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A Decision Support System for the design of Cellular Manufacturing Systems: database conceptualization

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Abstract

In Cellular Manufacturing Systems (CMS) resources are grouped to create independent cells capable of completely processing a set of similar parts. The design of such a system is complex and entails several interconnected problems. The decision process regarding the design of CMS must, therefore, be sustained by solid data and supported by adequate models capable of helping the decision maker in the development of an adequate solution. In this context, a Decision Support System (DSS) for the design of CMS is being developed, and the purpose of this work is to present the conceptualization of the database required for such DSS.

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1. Introduction

In industrial environments, production systems that require flexibility and the possibility to produce small batches of a large range of different products are, traditionally, organized into functional departments (functional system). In this type of system, functionally similar equipment are grouped together in a department and parts are moved between departments according to their processing sequence[1].

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Although very flexible, this type of system is very inefficient resulting in long lead times, high levels of work-in-process inventory, high transportation costs, and a more disordered production environment that, consequently, is harder to manage.

Cellular Manufacturing Systems (CMS) have emerged in the last decades as a viable alternative to functional systems. Manufacturing cells are physical groups of different machines assigned to a family of parts with similar processing requirements. This way of organizing manufacturing resources still maintains some flexibility in the system while improving its performance.

There has been an increase in the popularity of CMS in industrial organizations, also due to the popularity of Lean Production principles[2, 3], that point to this type of system as a tool for reducing waste.

However, literature indicates that the design of CMS for industrial applications is a complex task that requires "a knowledge intensive process as it involves the consideration of many factors including production data and process characteristics"[4], having, in this context, a Decision Support System (DSS) an important role.

The proposed DSS will incorporate some, already developed, metaheuristics based algorithms[5,6], as well as new algorithms to be developed. In this work a crucial part of the DSS is presented: a database that comprises all the required information used to solve the different problems entailed in the design of CMS, as well as to store the proposed solution(s).

2. Background: the relevance of a DSS in CMS' design

Nowadays industrial companies must be prepared to produce a high variety of products in order to compete in a global market and respond to the demand for personalized, high quality and low price products. The way the manufacturing system is organized is decisive for its performance and for how the company can overcome the challenges imposed by the market and the competition[3].

In a manufacturing environment where there is a high diversity of products and low volumes (small size batches) the traditional way to organize the manufacturing resources is in functional departments[1]. This type of layout is quite inefficient and Singh and Rajamani[7] estimates that, on average, only 5% of the time a product spends in the system is used in value-added activities (manufacturing operations). The remaining 95% is used in waiting or in transportation and storage activities.

Other types of manufacturing systems have emerged as valid alternatives to functional systems. Cellular Manufacturing Systems try to maintain some flexibility while being more efficient and are usually pointed out as way to reduce waste and help implement Lean Manufacturing concepts[2,8], what has led to an increase in their popularity[3].

The design of CMS is usually a quite complex process and involves solving a set of interrelated problems[9,10], namely:

- assignment of operations to machines;
- cell formation problem (machines and parts);
- machine duplication;
- intracellular layout;
- intercellular layout.

It is important to highlight that there is a lot of interaction between these problems but they are, traditionally, solved in a sequential manner instead of, ideally, being solved concurrently[9,11].

Most researchers tackle one, or sometimes a combination of no more than two, of those problems since they are, by themselves, quite complex. Moreover the amount of necessary data to address those problems is quite large.

There is, for example, a considerable amount of research about the family formation problem (e.g.[12,13]), but usually the focus is on the cell formation problem (determining the families of parts and the groups of machines). A big part of the work, however, uses an incidence matrix that represents a very limited source of manufacturing information[3]. On the other hand the diversity of approaches used is quite interesting and one can find some works using mathematical programming models[14,15], clustering algorithms[16], metaheuristics[5,17-24], and other techniques (e.g. neural networks[25]). It is noticeable that the use of metaheuristics seems to prevail over the other approaches.

The need to better understand these systems, how they can be designed, and how they perform in different conditions, seems apparent. Additionally, in[26], a state-of-the-art review of the papers published in CMS' design and analysis, in the last 44 years, in a specific scientific journal, states that more realistic approaches, that encompass the requirements of industrial organizations, are necessary.

Furthermore there is very few known work developed in the context of DSS for CMS and some work already published[4,27] is still very incipient.

In[28] a more sophisticated DSS is proposed but it has some drawbacks, namely it only considers the cell formation problem, the algorithms incorporated are based on the part-machine incidence matrix (a limited source of information), and interaction with the decision maker, in order to incorporate further inputs, is not promoted.

The analysis of the work developed so far, and the indications for future research that some authors have pointed out support the need for the proposed DSS.

The need for a DSS is due to several important aspects of the problem at hand, specifically:

- the amount of data required for solving the inherent problems when designing CMS;
- the complexity of each of the sub-problems and the inherent difficulty of solving them simultaneously;
- the interaction between those sub-problems;
- the importance of incorporating the decision-maker knowledge into the analysis and improvement of the solutions;
- the necessity for providing the decision-maker with different alternative solutions.

Furthermore, the pressure from the market and the volatile environment has led companies to recognize the need for more frequent restructuring of their manufacturing systems. From this perspective a DSS of this nature can be a very interesting tool for any decision-maker.

3. Practical case

The decision-making process, when designing a manufacturing system, is quite complex and involves a large amount of information. Furthermore the efficiency of a production system is, to a great extent, determined by the quality of the system's design since it has a critical impact on the flow of materials and people within the production area. Additionally, decisions of this nature may require large investments and have a long term impact since it is not easy nor inexpensive to change the organization of a production system.

In this context an adequate DSS can assist decision-makers in their work, helping them to gather the required data, analyzing that data, developing and comparing solutions and providing them with essential information.

In the next section a global structure of the proposed DSS is presented followed by the explanation of the data model.

3.1 Structure of the proposed DSS for CMS' design

The main purpose of the proposed DSS is to contribute to the solution of the problems intrinsic to the design of CMS. It should also be capable of interacting with the decision-maker so that particular aspects of the problem at hand can be incorporated in the final solution.

More specifically the system should be able to, taking into account data related to the production system:

- Assign operations to the available machines;
- Determine the composition of the manufacturing cells (parts and machines);
- Define the layout of the cells and the location of the cells within the plant area;
- Evaluate the solutions generated by the system as well as the ones obtained through the input of the decision-maker.

Additionally it is essential to help the decision-maker by providing the necessary information in order to provide support in the improvement of the solutions suggested by the DSS. For example information regarding the flow between cells and the costs associated with that solution (e.g. transportation, equipment acquisition and maintenance, outsourcing) can help the decision-maker evaluate the impact of decisions such as:

- duplicating machines;

- determining the need for hybrid layouts (with some machines arranged into functional departments);
- outsourcing parts or certain operations responsible for intercellular flow.

In order to achieve its purpose the DSS has three main elements: database, model base, and user interface[29]. These three components of the system work together so as to allow for a user friendly interaction, generate feasible solutions and facilitate the intervention of the decision-maker in those solutions.

The way the system is designed contemplates three modules, one for each problem that should be addressed: cell formation problem (that includes operations assignment); intracellular layout and intercellular layout.

Figure 1 shows the way those modules are connected. As one can see the outputs of the first module, such as intra and intercellular flows and cells' composition, are used as inputs for the following two modules. In those modules the location of machines within each cell and the location of the cells are determined taking into account the flow between machines/cells as well as other information (e.g. dimensions and configuration of the machines/cells).

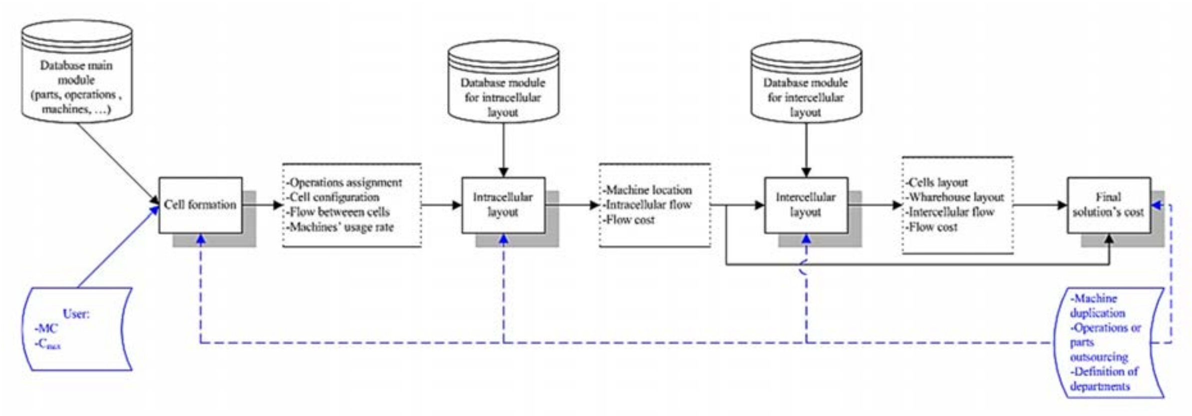

Fig. 1. DSS structure.

The final layout is evaluated considering the transportation costs for intercellular flows. The decision-maker can then try to reduce those costs through several options such as acquiring new equipment, outsourcing parts or operations, grouping machines into functional departments. The resulting new solutions should be assessed considering not only the flow costs but also the costs associated with the proposed changes.

The models that will be incorporated in the DSS have been partially developed[5,6]. The first one is a Simulated Annealing based algorithm for the cell formation problem as well as the assignment of operations to machines considering the existence of multiple identical machines, and it measures flow in terms of number of parts moved or trips performed. The other one is a Genetic Algorithm for facility layout design when sections have fixed geometric configurations and distances are measured between the entry and exit points of the sections.

Nonetheless, new algorithms are still being constructed and, in all of them, metaheuristics (e.g. Simulated Annealing, Genetic Algorithms) are being used as a way of analyzing more solutions and, ideally, find, in a reasonable amount of time, a good solution.

The following section presents the database conceptualization of the system that is currently being developed.

3.2 Data model conceptualization

For the conceptualization of the database static structural models, more specifically, UML (Unified Modeling Language) class diagrams were used. UML notation is a universal way of representing complex systems that would be hard to explain in a non-graphical form[30].

For this DSS class diagrams were used to represent the main module and the layout modules (intracellular and intercellular).

The main module of the database includes the required data for solving the cell formation problem (including assigning operations to machines) as well as information regarding the several types of costs used to evaluate solutions. That class diagram, presented in Figure 2, is briefly explained as follows.

Each part can be built using zero other parts (if it's a simple component that only includes one material) or several parts (if it is a complex product assembled with several components). The class 'Structure' determines, in this way, the Bill of Materials for all parts/products considered in the study. For each part it is also necessary to know its demand and the cost of outsourcing its production. Furthermore the sequence of operations (manufacturing but also transport, storage and inspection) required for producing a certain part is also defined.

Operations can be of different types (manufacturing, transport, storage and inspection) and can also be outsourced at a cost. Operations can have equipment associated (machines or transportation equipment) and consume different amounts of time in certain actions (setups, manufacturing, loading and unloading).

Each machine type is characterized by its capacity, its usage rate and associated costs (acquisition and maintenance). There is also the number of available machines of each type because one of the assumptions for the cell formation problem is that you can have multiple machines functionally equivalent.

The data related to the solutions are represented in Figure 2 in blue. Solutions can be generated by the system or can result from changes done by the decision-maker to proposed solutions.

For each solution there is a total cost that includes the total transportation cost as well as the costs associated with the changes proposed by the decision-maker, namely, the cost of acquisition and maintenance when new machines are considered or outsourcing costs (for a part or operation) when that is tested.

Generated solutions can then be changed by the decision-maker and re-evaluated. An important aspect should be the possibility of penalizing certain specific flows as a way of eliminating them from a certain solution.

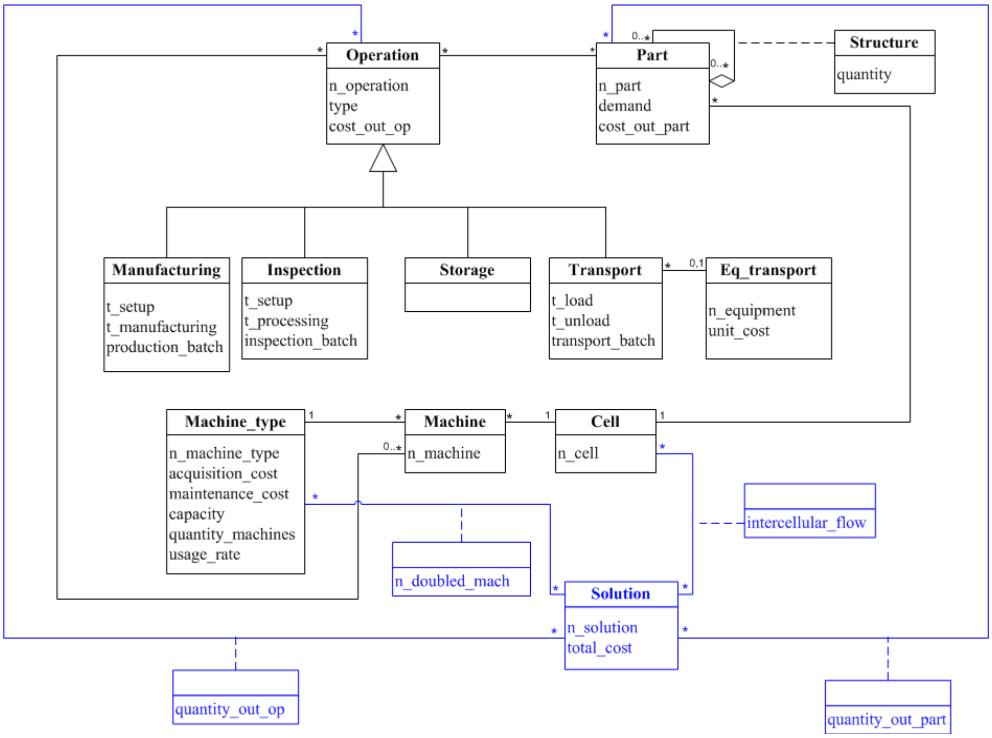

Fig. 2. UML class diagram for database main module.

From the results obtained from solving the cell formation problem it is then possible to determine the layout of each cell (intracellular layout). Figure 3.a shows the class diagram that specifies the required information for tackling this problem.

A work space is allocated to each machine thus defining the workstations. Taking into account their configuration and the flows between workstations, they can then be placed inside each cell.

Finally the global layout (intercellular layout) can be determined which will facilitate the evaluation of a final solution since, at this moment, not only flows are known but also the distances between departments (in this case cells) and the respective machines.

Figure 3.b also shows that, for defining the final layout the available total area must be known as well as other unavailable or occupied areas (e.g. warehouses), namely their size and placement.

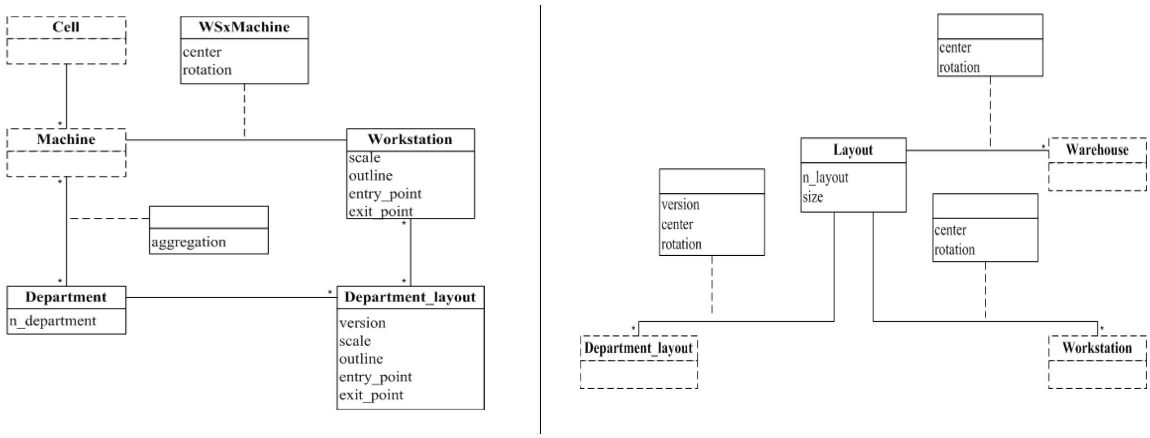

Fig. 3.UML class diagram for database intracellular layout module (a. left right) and for database intercellular layout module (b. right side).

This type of models and their implementation in an object-oriented technology can facilitate the integration of future requirements that can emerge from new problems and/or new approaches for solving those problems.

4. Conclusions and further work

This paper presents an ongoing work whose main objective is the development of a DSS capable of supporting the design of CMS. Particularly the database modules were described using class diagrams.

The DSS should encompass the following issues: cell formation problem (including operations assignment) as well as intra and intercellular layouts. Furthermore, it should allow the decision-maker intervention in the solutions as a way to incorporate additional knowledge of the problem, generate more solutions and compare their performance.

To support the development of a solution for the CMS' design an adequate database is required, capable of accommodating the data used by the models to generate solutions, in addition to data used by the decision-maker, and also store the obtained solutions. It is important to notice that the correct conceptualization of the database is crucial for the usefulness and performance of the system.

The need for such a system is justified by the complexity of the problems and by the way they are interconnected. Also the possibility of including the decision-maker know-how into the construction of different solutions is key.

With regard to the database it is necessary to refine the conceptualization of the modules with new knowledge of the problems that can derive from the ongoing development of new metaheuristics based algorithms used to tackle them.

After finishing the models and the database conceptualization, the next stage should be the system's interface design and, finally, the development of a working prototype. The system should at that point, ideally, be tested and used in real life situations as way of validating and enhancing the final prototype.

This work is expected to contribute to the scientific research in the area of industrial engineering, and more specifically in manufacturing systems' design, mainly through the development of new algorithms directed at CMS' design. It should also have an impact in the area of DSS's development since it represents an applied case of the inherent procedures and methodologies of that area of study.

It will hopefully also contribute to the industrial reality when used by practitioners to evaluate alternative CMS' configurations, possibly to change from a functional layout or to improve existing CMS.

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