Facility layout in cellular manufacturing environments

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Abstract

Manufacturing systems with a wide variety of products and low volumes of products are usually managed under flexible manufacturing. Particularly in the case of the metallurgical industry in Colombia usually works on cellular facility layout, based in grouping the family of products, seeking process efficiency; although these efforts are grounded in the practical exercise, many companies do not have a visible or clear methodological approach, which generates results that are not necessarily those that are expected. This paper proposes a plant layout methodology for manufacturing systems in Colombian metalworking industry. It is based on quantitative methods for part-product families and cells grouping and in techniques for location of facilities in a plant. Part-product families are formed using geometric techniques and p-median modified model. The evaluation of plant layout alternatives uses the AHP technique. Evaluated alternatives vary according the number of families and the similarity coefficients used in the modified p-median model. The best layout seek to minimize the cost of material handling and grouping efficiency, which is measured with indicators of exceptional elements (EE) and the grouping capability index (GCI) (Yin Y. , 2006).

Keywords: plant layout; group technology; flexible manufacturing

1 Introduction

On markets that demands high competitiveness, the business administration faces problems that must solve strategically to keep successful companies. This implies to take decisions that involve policies with long-term consequences for the organization (Solow y Mathur, 1996). Among those decisions is highly relevant: meeting the needs of external customers, at product manufacturing and service level, finding that deliveries compliance provides great value for the last one.

The deliveries compliance is strongly associated with the organization of the manufacturing processes, which helps to optimize the capacity facility, and one tool to achieve this purpose is facilities planning, with which the "production time" the productivity and efficiency is improved (Amine, Pierreval y Hajri-Gabouj, 2007), by reducing material handling costs, where "this comprise around 20% to 50% of cost total manufacturing" (Tompkins, White y Bozer Y. A., 2003.)

Facilities planning play an important role in organizations, since 1995 each year the companies spent about 8% of GDP in new installations according to United States census (WB Thompkins, 2006) (Table 1). Where the investment in facilities planning are intended to implement strategies based on improving flexibility, production volumes, types of processes, process flow, or other types of products.

Table 1. Typically percentage of GDP spent on new installations from 1995 to today.

Industry	PIB
Manufacturing	3.2
Mining	0.2
Railways	0.2
Aerial transportation and other	0.3
Public Facilities	1.6
Communication	1.0

Industry	PIB
Commercial and another	1.5
All industries	8.0

Source: Adapted from The Importance of planning in the facilities (Thompkins and Bozer, 2006)

Due to the flexibility is required by the current markets with high products variability and low production volumes, is widely applied the philosophy of flexible and cellular manufacturing, which implies to group common parts to process in a work station (cell) which have necessary machines to produce them. In this way, metallurgic industry use the cellular distribution of facilities based on product families groups to improve the process efficiency (Flores, 2003).

This article proposes a methodology of facility layouts for flexible manufacturing in metalworking industries; it is based on quantitative methods of families and cells grouping, and distribution techniques for facility location. The products grouping consider geometric techniques and p-median modified model. The facility layout is chosen using the AHP, in which the different alternatives are evaluated from the change in the number of families and similarity coefficients used in the modified p-median model. The considered criteria at the selection of the facility layout seek to minimize the material handling cost and grouping efficiency.

With the models used for the cells grouping proposed in manufacturing and layout facility, it aims to reduce material handling costs, have flexibility, modularity, easy upgrade plant, adaptability and operative selectivity.

2 Problem

In the case of facilities planning in flexible manufacturing environments, it is highlighted some of the disadvantages of companies working in these environments.

- The management of large numbers of items, with production orders of small quantities, generates a products portfolio with great difficulty in managing the planning and production.
- The products arranging to be manufactured at each facility, determining the required groups of products and work cells, to improve the quantity of flows.
- Establish a facility layout, or develop alternatives of facility layout that finally will define the distances of the production flows (material handling cost), the plant capacity and inventory at process.

Adding the challenges and issues that has the metalworking sector companies in Colombia, many have formed machines groups without a properly criteria for a adequate layout plant, which has serious long-term impact on the workflow and machines workload (in some cases, with the underutilization of them). It also presents long distances between each of the workshops, increases the presence of in-process inventory, and generating chaos, hampering the normal functioning of the production process.

The great problem that arises is: ¿how to design a facility planning model that minimizes the in-process product flow cost and the material handling costs to obtain an efficient system of facility layout in flexible manufacturing environments at metalworking industry sector?

To answer the general question, is specifically required to answer the following questions:

- What are the variables, parameters and appropriate constraints that will get the more efficient system?
- What is the more appropriate performance function?
- How should be considered the intracellular and intercellular flows?

To answer these questions, several stages are used that will allow to structure a planning facilities methodology, using Group Technology (GT) to identify product families by grouping machines in cells,

impacting directly on flows, and Cells, that are set up with a mathematical model of facility layout, impacting the reducing of the material handling cost.

3 State of the art

There are numerous studies that have treated group technology and facility layout problems. They include treatments of the problem from the point of view of static, dynamic, discreet formulations, continuous, diffuse, multi-objective and single objective approaches with exact and approximate solutions. For this particular case, the group technology and the quadratic assignment problem (QAP) will be reviewed, under the discreet approach.

3.1 Technology Group

In the late 50's, Mitrofanov introduced the concept of Group Technology (GT) in the USSR (S. Heragu 1994). It has been implemented, multi-point solution, but our responsibility in reviewing the state of the art, is the cluster analysis point of view, in the sub-emphasis of mathematical modelling applied to the formation of groups. Here is framed the P-median model, suggested by Kusiak, which minimizes the total sum of distances between each pair of products / machines (A. Kusiak, 1987).

Also, there are models of flow shop cells formation, allowing to limit the number of machines in each cell, and also there are simultaneous clustering models of parts and machines, which were structured by Foulds & Wilson, where are assigned parts simultaneously to individual machines and cells are formed. It is found in the literature, optimization models such as "Genetic Programming Single-Linkage Cluster Analysis (GP-SLCA)," an evolutionary approach to cell formation in a multiobjective (Dimopoulos 2007).

Essentially, modelling the problem of clustering is a two stages integer programming problem, which first determines product families and then assigns product families to the cells, using in the measurement of proximity, the manufacturing operations and sequence, in order to minimize costs (Choobineh, 1988).

Akturk and Turkcan propose an integrated algorithm that solves the grouping machine / product problem considering simultaneously the problem of the disposition inside the cell (Akturk and Turkcan, 2000).

In 2003, it is presented a linear assignment algorithm and family formation using similarity coefficients (J. Wang, 2003).

Getting closer to 2005, it is proposed a new major focus on flexibility in the grouping of operations, where the procedure uses three phases. The first, primary cells are formed by dividing operations into three ranges. The second phase involve the decomposition of individual primary cells into sub-cells using phase one, and continue dividing until the job is impossible. The last phase develops the operations based on the use of machinery in the cell. The model is multicriteria (Chowdary and Praveen, 2005).

By 2006, it is founded one of the models that uses group technology and genetic algorithms to minimize the total weight of the load, measured as intracellular and intercellular movement (Yu and others 2006).

Also, new models have been developed, based on formulation of a 0/1 quadratic program, directed to multiple targets in group technology problems, solved by a tabu search (Wang, Bahram and Glover, 2006).

3.2 QAP and their derivations

The first formulation of the system design problem was found as a QAP (Koopmans and Beckmann 1957). The researchers began applying approaches of intelligent heuristic for the QAP. Simulated annealing and Tabu search are the most popular. Burkard and Rendal (1984) were the first to apply algorithms Simulated Annealing (SA) for the QAP formulation. Computational results indicate that the SA generated deflected solutions only 1 to 2% of the best known solution (Chiang and Chiang, 1998).

Procedures for the QAP optimal solution have been developed from its beginning, but computational experience in the literature indicates that the biggest problem of system design has been optimally solved

for 20 machines. This inefficiency has led researchers to focus on developing heuristics for the solution (Tompkins, Bozer YA and White, 2003).

These heuristics are classified into methods of construction (structure a layout from scratch), methods of improvement (Improve an existing layout) (Foulds,l 1983).

From the perspective of system design, a variety of applications and alternative formulations have been investigated, but relatively few have been made with the design of facilities with interference. Many have identified the interference as one of concerns in the traditional design of facilities, and an alternative approach to the QAP was studied with the impact of interference in the intercellular flow and was formulated with a difference of QAP by not considering the relative location of pairs locations, but takes into account "pairs of pairs" locations to minimize interference with the flow (Chiang, Kouvelis and Urban, 2002).

To structure the measurements that specifically assess the plant layout, it has been defined some models that provide the highest proportion of production variables, and are called FLE (Facilities Layout Effectiveness), composed by the closeness gap (CG), facility layout flexibility (FLF) and the use of the productive area (PAU) (Raman, Nagalingam and Lin, 2008).

4 Methodology

With the models used for the proposal of manufacturing cells grouping and facility layout, it is pretended to reduce material handling costs, have flexibility, modularity, easy upgrade, adaptability and selective operation.

At the first stage of methodological development were founded through the design, manufacturing process or its combination, the creation of families, selecting the necessary similarity coefficients

Following the methodology proposed by Jajodia in 1992, in step (i) the P-median model is used(A. Kusiak, 1987), which is responsible to group machines into work cells and the allocation of families products to such cells, Hereinafter referred to as model 1. The model 1 input requires the calculation of the coefficients of similarity between the products / machines. For this case the product matrix requires the allocation of machines.

In step (ii) it is defined the area in where the formed cells will be located in the production plant. For this, we use the QAP combinatorial allocation model proposed by Koopmans and Beckman (Cela, 1998), Hereinafter referred to as model 2, because of its diversity of applications and the inherent complexity of the problem. The problem was solved to minimize the cost associated with distance due to the intercellular flow.

The third step involves a multicriteria-tool to define which of these gives a solution tailored to the needs of the company.

The following describes in general terms the proposed methodology with a further explanation of each step:

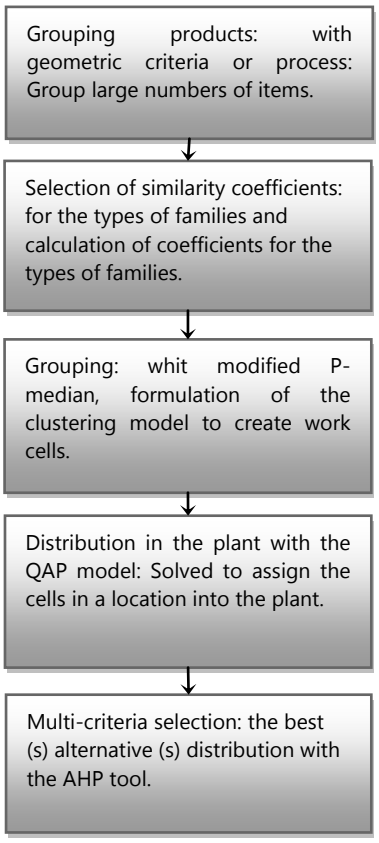

Figure 1: Diagram of methodology. Source: The Authors

4.1 Grouping products: with geometric criteria or process

The metalworking sector usually has a large volume of items to be manufactured. Therefore a basic criterion should be used for grouping, in order to make a family group of items, thereby reducing the total to a amount that may be worked mathematically with the p-median model. Among the criteria used for grouping, there are the following:

- Geometric or graphical parts: size, shape etc.
- Functions of components: handle, clamp, etc.
- Depending on the type of construction: lot size, process route, etc. (See Figure 18)
- Work piece material.

4.2 Selection of similarity coefficients

The coefficients of similarity were selected based on the following criteria:

- The number of its application in the state of the art of technology groups.
- That the study data are binary with presence and absence due to a contingency table.

Table 2. Contingency table

		Individuo i	
		1	**0**
Individuo j	**1**	a	b
	0	c	d

Source: (Vicente, 2005, pág. 9)

- Also it is included some distance and association coefficients to make a comparative study at the end, Into the 27 and 1 alternatives, the similarity coefficients are:

Jaccard Coefficient (Sneath): (Cuadras, 1989). $S_j = \frac{a}{a+b+c}$.

Dice Coefficient (sorensen): (Vicente V., 2005). $S_D = \frac{2a}{2a+b+c}$.

Ochiai Similarity Coefficient: (Cuadras, 1989). $S_s = \frac{(a+d)}{\sqrt{(a+b)(a+c)}}$.

Anderberg Coefficient: (Cuadras, 1989). $S_D = \frac{a}{a+2(b+c)}$.

Rogers and Tanimoto Coefficient: (Cuadras, 1989). $S_{R\&T} = \frac{(a+d)}{a+2(b+c)+d}$.

4.3 Grouping: with modified p-median model

The model starts with the group of product family types, using the model (A. Kusiak, 1987). Subsequently raised with some modifications, is modelled in AMPL to achieve the machines grouping, for the maximization of the objective function where one of the input parameters are the similarity coefficients, maximizing this feature. In the case of minimization of the objective function, the input parameters are the distance, similarity and association coefficients.

The objective function maximizes the sum of similarities between machines. The binary variable is 1 if one machine is assigned to work cell or 0 otherwise. Constraints ensure respectively that the machines are assigned exactly to the cells according to the availability and that exactly *p* machine cells are specified by the cell designer. Constraints guarantee that at least 1 machine must be assigned to cell formed.

Within the modified P-Median model, the following criteria were included into the model:

- The restrictions are a group of machines of each type, which are defined as the parameter Ui. One (1) is the lowest available machines and the maximum depends from real availability.
- The machines are distributed in work cells and are allocated taking into account that the sum of the machines of a specific type assigned to different cells is less than or equal to the maximum number of each type.

4.4 Facility layout: Using QAP model

After obtaining the machines grouped into teams, they should be distributed within the space available for operations, to determine the allocation of cells to the available areas it is used the criterion of minimizing the costs associated with travelled distance, where the objective is to minimize the total flow among facilities. There are a flow matrix and a distance matrix in the facility location application. The model has a binary variable, where 1 means that one facility being placed in a location and 0 if the facility is located in other location.

Model Assumptions

- Intercellular flow
- Consider the allocation of pairs of cells to assign costs (Amine, Pierreval, &-Gabouj Hajri, 2007).

4.5 Selecting multicriteria

In this phase, the hierarchical structure is developed based on the calculation of performance measures, identified through factors that allow the measurement of the modified cluster model and the QAP facility layout model that affect the management materials cost minimization. The criteria will be Assed in each case that involves the validation of the solution of clusters based on similarity coefficients, to ensure that the cells formed and the proposed distributions are appropriate. It is therefore necessary to use AHP (Analytic Hierarchic Process) to identify the importance of each criterion with respect to others.

Choose the best facilities layout

- Exceptional Elements (EE)
- Group capability index (GCI)
- % Machine Utilization
- Material handling cost (MHC) Closeness gap (CG)

5 Case study

The methodology was validated, in a company of the metallurgical industry specialized in automobile parts. The case was chosen because these kind of businesses are a good representation of the flexible manufacturing environments, since they are characterized by high levels of customization, the adaptation of flexibility in production processes, and for having within the manufacturing environment two sets that bring together available machinery: the first one set belong the low cost standards machines and the second one set belong specialized high cost machines.

The machines used in this sector varies from a universal to a specialized type or even high-tech in more complex process which involves wide range of products.

The current product portfolio of the selected company is of 30000 items and its main processes are cutting, shaping, drilling, heat treating, finishing and sanding. The amount of available machines of each type and the time required for each operation is shown in Table 6, taking into account that the company has the availability of three shifts of 8 hours each.

Table 3 Characteristics of capacity of common machines / processes

Machine No.	type of process	Number of machines (U)	Processing time [min]	Cap [unit/min]	Cap tot [u/min]
1	Uncommon	4	2.0434471	0.4893692	1.9574767
2	Uncommon	4	1.4847384	0.6735193	2.6940772
3	Uncommon	1	1.6550172	0.6042233	0.6042233
4	Uncommon	1	1.6550172	0.6042233	0.6042233
5	Uncommon	4	1.2155824	0.8226509	3.2906038
6	Uncommon	1	15.0000000	0.0666667	0.0666667
7	Uncommon	1	0.8960766	1.1159761	1.1159761
8	Uncommon	4	0.9098307	1.0991056	4.3964225
9	Uncommon	4	0.8521846	1.1734547	4.6938186
10	Uncommon	4	1.5941665	0.6272871	2.5091483
11	Uncommon	1	1.0332000	0.9678668	0.9678668
12	Uncommon	1	1.9411181	0.5151670	0.5151670
13	Uncommon	1	1.9411181	0.5151670	0.5151670
14	Uncommon	1	15.0000000	0.0666667	0.0666667
15	Uncommon	1	1.7838579	0.5605828	0.5605828

Source: Authors

The plant has a space of 2286 m^2 available for the creation of groups and the location of the machines. The created groups in the case of the cells, must be at least equal to 2 so that the philosophy of cellular structure makes sense and maximum 5 by currently available space.

The general facilities layout characteristics are:

- The facility must have at least one machine or work station of each type to ensure the manufacture of all products, i.e. the lower limit machines in the plant type must be equal to 1.
- The groups formed to obtain work cells, must be at least 2, because the philosophy of cellular manufacture needs several work station. And maximum is 5 per availability of space currently in the particular case.

6 Results

In the development of the process of preliminary portfolio of more than 30000 items, the criterion of active items, it allows a reduction in the analysis from 30000 to 13812 items. The demand criterion that selected the items that were moving over the time horizon, reduced the number of items from 13812 to 3787, and in the creation of parts families for process analysis, it was founded that within them, there were products bearing the same process manufacturing, making the clustering process, obtaining 120 families.

The similarity matrices, introduced in the P-median model for 120 types of product families, yielded different group of cells, each of these associated with a P value between 2 and 5, and the selected similarity coefficients. Each alternative of the cells was run with the QAP formulation using AMPL model to generate the different options of 47 alternative of facility layout.

The best cell configuration options are 1 and 27, when P equals 2, for the coefficients Jaccard, Dice, Anderberg and Ochiai and when P equal 4 for the Rogers and Tanimoto coefficient. The selected options are those with the highest percentage in the MHC with values of 13.74% and 14.67%, being the MHC the criterion with more weight on the percentage of priority with a value of 45.5%. For the following criterion in weight is the utilization rate of machines with a weight percentage of 28.6%, but is not found much difference in the evaluation of alternatives to general average which is 2.13%. We find that for P = 2, the GCI value was 2.45 and for P equal to 2.10% 5. The best configurations were:

Alternative 1. Jaccard, Dice, Ochiai, Anderberg							
Location / Cell	1	2	3	4	5	6	7
1	0	1	0	0	0	0	0
2	0	0	1	0	0	0	0
3	1	0	0	0	0	0	0
4	0	0	0	1	0	0	0
5	0	0	0	0	0	1	0
6	0	0	0	0	1	0	0
7	0	0	0	0	0	0	1

Alternative 27. Rogers & Tanimoto									
Location / Cell	1	2	3	4	5	6	7	8	9
1	0	0	1	0	0	0	0	0	0
2	0	1	0	0	0	0	0	0	0
3	0	0	0	1	0	0	0	0	0
4	0	0	0	0	0	1	0	0	0
5	1	0	0	0	0	0	0	0	0
6	0	0	0	0	1	0	0	0	0
7	0	0	0	0	0	0	1	0	0
8	0	0	0	0	0	0	0	1	0
9	0	0	0	0	0	0	0	0	1

That is, when P equals 2, for the coefficients Jaccard, Dice, Anderberg and Ochiai and when P equal 4 for the Rogers and Tanimoto coefficient and occurred because: shown in Table 17.

Table 3: Comparative analysis of alternative 1 and 27

Criterion	Alternative 1	Alternative 27
EE (Exceptional Elements)	32	94
GCI (Grouping Capability Index)	0.93	0.794
MHC (Material Handling Cost)	120637	112989
Total	7.78%	7.40%

Source: The Authors

These criteria are the most important in the evaluation of the selection, and alternative 1 has slightly better features compared to the 27 because the items come less than one cell to another with this

configuration. Additionally, grouping capability index is higher for this case. That is, the options selected are those with the highest percentage in the MHC with values of 13.74% and 14.67% being the standard with more weight on the percentage of priority with a value of 45.5%. For the following criteria in weight is the utilization rate of machines with a weight percentage of 28.6%, but is not much difference in the evaluation of alternatives to general average which is 2.13%. We find that for P = 2, the GCI value was 2.45 and for P equal to 2.10% 5.

7 Conclusions

• The geometric clustering techniques and the P-median modified, allowing the methodological support of the technology groups and get results that provide objective measures in the development of flexible manufacturing.

• There exist a wide variety of scientific papers backing this research to the correct selection of the flow and distance parameters in the case study, which are part of the QAP facility layout model and with the extensive review of the state of art was validated the wide use of the model, since its approach in 1957 by Koopmans and Beckmann, determining the applicability to the case was structured as it is a problem applicable to a number of situations as shown in the literature of great interest to scholars in the different academic disciplines.

• We selected a typical case study of flexible manufacturing, such as the automobile engineering sector, which has an interesting complexity to the grouping models, providing important knowledge on the subject of plant configuration based clustering participants of this study.

• The sensitivity analysis shows that the methodology is primarily affected by changes in the parameter U (number of machines available), a situation that requires special care when selecting it for modelling, since the overall outcome will depend on such selection in each case. In particular, the parameter is modified in the case study for low-cost machines, since from the practical point of view the high cost machines regularly will have a value of one, unless the demand is increased, due to lack of capacity. Was also assessed the increase in demand, but the layout no change, only the material handling cost, which is consistent with the increased flow within the plant.

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