Analysis and Development of Manufacturing Cell Design Algorithms: A Case Study Perspective

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Abstract

This paper examines contemporary cell design issues from a theoretical and applied perspective. Three cell formation algorithms were tested for a company that manufactures precision gauges for the aerospace industry. The manufacturing system that was modeled had 280 machines and over 2800 parts that were grouped under various cost centers. It was decided to develop manufacturing cells for three cost centers using cell formation algorithms. Solutions for cell formation were found using Production Flow analysis Single Linkage Clustering and an Assignment model.

The authors also discuss the modifications made to the original cell designs, which were obtained using theoretical solutions. It was observed that the algorithms tended to give solutions that consisted of one large cell and many small cells. The large cell had to be split into smaller cells by solving the problem again using appropriate algorithms. Some of the smaller cells were merged to form cells of an acceptable size. The authors also present solutions obtained by an algorithm that combines the salient features of production flow analysis and the assignment model.

Keywords

Cellular Manufacturing, Production Flow Analysis, Clustering algorithms.

Introduction

A Cellular Manufacturing System (CMS) is an application of Group Technology in manufacturing. The system provides a strategy for obtaining economic advantages in an environment of high-variety, low-demand production that are normally associated with high-volume repetitive flow production [4]

The application of a CMS may frequently result in reduced time and cost of product development. Productivity and cost savings in manufacturing are realized by exploiting similarities in machining operations, tooling, set up procedures and material handling. Parts having similar requirements can be processed together in dedicated work centers [4]

Today Cellular Manufacturing is an accepted application to improve productivity in the batch-manufacturing environment and is being implemented by many organizations [6]. It has also been accepted as the first step towards the implementation of Just-In-Time systems and Flexible Manufacturing systems [4].

Role of algorithms in cell design

One of the important steps in the implementation of CMS is the identification of machine cells and part families. This has been shown to be a difficult problem to solve and several approximate algorithms are available to solve this problem [1].

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Cell formation aims at grouping machines into cells and grouping parts into families such that a part family undergoes all the processing in its assigned cell. Usually machine-part incidence data in the form of a zero-one matrix is used to solve this problem of reorganizing an existing layout to a CMS. It is customary to use the zero-one data for analysis because of its accuracy and stability. Additional information such as product volumes, processing times of parts, and the number of machines of each type available can be used in cell design. Most available algorithms for cell design construct a matrix of similarities or dissimilarities of machines. The algorithms then attempt to form machine clusters based on maximizing similarities or minimizing dissimilarities or distances. There are very few applications of these algorithms in practical cell formation problems; however, they can provide solutions for preliminary cell design.

The practical shop floor manager is interested in the "natural groups" of machines before he or she can fix the number of groups and cell size. The following two phased approach was followed in the design of manufacturing cells in all of the exploratory studies and applications in which the authors have been involved:

1. Analyze the natural machine groups and part families
2. Provide groups with fixed number of cells and with restrictions on cell size.

The first phase was completed using algorithms such as Production Flow Analysis [2] or Single Linkage Clustering [3], which are familiar to the shop floor manager. These approaches are popular and have been applied extensively in many studies in cell formation [6]. In the case study presented in this paper the authors report the solutions using the Single Linkage, Production Flow Analysis, and GRAFICS algorithm [5]. The GRAFICS algorithm uses the results of solving an assignment problem to group machines into cells.

Details of case study

The Cellular Manufacturing design was made for a company that makes mechanical gauges for the aerospace industry. The company has a product lead time of three weeks and has suffered from excess material handling among its various focused factories.

Machine groups with similar processes are called focused factories. Machines are assigned to machine groups and components are routed through these groups. The machine groups consist of similar machines or processes. Each focused factory has a job shop or process layout with machines belonging to a specific group are positioned within close proximity to each other. Many components have a majority of their operations performed within a focused factory. However there is a large demand for processes not included in the focused factory. Also, many components are assigned to factories by their first operation but have a majority of operations in another factory. Both these problems results in high material handling costs.

The organization felt the need to reduce cost of material movement among the focused factories. Cellular Manufacturing was considered among several alternatives to be the appropriate methodology because it met the proposed objectives of the firm.The purpose of the exploratory study was to define manufacturing cells within and around the focus factories that would streamline the flow of operations, reduce material handling, and improve throughput.

Methodology

Data Collection

The shop floor was subdivided in individual business units. These business units were divided in cost centers and the cost centers were further subdivided into machine groups. The machine groups included sophisticated CNC machines as well as simple drilling machines. In theory, each machine in the group can perform the same operations but there were contradictions to the rule due to add-on equipment or special purpose attachments. A total of 217 machine groups existed. The case study was performed on a total of 1749 parts that were being processed through these machine groups.

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Available information from the Industrial Engineering Department consisted of all of the part routings that identified the cost center and machine groups. Initial sample validation revealed that not all of the routings were accurate. The detailed routing included part numbers, sequence of operations, and monthly demand. The assignment of parts to a particular cost center was determined by the component's first operation. Routings with less than ninety five percent accuracy were either corrected or discarded from the analysis. Set-up and cycle times were obtained from the MIS department for all components manufactured during the preceding twelve months in order to determine the utilization of the equipment within each standard. Therefore information about set-up and cycle times was not available for the parts that were made prior to those twelve months. As a result, zero machine utilization was calculated for the older parts.

Data Analysis

The data analysis was performed in two phases: an As-Is and To-Be. The As-Is analysis was important to verify that the component parts belonged in their assigned Cost Center. The routing information was also used to generate a graphical representation of the material handling for the To-Be analysis. The Single Linkage Algorithm was utilized to generate part-families and machine group cells. The results of these traditional Single Linkage Clustering Algorithms were augmented with the sorting and query ability of a Microsoft Access database application in order to determine the utilization of the machine groups within each cell.

As-Is Analysis

The analysis began with verifying that each component was assigned to its proper Cost Center. The operating procedure followed by the organization assigned components to cost centers according to their first operation. Therefore it was necessary to determine if the majority of operations occurred in the assigned Cost Center.

The number of visits of individual components to each machine group was determined from the available routing information. This was accomplished by processing the routing information with the help of a C+ routine that returned a matrix of parts in rows and their corresponding number of visits to the machine groups in columns. The information was sorted according to Cost Centers to determine the percent of visits for each component that passed through a particular Cost Center. The total number of visits did not include the visits to the paint or the metal plating Cost Centers since they would not be moved for environmental reasons. This preliminary analysis revealed that low percentage (less than five percent) of components were assigned to an incorrect Cost Center. Miscellaneous parts that did not have seventy five percent of their operations within a Cost Center were eliminated from further analysis.

Factory Flow

The Factory Flow application was used to identify the total distance that components traveled between operations through out the facility. This analysis was particularly helpful since the shop floor was 136,000 square feet and the operations were spread out by function. Static material handling intensity diagrams were obtained by processing the available routing and layout information. The results illustrated very complicated material handling patterns on the shop floor, which is typical of a functional layout.

It was necessary to include the monthly demand of the part routings, and batch size for this analysis. The batch size was assumed to be one per month to simplify the analysis. To eliminate unnecessary data entry in the Factory Flow application, the part routing information was processed with a C+ routine to generate a compatible format that is required by the Factory Flow application. A detailed facility layout was drawn to scale. Each machine group was labeled and all aisles were defined to calculate actual material handling distances. The Factory Flow application produced a report detailing the distance between each machine group for each component. This report was imported into Microsoft Access to analyze the number of trips between each machine group and the total distance traveled for all parts between these machine groups. This information was vital in defining future locations of the machine groups.

To-Be Analysis (Single Linkage Clustering Algorithm)

The Cost Centers with the highest quantity of parts assigned to them were analyzed through sorting. The three Cost Centers were comprised of a total of 713, 698, and 338 parts and 76, 86, and 45 machine groups respectively. The Single Linkage Clustering Algorithm was utilized because of its simplicity and versatility. Table 1 shows the summary of the data used for this analysis. For each matrix, the maximum and minimum number of parts that visited each machine and the maximum and minimum number of machines visited by the parts are shown.

Table 1. – Summary of data used in the analysis

Matrix	Size	No. of '1's	Machines		Parts	
			Max	Min	Max	Min
Cost Center #1	76 x 713	2062	214	1	10	1
Cost Center #2	86 x 698	1902	174	1	8	1
Cost Center #3	45 x 338	1107	133	1	10	1

The analysis was carried out on the three Cost Centers by converting the raw routing information into machine-part matrices through the utilization of a C+ program. The similarity threshold was varied from 0.20 down to 0.05 to determine the optimal number of cells. Through visual inspection of the grouping matrix it was apparent that many parts were linked through two common machine groups which resulted in one large cell. Therefore, the two machine groups were dropped from consideration in an attempt to produce an even distribution in the grouping matrix.

Utilization

It became clear that additional analysis would be required as a result of a visual inspection of the grouping matrixes. The clustering analysis produced nineteen cells for the first cost center; the majority of the components were assigned to one of five cells. It was necessary to determine the utilization of the machine groups within each cell because the machine groups were formed from one or more similar machines.

Additional information was gathered from the MIS Department in analyzing the utilization of each machine group within each cell. This information included the set-up time, cycle time, and demand for all components produced in the last year. For simplicity, it was assumed that demand was constant throughout the year and that only one batch per month per part was run. Using Microsoft Access, queries were written to calculate utilization. The information was sorted and reports were generated for all of the machine groups that were assigned to a particular cell as well as the utilization of those machine groups from other cells. This allowed for the evaluation of the number of machines required in each cell.

Results of analysis using Single Linkage Clustering Algorithm

The following results were obtained for similarity thresholds of 0.05 through 0.20. *Similarity* indicates the similarity threshold between machine groups within the assigned cells. *No. of Cells* is the number of distinct cells that was returned from the clustering algorithm for each specified similarity threshold. *No. of Active Cells* refers to those cells that had parts assigned to them during the analysis. The maximum number of visits to each cell determined the part assignments to a particular cell. If two or more cells tied for maximum visits, the tiebreaker went to the first cell checked. The solutions using Single Linkage Clustering Algorithm for three cost centers are shown in Tables 2 to 4.

Table 2. – Results of SLC algorithm for Cost Center 1

Similarity	No. Of Cells	No. Of Active Cells
0.05	19	14
0.06	24	18
0.09	30	19
0.11	38	21
0.13	39	20
0.17	42	22
0.19	47	26

Table 3. – Results of SLC algorithm for Cost Center 2

Similarity	No. Of Cells	No. Of Active Cells
0.05	16	11
0.07	19	12
0.10	22	12
0.12	25	12
0.15	29	13

Table 4. – Results of SLC algorithm for Cost Center 3

Similarity	No. Of Cells	No. Of Active Cells
0.05	14	9
0.10	16	9
0.12	17	9
0.15	18	9
0.20	21	8

Utilization

For a similarity threshold of 0.05, the following sample results illustrate the utilization of machine group 133 for all parts assigned to Cost Center 1. Through the clustering analysis, **machine group** 133 was assigned to cell 7. The utilization of this machine group is 44% within cell 7. This indicates that only two of the four machines are needed. The remaining two machines are assigned to cell 5 with a 32% utilization. The total utilization in Cost Center 1 for machine group 133 is less than 100%, which indicates that other Cost Centers will require time on this machine group (Table 5).

Table 5. – Utilization of machines in cost center 1

Machine Group	*Cell*	*No. Of Mach*	*% Total Hours*
133	4	4	0.42%
133	5	4	31.39%
133	6	4	10.86%
133	7	4	43.76%
133	13	4	5.13%

Solutions reported using cell formation algorithms

Other cell formation algorithms such as Production Flow Analysis (PFA) and the GRAFICS algorithm [5] were employed to study different possible solutions. Since these algorithms use zero-one data, the three matrices were tested using programs written in FORTRAN. The production flow analysis divides the machines and parts into groups with no inter cell movement. While every part is assigned to only one group, a machine is assigned to more than one group, which necessitates the duplication of machines to obtain zero movement. The PFA algorithm resulted in 59, 70 and 29 groups for the three matrices considered. It was obviously necessary to reduce the number of groups. Therefore an algorithm that uses similarity coefficients and part assignments as in the GRAFICS algorithm was developed and tested on the matrices. These results are shown under the PFA algorithm in the following table because the initial solution was obtained from the PFA algorithm. The results of testing using the GRAFICS algorithm are also shown for comparison. It may be observed that in this application the GRAFICS algorithm results in large cells compared to the Single Linkage Clustering and PFA algorithms. The PFA algorithm results in more inter cell movement. This tends to support the authors' further analysis on machine utilization and part allocation for the SLC solution. The number of inter cell moves are shown in Table 6.

Table 6. – Summary of results using cell formation algorithms.

Matrix	SLC algorithm			PFA algorithm			GRAFICS algorithm		
	C	N	I	C	N	I	C	N	I
Cost Center #1	14	11	601	12	16	904	13	38	524
Cost Center #2	19	15	710	9	10	739	20	10	797
Cost Center #3	14	9	363	10	15	370	8	15	268

C = number of cells, N= maximum cell size, S = number of cells with one machine
I = inter cell moves

Modifications made to analytical solutions

Initial trials with the SLC algorithm gave solutions that had few large cells and many small cells. This feature is common to all the three algorithms that were considered in the study because these algorithms do not restrict the cell size. The disadvantage of constraining the cell size is that it invariably gives too much inter-cell movement. The natural cell formation is therefore lost in this process. It is necessary to split the large cells into cells of manageable size.

It is to be noted that the similarities used in the algorithms are numbers that express the desirability of machines to be placed in the same cell. This is based upon part processing requirements and is indifferent to the characteristic features of the machines. Factors such as ease of shifting the machines, operator manning procedures, desirable machine utilization, etc., were considered while splitting the large cells into cells of a more manageable size.

Conclusions

This paper presents the results of an exploratory study for cell design for a plant making precision gages. A Single Linkage Clustering Algorithm was used for cell design and gave good results with fewer inter cell moves than other algorithms. The solutions provided by the theoretical models were modified in some cases to provide smaller sized cells for better manageability. Factors such as expected machine utilization were included in the detailed analysis of the cell design for better operational control.

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