1				1				
P7			1			1				
P8								1	1	
P9	1			1						
P10							1	1	1	
P11	1			1						
P12							1		1	
P13							1	1		
P14							1		1	
P15				1	1			1		
P16	1			1	1					

The rank order clustering method assumed that the algorithm would normally begin with the original machine-component matrix but it does not matter, the procedure is iterative and it is possible to start with any rearranged form of the matrix.

The ROC algorithm rearranges rows and columns in an iterative manner. will, ultimately, and in a finite number of steps, produce a matrix in which both columns and rows are arranged in order of decreasing value when read as binary words. The approach is perhaps best illustrated with reference to the example problem once again. Table 2. shows the initial matrix but now with the binary weights associated with the column entries in each row. As shown on Table 2., the first row as a binary word is 111, which has the decimal equivalent of 1 x 1+ 1 x 128 + 1 x 256=
385. The other rows are evaluated in a similar manner and then rearranged in increasing rank order to produce the results.

Table 2. Second iteration of initial matrix.

Step 1	512	256	128	64	32	16	8	4	2	1	Binary	
	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	Dec.Equ.	Rank
P1		1	1							1	385	6
P2				1	1						96	11
P3		1	1			1					400	5
P4	1				1						544	4
P5			1			1				1	145	8
P6		1				1					272	7
P7			1			1					144	9
P8								1	1		6	16
P9	1			1							576	2
P10							1	1	1		14	12
P11	1			1							576	3
P12							1		1		10	14
P13							1	1			12	13
P14							1		1		10	15
P15				1	1			1			100	10
P16	1			1	1						608	1

By repeated operation of this pairwise word comparison processes any set of binary words, and may thus be ranked in order of decreasing binary value.

Table 3. Third iteration of initial matrix.

Step 2	512	256	128	64	32	16	8	4	2	1	Binary
	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	Dec.Equ.
P16	1			1	1						608
P9	1			1							576
P11	1			1							576
P4	1				1						544
P3		1	1			1					400
P1		1	1							1	385
P6		1				1					272
P5			1			1				1	145
P7			1			1					144
P15				1	1			1			100
P2				1	1						96
P10							1	1	1		14
P13							1	1			12
P12							1		1		10
P14							1		1		10
P8								1	1		6

For applying ROC, the row weights (binary equivalent) have been calculated and then the rows or machines are ranked according to the of weights (Table 3). And decreasing order then, columns are weighted and re-arranged.

Table 4. Fourth iteration of initial matrix.

Step 3											
	M1	M4	M5	M2	M3	M6	M10	M8	M7	M9	Binary
P16	1	1	1								32,768
P9	1	1									16,384
P11	1	1									8,192
P4	1		1								4,096
P3				1	1	1					2,048
P1				1	1		1				1,024
P6				1		1					512
P5					1	1	1				256
P7					1	1					128
P15		1	1					1			64
P2		1	1								32
P10								1	1	1	16
P13								1	1		8
P12									1	1	4
P14									1	1	2
P8								1		1	1
Dec.Equ.	61440	57440	36960	3584	3456	2944	1280	89	30	23	

A block diagonal matrix is one where boxes on the main diagonal contain ‘0’s and ‘1’s, while the off diagonal boxes contain all ‘0’s. In this procedure, the rows and columns are considered as binary strings, left to right for rows, and top to bottom for columns. ROC carried out in steps given below:

In each row of matrix read the series of 1’s & 0’s from left to right as a binary number, Rank the row in order of decreasing value.

Table 5. Fifth iteration of initial matrix.

Step 4	512	256	128	64	32	16	8	4	2	1	Binary
	M1	M4	M5	M2	M3	M6	M10	M8	M7	M9	Dec.Equ.
P16	1	1	1								896
P9	1	1									768
P11	1	1									768
P4	1		1								640
P15		1	1					1			388
P2		1	1								384
P3				1	1	1					112
P1				1	1		1				104
P6				1		1					80
P5					1	1	1				56
P7					1	1					48
P10								1	1	1	7
P13								1	1		6
P8								1		1	5
P12									1	1	3
P14									1	1	3

1. In case of tie, rank the rows in the same order as they appear in the current matrix.
2. Numbering from top to bottom is the current order of rows the same as the rank order determined in the previous step. If yes, go to step 7, if no, go to the following step.
3. Reorder the rows in part-machine incidence matrix by listing them in decreasing rank order starting from the top.

The process is repeated on the matrix of Table 2 .but this time on the columns. The binary weights for each row entry in each column are shown in Table 4., thus, the first column entry 1111 has the decimal equivalent value of 1 x 32,768 + 1 x

16,384 1 + x 8,192 +1 x 4,096= 61,440

Table 6. Sixth iteration of initial matrix.

Step 5											
	M1	M4	M5	M8	M2	M3	M6	M10	M7	M9	Binary
P16	1	1	1								32,768
P9	1	1									16,384
P11	1	1									8,192
P4	1		1								4,096
P15		1	1	1							2,048
P2		1	1								1,024
P3					1	1	1				512
P1					1	1		1			256
P6					1		1				128
P5						1	1	1			64
P7						1	1				32
P10				1					1	1	16
P13				1					1		8
P8				1						1	4
P12									1	1	2
P14									1	1	1
Dec.Equ.	61440	60416	39936	2076	896	864	736	320	27	23	

The other column values are similarly determined. The columns are now rearranged in increasing rank order to give the matrix shown in Table 5. The process is repeated once more, this time on the rows of the matrix of Table 6., Table 7., and Table 8., it will be seen that the rows, as well as the columns, are both in rank order. This indicates that this is the last iteration and hence Table 9., shows the resulting machine - part groupings.

Table 7. Seventh iteration of initial matrix.

Step 6	512	256	128	64	32	16	8	4	2	1	Binary
	M1	M4	M5	M8	M2	M3	M6	M10	M7	M9	Dec.Equ.
P16	1	1	1								896
P9	1	1									768
P11	1	1									768
P4	1		1								640
P15		1	1	1							448
P2		1	1								384
P10				1					1	1	67
P13				1					1		66
P8				1						1	65
P3					1	1	1				56
P1					1	1		1			52
P6					1		1				40
P5						1	1	1			28
P7						1	1				24
P12									1	1	3
P14									1	1	3

The above illustrates the essential concept of the approach. In operation however, the ranking process is performed without actually determining the value of the binary word representing the cell entries.

Table 8. Eighth iteration of initial matrix.

Step 7	M1	M4	M5	M8	M7	M9	M2	M3	M6	M10	Binary
P16	1	1	1								32,768
P9	1	1									16,384
P11	1	1									8,192
P4	1		1								4,096
P15		1	1	1							2,048
P2		1	1								1,024
P10				1	1	1					512
P13				1	1						256
P8				1		1					128
P3							1	1	1		64
P1							1	1		1	32
P6							1		1		16
P5								1	1	1	8
P7								1	1		4
P12					1	1					2
P14					1	1					1
Dec.Equ.	61440	60416	39936	2944	771	643	112	108	92	40	

In each column of the matrix read the series of 1's & 0's from the top to bottom as a binary number. Rank the column in order of decreasing value. In case of tie, rank the rows in the same order as they appear in the current matrix.

4. Numbering from left to right is current order of column the same as the rank order.

Table 9. Ninth iteration of initial matrix.

Step 8	512	256	128	64	32	16	8	4	2	1	Binary
	M1	M4	M5	M8	M7	M9	M2	M3	M6	M10	Dec.Equ.
P16	1	1	1								896
P9	1	1									768
P11	1	1									768
P4	1		1								640
P15		1	1	1							448
P2		1	1								384
P10				1	1	1					112
P13				1	1						96
P8				1		1					80
P12					1	1					48
P14					1	1					48
P3							1	1	1		14
P1							1	1		1	13
P6							1		1		10
P5								1	1	1	7
P7								1	1		6

5. determined in the previous step if yes, go to step 7, if no, go to the following step.
6. Re-order the columns in the part-machine incidence matrix by listing them in decreasing rank order starting from the left column, go to step 1.
7. Stop.

Based on the data as shown in table 10., the part families and machine groups are as

follows: (1) P16, P9, P11, P4, P15, P2, and M1, M4, M5. (2) P10, P13, P8, P12, P14, and M8, M7, M9. (3) P3, P1, P6, P5, P7, and M2, M3, M6, M10. Note: Part P15 in-group 1 requires processing in machine group 2.

Table 10. Block diagonal matrix.

Step 9	M1	M4	M5	M8	M7	M9	M2	M3	M6	M10	Binary
P16	1	1	1								32,768
P9	1	1									16,384
P11	1	1									8,192
P4	1		1								4,096
P15		1	1	1							2,048
P2		1	1								1,024
P10				1	1	1					512
P13				1	1						256
P8				1		1					128
P12					1	1					64
P14					1	1					32
P3							1	1	1		16
P1							1	1		1	8
P6							1		1		4
P5								1	1	1	2
P7								1	1		1
Dec.Equ.	61440	60416	39936	2944	864	736	28	27	23	10	

3. CONCLUSIONS

This research work focused on the implementation of GT, in CMS, to optimize production processes by efficiently organizing parts and machines into cells. The chosen approach involved using Microsoft Excel to analyze data, with a specific emphasis on the ROC algorithm. By conducting a thorough case study using a binary part-machine matrix, the ROC algorithm was repeatedly applied to rearrange rows and columns based on binary values. This iterative process resulted as shown in table 10, titled as block diagonal matrix that represented groupings of machines and parts. While the outcomes varied between limited and satisfactory, the iterative nature of ROC highlighted its potential in effectively organizing manufacturing layouts. Overall, this research contributes to the understanding of how methodologies like ROC can enhance productivity and efficiency in manufacturing systems. Further exploration and refinement of ROC algorithm could lead to significant advancements in manufacturing optimization and process management, benefiting industries that strive for increased efficiency.

4. REFERENCES

[1] Amruthnath N, Gupta T. Modified Rank Order Clustering Algorithm approach by including manufacturing data. *IFAC Conference Paper Archive*. 2016;49(5):138-42.

[2] Ghosh T, Dan PK. An effective machine-part grouping algorithm to construct manufacturing cells. In: *Conference on Industrial Engineering (NCIE)*; 2011; India.

[3] Kumara S, Singh R. Rank order clustering and imperialist competitive optimization-based cost and RAM analysis on different industrial sectors. *Journal of Manufacturing Systems*. 2020.

[4] Bhuyan P. Study of Rank Order Clustering (ROC) technique for cell formation in cellular manufacturing system. *International Journal of Production Engineering*. 2017;3(1).

[5] Mostafavi S, Hakami V. A new rank-order clustering algorithm for prolonging the lifetime of wireless sensor networks. Iran; 2020.

[6] Salum L. The cellular manufacturing layout problem. *International Journal of Production Research*. 2000;38(5):1053-69.

[7] King JR. Machine-component grouping in production flow analysis: an approach using a rank order clustering algorithm. *International Journal of Production Research*. 2014;18(2):213-32.

[8] Padmakar KP. Case study on plant layout optimization using rank order clustering method. 2018;5(7):543-52.