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COMPARISON BETWEEN TRADITIONAL AND VIRTUAL CELL LAYOUTS USING PROCESS PLANS WITH ALTERNATIVES BY MEANS OF SIMULATION AND DESIGN OF EXPERIMENTS

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Abstract*. The choice of the physical arrangement and the process plan is essential in order to improve the efficiency and effectiveness of a manufacturing system. Many industries operate in a batch-based approach using the traditional cell layout, which seeks to attain high flexibility and efficiency that are characteristic of the traditional cellular arrangement. The objective of this study is to compare the traditional cell layout with the virtual cell layout using simulation and design of experiments. Each system contains 10 machines, 8 operators, and 3 suppliers, and an analysis is made using five control factors with regard to resource utilization. The simulation model is subdivided into two stages. In the first stage production orders are generated for the systems, and each order is built based on the following factors: features present in the parts, amount of duplicate features, lot size, type of demand, machining sequence, and machining times. These data are stored in a spreadsheet that is used as input to the simulation model. The results of simulation are stored in another spreadsheet for analysis of variance (ANOVA). In this work full factorial design was used in the execution of the experiments. As a result, the resource utilization of the virtual cell layout is 20% higher than the traditional cell layout.*

Keywords: *Virtual Cell Layout; Traditional Cell Layout; Simulation; Manufacturing; Design of Experiments.*

1. INTRODUCTION

The increasingly globalized market demands an ever better performance of each organization, so that it would hold up to the challenges that arise. Such challenges often can be overcome only through continuous reduction of the times of activities that do not add value to the customer (Slack *et al.*, 2009).

According to Brennan and Foroughi (1999), manufacturing has been changing its characteristics, and this affects the way its functions should be seen and executed. Numerous times on the shop floor it is not possible to meet important requirements such as quality, productivity, flexibility, cost, innovation, among others, due to the occurrence of problems. Among these problems the following can be cited: inadequate layout, long setup times, large inventory, etc.

In this scenario, the use of process plans with pre-established alternatives may prove to be advantageous since a previously selected alternative resource may be included during the preparation of the process plan. The presence of pre-planned alternatives is likely to provide more flexibility in decision-making (Ferreira and Wysk, 2001a, 2001b).

Kilwhani *et al.* (2011) show that an adequate choice of layout configuration on the factory floor is key to enable and enhance the competitiveness of a company in today's global economy. Both the reduction of flow times and setup times, as well as part routing flexibility are very important for the viability of the business.

The traditional manufacturing cells were devised to achieve the above characteristics. According to Greene and Sadowski (1982), each cell is designed to produce a family of parts, which require similar machines, tooling, and fixtures. The parts in the family usually go from raw material to finished parts within a single cell.

Traditional cell layout has advantages compared with the job shop (i.e. functional) layout such as reduced setup times, reduced work in process (WIP), and increased part flow. However, conventional cellular manufacturing may not be appropriate if operation routing is prone to change in time (Drolet *et al.*, 2008), which can be the result of a high variability of parts to be manufactured.

In this work the concept of virtual cells is considered. According McLean *et al.* (1982), a virtual cell is made up of different machines that are logically grouped for a certain period of time, functioning as a manufacturing cell in order to meet the production requirements as in a traditional cellular system. An example of a virtual cell layout is shown in Figure 1, where three cells are temporarily formed to manufacture one order each, and there are four types of machines, which are represented by geometric shapes.

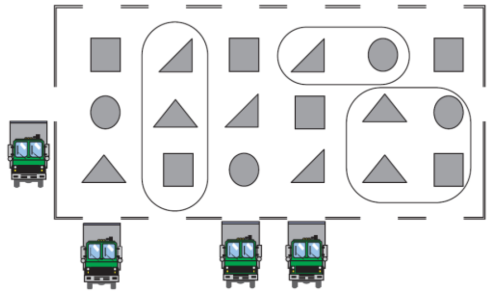
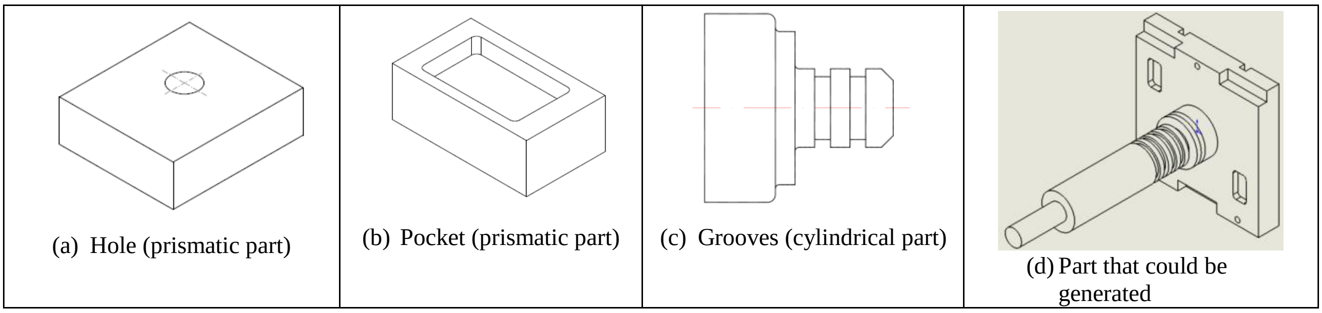


Figure 1. An example of a virtual cell layout (Drolet *et al.*, 2008)

This research seeks to study the virtual cell layout, comparing it to the traditional cell layout, aiming at identifying conditions in which the virtual cell layout achieves better results. The methods of design of experiments combined with discrete event simulation were used as a means to carry out this research.

In this work the parts are randomly formed, considering a universe of features from which to generate a multitude of different parts. The features considered in this research include holes, pockets, and grooves (Figure 2), and an example part is also shown in the figure. In the case of traditional cell layout, one cell makes prismatic parts, while the second cell manufactures general parts (with prismatic and cylindrical characteristics), and the third cell produces only cylindrical parts. Setup times are considered, and it is the loader who performs internal transport of parts in the cell. A limitation on the flexibility of operators was included, which was applied in a simplified manner, in which the only flexibility is the worker who operates the drilling machine, who can also operate the CNC milling machine.



(a) Hole (prismatic part)
(b) Pocket (prismatic part)
(c) Grooves (cylindrical part)
(d) Part that could be generated

Figure 2. Some of the features considered in this work, and a part that could be generated using the features considered

2. SHOP FLOOR LAYOUT AND PROCESS PLANNING

2.1. Shop floor layout

The layout establishes the physical location of resources, which include machines and people. In addition, the layout sets how the processed items (i.e., raw materials and parts) should flow during the operations. According to Khilwani *et al.* (2011), the type of layout should increase the flow in order to reduce costs and increase production efficiency.

The arrangement of resources in a shop floor directly affects the costs of production and productivity. A rational allocation of resources contributes significantly to increasing the efficiency of operations and reduces transport costs (Drira *et al.*, 2007). Companies should arrange layouts with high flexibility and lower transport times and costs, so that a wide range of production conditions can be performed (Hamedi *et al.*, 2012a).

Slack *et al.* (2009) mention four basic types of physical layouts: positional, functional (job shop), cellular, and product. In the literature virtual cells are not considered in this classification. One of the objectives of a virtual cell layout is to reduce flow time and setup time, while increasing routing flexibility. Machines in each virtual cell are physically next to machines with different characteristics (Kannan and Ghosh, 1996).

2.1.1 Manufacturing systems using virtual cells

Khilwani *et al.* (2011) point out that manufacturing systems with virtual cells are a new type of cellular manufacturing system, corresponding to a very interesting alternative to the creation of cells in real time. One of their conclusions is that the benefits of the use of virtual cells increase with growth in the types of machines required for processing a particular part, which points to the need to further study the virtual cells.

According to Hamedi *et al.* (2012b), increasing the production mix and demand fluctuations require an increasingly rapid response from manufacturing systems. Thus, the concept of manufacturing systems with virtual cells may be used in such conditions.

In the context of virtual cells, there is a significant amount of techniques to solve the problem of formation of virtual cells. Hamedi *et al.* (2012a) proposed a method that uses a non-linear programming model to form the virtual cell based on the capacity of the manufacturing system. According to the authors, the virtual cells resulting from this method outperformed the traditional cellular systems.

Hamedi *et al.* (2012c) mentioned that the choice of the most appropriate layout of virtual cells leads to an improvement in their performance. The authors proposed a mathematical model using a multi-objective approach based on the features and resources, and they verify the performance and the validity of the model by means of an example from the literature. Furthermore, Hamedi *et al.* (2012c) sought to compare the performance of the virtual cell manufacturing system (VCMS) with the manufacturing system with the traditional cell layout, using the criterion of capacity utilization. With the results, the authors conclude that companies can take advantage of VCMS.

2.2 Process planning

Deja and Siemiatkowski (2012) mention that the task of process planning involves the interpretation of the design specifications of the product in order to manufacture it. Nowadays process planning has become increasingly complex, due to the significant variation in product demand, and the high quality requirements. In addition, there has been an increasing demand for customized products (Deja and Siemiatkowski, 2012).

2.2.1 Process planning with alternatives

According to Ferreira and Wysk (2001a), there is often more than one alternative process plan for manufacturing a part. Colosimo *et al.* (2000) point out that usually the elaboration of process plans does not consider alternative resources, despite both the concept and discussion have been present in the literature for a long time.

Fung *et al.* (2008) point out that the capacity limits of each machine and the operations that it can perform are well defined. However, some operations can be performed on more than one machine, resulting in the dynamic aspect of process planning. Deja and Siemiatkowski (2010) report that the presence of alternatives in process planning can contribute significantly to the integration of product design, process planning, and production scheduling.

3. CONTROL FACTORS, RESPONSE VARIABLES, AND SIMULATION STAGES IN THIS WORK

3.1. Control factors and Response variables

Design of experiments consists of defining the control factors and response variables, and such a technique is useful for determining whether or not a factor influences the response of a system (Montgomery, 2001). Control factors are process variables whose values can be controlled. Table 1 presents the control factors used in this study.

Table 1. Control factors used in the proposed experiment

Control Factor	*Description*	*Level*	*Value*
Features per part	Quantity of features in the part	Low	1 to 3 features per part
		High	7 to 10 features per part
Duplicated Features	Quantity of duplications of the same feature in each part	Low	1 to 3 features
		High	7 to 10 features
Batch Size	Quantity of parts in each batch	Low	10 to 50 parts
		High	200 to 500 parts
Type of Demand	Type of demand which will be applied to the system	Low	random
		High	controlled
Type of Plan	Process Plan used in the simulation (with or without alternatives)	Low	Plan WITHOUT Alternatives
		High	Plan WITH Alternatives

In this method the response variables are chosen so that they are consistent with the proposed performance criteria, in order to carry out the analysis of the influence of the control factors. The response variable used in this study is the utilization of resources (%), which is calculated considering the period in which the resource was utilized (Δtu) in a certain time interval (Δt). This formula is shown in equation (1).

$$U = \frac{\Delta tu}{\Delta t} \tag{1}$$

For both layouts process plans with and without alternatives are considered.

In order to reduce errors inherent to the system variability, 10 simulations were performed for each combination of factors, that is, each experiment was replicated 10 times. We also opted for the full factorial design and, therefore, all possible combinations have been tried. Considering that there are five control factors (Table 1), and having been chosen two levels in each factor (low and high), $2^5 = 32$ experiments were performed. Since for each experiment 10 simulations were performed, the experiments amounted to 320, and each of these experiments was applied to two different layouts (virtual and traditional cellular layouts), totaling 640 experiments.

3.2. Simulation stages

With regard to the construction of the simulation models, this task is divided into two stages. In the first stage the production orders of the batches of parts are generated. At this stage the following activities are undertaken: generation of the features in the parts, setting the amount of duplicated features, setting the batch size, definition of the type of demand, generation of the machining sequence, and calculation of machining times. These data are stored in a spreadsheet that is used as input for subsequent simulation in the Arena® simulation software.

In the second stage simulation is performed, and the results are also stored in a spreadsheet that will be used to perform the statistical analysis. The flow diagram in Figure 3 illustrates these two stages.

4. APPLICATION OF THE PROPOSED METHOD

The template of each modeled layout contains the same number of machines, which can perform certain features. Each layout contains 10 machines: 2 drilling machines, 2 conventional milling machines, 2 CNC milling machines, 2 conventional lathes, and 2 CNC lathes. Also, there are 8 operators and 3 loaders. In total each model has 21 resources.

With regard to the operators, some of them are dedicated to two different resources, while others are dedicated to only one type of resource. The loaders are responsible for transporting the batches of parts from the entrance of each manufacturing system to each machine and eventually deliver them to the expedition area. Table 2 shows the 5 different types of machines and the features that each machine can manufacture.

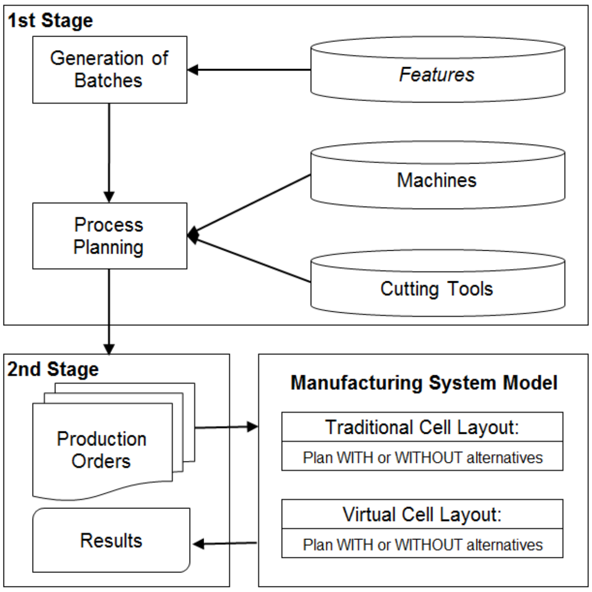


Figure 3. Structure of the simulation model

Table 2. Types of machines and their operations

Machine	Operation	Process Plan WITHOUT	Process Plan WITH Alternatives
1	Drilling Machine	Hole	Hole
2	Milling Machine	Shoulder, Slot	Hole, Shoulder, Slot, Pocket
3	CNC Milling Machine	Pocket	Hole, Shoulder, Slot, Pocket
4	Lathe	Knurl, Groove	Turn, Face, Groove, Knurl
5	CNC Lathe	Turn, Face	Turn, Face, Groove, Knurl

In the model the cells were set up by the criterion of the type of part in each batch. That is, the parts are based on 40 different features, which are divided into two groups: features for cylindrical parts, and features for prismatic parts.

Also, one of the control factors is the type of demand, which can be entirely random, or controlled. In the case of controlled demand, the formation of the parts is as follows: 20% cylindrical assemblies, 30% prismatic parts, and 50% combined parts (i.e. parts with both cylindrical and prismatic features). Three different cell types were studied: the first cell only manufactures prismatic parts, consisting of only one drilling machine, one conventional milling machine, and one CNC milling machine.

A second cell has been established to make parts that contain both cylindrical and prismatic features. Therefore, this cell will be composed of one drilling machine, one CNC milling machine, one conventional milling machine, one conventional lathe, and one CNC lathe. The third cell was designed to make parts containing only cylindrical shapes and it contains a conventional lathe and a CNC lathe. Each cell has one loader who is responsible for collecting the raw materials early in the process and transport the finished product to the exit of each system. This loader is dedicated, not interacting or changing between cells.

In the virtual cell layout, with respect to loaders, they have complete freedom to walk on the shop floor, from the entry of the raw material in the system to the exit of the batch of finished products.

One of the control factors used in this research is the type of process plan. In the case of the use of a process plan with alternatives, a second machine option is defined in order to perform the operation.

For each feature the operation time was calculated considering the first machine option. In the case of the alternative operation, which is the second option, it was established a penalty of 40% on the machining time. It can also be interpreted that the alternative resource is 40% less efficient than the first option machine.

For each model it was necessary to establish some parameters regarding transport times. For the traditional cellular layout it was used a uniform distribution of 3 to 6 minutes to enter the cell, and also a uniform distribution of 3 to 6 minutes to start the operation at each resource. Besides the mentioned transport times, the distances between each resource were specified, as well as the speed with which the loaders perform the transport.

For the virtual cell layout it was established a uniform distribution with a value of 30 to 60 minutes for transport between departments, and a uniform distribution of 3 to 6 minutes to start batch processing on the selected feature. In general, the distance between pieces of equipment was 5 meters, from the entrance of the manufacturing system to the equipment was equal to 10 meters, and the distance between the equipment and the expedition sector (i.e. output) was 20 meters. The speed at which the loader transports each batch was set at 5 m/min for all models.

With respect to the setup times the same values were adopted for both models, which were obtained from Hamedi *et al.* (2012a): (a) drilling machine and lathe = 20 minutes (b) milling machine, CNC milling machine, and CNC lathe= 35 minutes.

The values assigned to the tool change time were established according to studies reported in the literature and data from the catalogs of manufacturers. The time between cutting tool changes in the drilling machines, CNC milling machines, and milling machines was established as a Poisson distribution with 60min average value, and for the tool change time a normal distribution of 5-10 minutes was used. The interval between cutting tool changes for CNC lathes and conventional lathes has a uniform distribution of 5 to 10 minutes, whereas an Erlang distribution with an average of 2 was considered for the tool change time (Al-aomar and Al-okaily, 2006).

It is important to point out some hypotheses that guided the experiment: (a) the machines used can provide the cutting power required for any of the cutting tools used, (b) at the beginning of the simulation process, all resources, machines, operators and loaders are available, (c) it was not considered the occurrence of scrap or rework, (d) operators are available in 100% of its capacity, (e) absences from the work stations were disregarded, (e) the tolerances of parts, the tool magazine size, and the condition of the machines were not critical factors, (f) process inventories obey the FIFO (first in first out) priority rule.

4.1 Procedure applied to generate the production orders

In order to facilitate the understanding of the procedure, Figure 4 shows a flowchart with the program that generates the production orders.

The arrival of a batch in the system is the event that starts the simulation. Therefore, considering that batches of parts to be manufactured have been defined in the previous stage, it is necessary that the model can reproduce the desired characteristics. The model then should be able to differentiate each batch with regard to the type of feature in each batch, the duplication of features, and the number of parts in each batch.

Then, according to the features in each batch of parts, the operations to be performed are defined. From the operations the machines for producing the batches of parts can be selected. Before checking the machines, it should be verified whether the process plan has alternatives or not. If the plan has no alternatives, the machine established as the first choice for machining that feature is selected. On the other hand, if the plan has alternatives, the work in process is taken into account to select the machine.

The following stage corresponds to calculating the machining time, which is performed taking into account the type of plan selected. After the times are defined, one loader is requested to transport the batch. The loader is also requested: (a) when a batch needs to enter the system, (b) to move the batch to the next machine, or (c) to transport the batch to the expedition area. All the movements that the loader performs have predefined routes and speeds and, thus, the times related to transporting the batches of parts can be determined.

Although a priori all resources are considered available, before performing the selected operation there may be work in process in front of the resources. The batch leaves the selected machine only when all the parts in the batch are machined. In the case of process plans with alternatives, before leaving the machine, it is verified the possibility of using the second machine option in the next operation to be equal to the current machine. This is done by comparing the work in process in the selected resource for the next operation (first option) with the current resource (second machine option). If the second machine option selected for the next operation is equal to the current machine, the work in process is evaluated in order to avoid a machine change, which reduces significantly the number of setups.

It is checked whether all operations were carried out. If there are no more operations, the batch leaves the system, but before that its statistical data are collected for the calculation of resource utilization. When the simulation ends, with all simulated batches, it stores up the report generated by the Arena software with data to be used for calculating resource utilization.

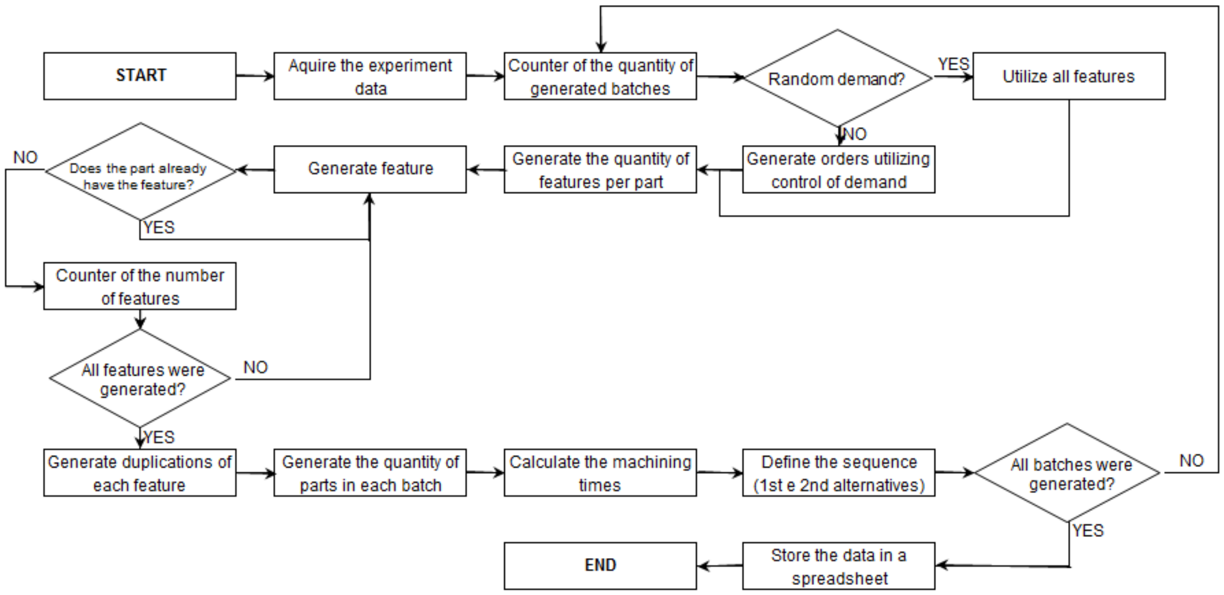


Figure 4. Flowchart for generating the production orders

Usually the logic of a system in the Arena software can be represented through the modules available in each template. However, since the model in this paper has a level of detail slightly higher than usual, it was necessary to use the Visual Basic language. Therefore, a program in Visual Basic was developed with support programs integrated with models in Arena. Figure 5 illustrates a flowchart describing the models simulation.

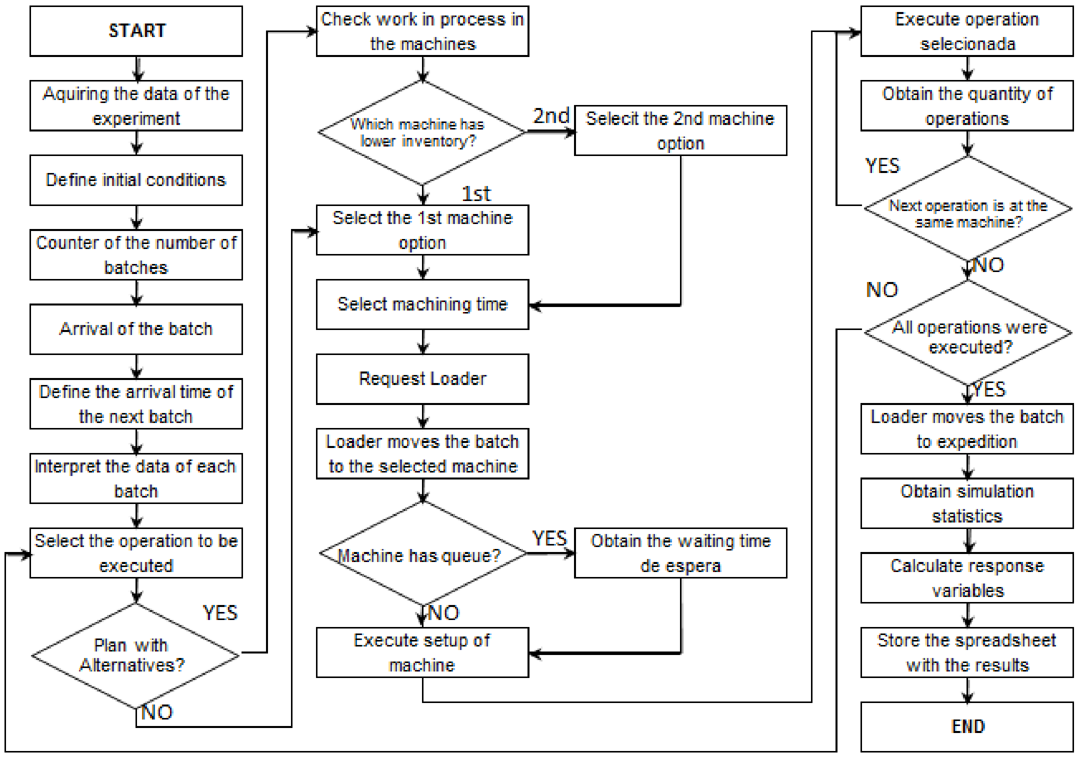


Figure 5. General flowchart for the models simulation

4.2 Simulation of the layouts

With the models ready and the production orders generated, the simulation stage starts. With respect to input parameters for the Arena simulation software, 10 replications were performed. The time shown in the report is in minutes, and it is considered that the manufacturing system works 24 hours a day, nonstop.

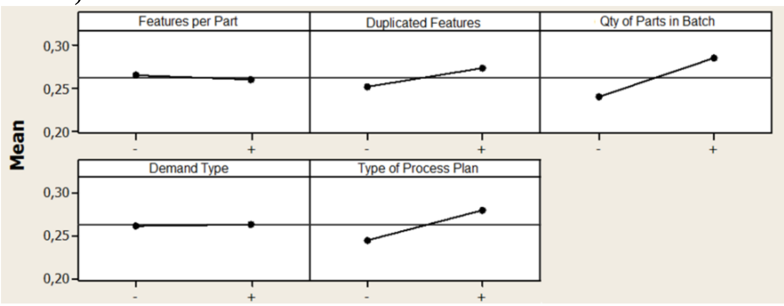
During the simulation tests the models were simulated in a low speed in order to visualize possible errors, and also to check whether the model was running properly.

5. RESULTS

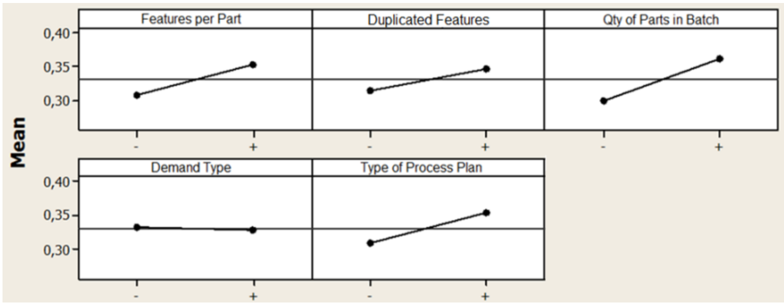
This section is divided into two stages. Firstly the results for each type of layout with respect to the use of resources are obtained. Secondly, the layouts are compared, seeking to find in what situations each layout is more suitable.

In the first stage of analysis of results, the main effects for the layouts, which were obtained using the software Minitab®, were similar (Figure 6). In order to facilitate the understanding of the results, a summary is shown in Table 3, which shows the relationship of each control factor with the utilization of resources in each layout. It should be mentioned that the analysis of statistical significance was done by calculating the Analysis of Variance (ANOVA) with the P value calculated for the level of significance of 0.05 (Montgomery, 2001).

Although the layouts had very similar behavior for resource utilization, the average value for the virtual cell layout was higher the value for the traditional cell layout. The complexity of the batches of parts (resulting from the randomness of their formation) contributed to this result.



(a) Traditional cell layout



(b) Virtual cell layout

Figure 6. Main effects plot for resource utilization for (a) traditional cell layout, (b) virtual cell layout

In the second stage of analysis results, the type of layout was inserted as a control factor. Table 4 shows that the type of layout is statistically significant with respect to resource utilization. This analysis of statistical significance was based on the P value found in the calculation of the ANOVA, and compared with the P value estimated in the DOE, which was a 0.05 significance level. The confidence interval of resource utilization for the virtual cell layout was $0.315\% \leq \mu \leq 0.346\%$, which was larger than the confidence interval obtained for the traditional cell layout ($0.250\% \leq \mu \leq 0.273\%$).

Table 3. Control Factors X Resource Utilization in each type of layout

Control Factors	Resource Utilization (%)	
	Traditional Cell	Virtual Cell
Features per part	**ns**	**s**
Duplicated Features	**s**	**s**
Qty parts per batch	**s**	**s**
Type of demand	**ns**	**ns**
Type of process plan	**s**	**s**

s - with statistical significance
ns - without statistical significance

Table 4. Comparison between Control Factors X Resource Utilization

Control Factors	Resource Utilization (%)
Type of Layout	**s**
Features per part	**s**
Duplicated Features	**s**
Qty parts in a batch	**s**
Type of demand	**ns**
Type of process plan	**s**

s - with statistical significance
ns - without statistical significance

6. CONCLUSIONS

In this paper the methods of design of experiments and discrete event simulation were used to investigate the influence of factors in the resource utilization of two layouts: traditional cell, and virtual cell. The conducted experiment has the following characteristics that are not usually considered in previous related publications: (a) many resources (21) were considered in the analysis (including loaders), (b) resource utilization was the response variable considered, (c) the procedure for creating parts from features may result in a very high variability of parts.

In the presence of a large variety of parts, which can be formed from 40 different features, the results obtained for the traditional cell layout were worse when compared with the virtual cell layout. Moreover, the traditional cell layout configuration resulted in a significant disadvantage, since the machine setups for the manufacturing process occurred in batches rather than through part flow. With respect to resource utilization, it is noted that the virtual cell performance was better than the conventional layout cell by about 20% in average.

In view of the results obtained, there are scenarios in which the virtual cell layout has advantages. With respect to the use of process plans with alternatives, the analysis should be extended, perhaps with the inclusion of another level for the factor, or two different penalties so that the gains found in the literature can be shown, this being an area that can be investigated in a future work.

7. ACKNOWLEDGEMENTS

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9. RESPONSIBILITY NOTICE