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Overview of the FMS DESIGN GAME

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Abstract

This paper describes a computer based game used for teaching how to design a flexible manufacturing system. Purpose of the game is to make players familiar with the design process and to help them understand the influence of a number of loading and dispatching rules on the performances of the FMS production scheduling. Players can also test their own project against different market scenarios.

After a short presentation of the design process, rules, context and software architecture of the game are presented. The application of the game to university classes of Automated Production Systems has resulted in an improvement in the learning process of the students. A brief description of experience gained by using the game is also given.

The FMS DESIGN GAME software is available free of charge. Ordering procedures are outlined at the end of the paper.

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1. INTRODUCTION

Flexible Manufacturing Systems represent one of the most complex automated production systems. The complexity is generated by the high number of options available for plant configurations (number and type of machines, layout configuration, number and type of buffers, material and tool handling systems) and for scheduling rules (loading and dispatching rules).

J. O. Riis (ed.), *Simulation Games and Learning in Production Management*

Due to this complexity, the design process faces many problems and difficulties as well. Though design procedures are available, a good understanding of the system and of the correlations among system components is therefore a prerequisite for a good project.

For these reasons, simple theoretical explanations and traditional teaching examples have not proved very effective in teaching Flexible Manufacturing Systems. The alternative of using a game seems to be new and more effective.

Purpose of the FMS DESIGN GAME is to make students (i.e. players) familiar with the FMS design process and to help them understand the influence of different plant configurations and management choices on the system itself.

This paper is articulated as follows. In the next section the design process framework used in the game is introduced; Section 3 is dedicated to the game itself, whereas section 4 the design environment available in the game is explained. Software architecture is the topic of Section 5, in which software and hardware features are presented. In the last and conclusive section, experience gained by using the game is reported.

2. THE FMS DESIGN PROCESS

In this section, the design process which the FMS DESIGN GAME refers to is described in some detail.

The design process consists of the following phases:

- selection of main plant components: based on the requested production type, volumes and flexibility, this phase generates different alternatives for component choice;
- general plant layout;
- rough design (Average Workload Design Method): the number of machine types and the handling systems facilities required to fulfil the demand are calculated with a good degree of approximation based on average annual workloads;
- detailed design: based on the use of a queuing theory and of simulation techniques, the designer can set detailed aspects of the final system project;
- performance test: this phase is addressed to perform sensitivity analysis on the designed system by varying product mixes, required product volumes, management alternatives, etc. The behaviour of the designed system is tested against situations it was not designed for.

2.1 The "Average Workload Design Method"

After determining the types of machines the designer is going to use in his/her project, a rough design can be made by applying the following equations on the basis of the technological requirements of the workpieces to be manufactured,

load on machine type i : $L_i = \sum_{j=1}^{N} \frac{t_{ij} \cdot x_j}{C_s}$ [1]

available time : $Ha(n_s) = n_s \cdot H_t \cdot C_m \cdot C_{pi} \cdot C_{pp} \cdot C_n$

number of type "i" machines: $n_i = \frac{L_i}{Ha(n_s)}$

where:

t_{ij} = operation time of job j on machine type i
x_j = annual demand for workpiece j
c_s = coefficient (0÷1) to consider scrap;
Ha(ns) = actual available hours per year
n_s = number of shifts
Ht = hours per shift (theorical)
c_m = coefficient (0÷1) to consider maintenance
c_{pi} = coefficient (0÷1) to consider pallets interference
c_{ti} = coefficient (0÷1) to consider tools interference
c_{pp} = coefficient (0÷1) to consider production planning inefficiency
N = number of different workpieces

2.2. The queuing theory.

Purpose of the queuing theory is to calculate with a statistical approach the minimum number of buffers required to obtain the minimum throughput able to meet the demand.

The manufacturing system is modelled as a queue network made up of n workcenters (n was calculated in the previous step) and of a transport unit. By using a statistical approach [2] it is possible to estimate the throughput of the system for each buffer capacity value.

Assuming there is always a job in the queue waiting to get into the system, throughput depends on system *capacity C*, defined as the total number of available buffers. By calculating throughput for each C value recursively, it is possible to roughly determine the total number of buffers required to reach the desired throughput. This value is used in the following design phase as an estimation.

2.3. Simulation

Both the average workload design method and the queuing theory model are undetailed approaches, since they are based on average and statistical calculations. Because of the complexity of the system and the high investments involved in a FMS, much more careful results and information are needed.

Based on a detailed model of the manufacturing system under design, discrete simulation gives the designer a flexible and accurate tool to get information about the project. Using the outputs of the two previous phases, a preliminary model is designed. The outputs of the simulation campaigns are used to modify and improve the models recursively until alternative designs with satisfactory performances are generated.

The benefits of simulation in the design FMS process are:

- a much more detailed analysis;
- transient analysis;
- testing of different operative policies (loading and dispatching rules);
- what-if analysis.

3. CONTEXT OF THE GAME

In this game players are engaged in designing and managing a Flexible Manufacturing System. The player, whose role is to be a designer for a company selling FMSs, has been asked to personally follow the project of a plant a customer is going to buy. Obviously, the customer company has asked other competing firms for a similar project. Therefore, the player is engaged in a competition with other designer-players.

The winner is the player who succeeds in designing the best FMS, evaluated by a multi-criteria function built by the customer company. This function considers plant (plant configuration), economic (investments) and management aspects (delays, # of late jobs, etc.).

3.1. Game procedure.

The game starts by giving the player information about part types, demand, part routings, choice of available machines (special or general-purpose) and the number of coefficients reducing the availability of machines.

Based on these data, the game is structured in the four following sessions:

1. Plant design: in this first step the manufacturing system is designed by calculating the number of machine types to be used, the number of I/O buffers, the number of system buffers and pallets. This step is carried out as described in the previous section. Different software tools are available to the player:

- a spreadsheet to evaluate the number of required machines (Average Workload Design Method);
- a queuing theory software module to evaluate the number of required buffers;
- a parametric and interactive simulation model suitable to the player's design choices.

In this step, players deal just with design aspects of FMS. This allows them to face the complex problem outlined in the introduction by considering one aspect at time.

2. Production scheduling: In this second step, players mainly deal with the analysis and the understanding of the influence of a number of loading and dispatching rules on the performances of the FMS short term production planning.

The available loading rules are [3]:

- BL1: this rule loads the job which makes the current machine workloads as uniform as possible;
- BL2: this rule loads the job which keeps the ratios between machine workloads and the current bottleneck constant over time;
- BL3: the aim of this rule is to keep the ratios between machine workloads and the bottleneck constant over the planned time span;
- RND: jobs are loaded at random.

The available dispatching rules are:

- FIFO (first in first out): the job that first entered the machine queue is loaded first;
- LIFO (last in first out): the job that last entered the machine queue is loaded first;
- EDD (earliest due date): the job that has to be delivered first is loaded first;
- LWRK (least work remaining): the job with the minimum remaining global workload on the machine is loaded first;
- TWORK (Total Work): the job with the minimum total workload (sum of all operating times) is loaded first;

3. Market scenarios: the design and the scheduling choices made by players were based on a forecasted production mix. This step performs a sensitivity analysis on the designed FMS. A number of different scenarios with varying capacities and product mixes are available. The aim of this step is mainly to help players understand differences in behaviour between special and general-purpose machines. Scenarios can be prepared by teachers in a very simple manner.

4. Evaluation: as was stated in the introductory section, FMS are complex systems. The choice among alternative designs considers many evaluation parameters such as cost, throughput, occupation of resources and so on. Moreover, some of these parameters are conflicting; therefore, the choice becomes a multi-criteria decision.

A multi-criteria evaluation function is provided to players in order to assess projects and to select the winner.

4. DESIGN ENVIRONMENT

Due to the high number of different components (machines, material handling systems, I/O buffers, load and unload stations, tool buffers, tool handling systems), a high number of possible solutions results from the combination of available choices in the FMS design process.

Within the structured framework of a game, it is not easy to deal with such a high number of combinations. Moreover, our purpose is teaching; that is why a limited number of solutions was selected out of the large range of viable alternatives.

The design environment is therefore configured as follows:

- machine environment: special and general-purpose machines are available;
- buffer environment: players can choose between configurations with a common system buffer or a I/O buffer for each machine. In the latter option, players have to select the number of buffers to be used for each machine type;
- loading rules environment: four different loading rules are available (BL1, BL2, BL3, RND);
- dispatching rules: if a system buffer was selected, different rules are available;
- material handling system: a shuttle-type handling system was used. No options are available for this component;
- the tool buffer and tool handling system are not given further consideration in the game.

5. SOFTWARE ARCHITECTURE

In this section the software architecture of the game is described. The FMS DESIGN GAME was developed based on the Microsoft Windows environment. Within this environment the following software packages were used:

- Excel 4.0;
- a Fortran module;
- WITNESS 4.0.

These packages were structured in the following hierarchical way

Game control and management were implemented with an Excel Macro Sheet. This document is displayed as a front-end screen (user interface) from which he/she is able to retrieve all the phases described in the previous sections simply by clicking one of the available buttons. Once the running module is over, control returns to the front-end screen, which becomes available for another selection.

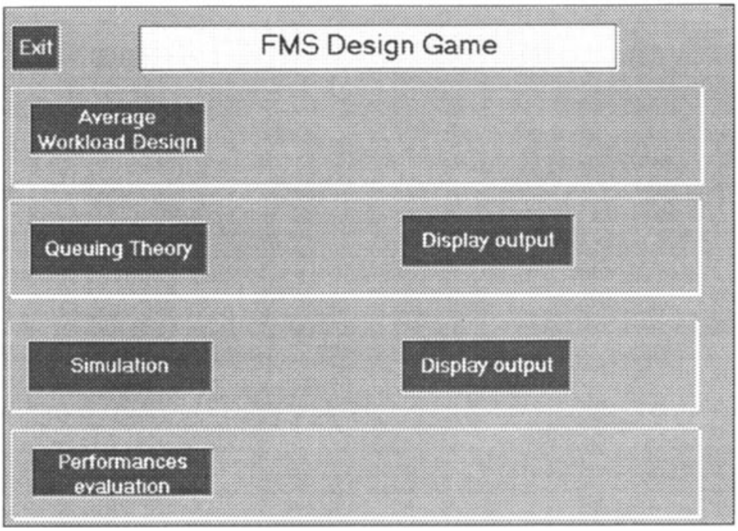

Figure 1. Front-end screen of the FMS DESIGN GAME.

The buttons available on the front-end screen are (Figure 1) as follows:

- *Average Workload Design Method*: when this button is clicked, an Excel worksheet provides the player with a tool which helps him calculate the number of required machine types by using standard worksheet functions available in Excel. The player will find in the worksheet all the data he/she needs to solve this phase, but no completely structured solutions. After completing this worksheet by entering the formulas for the Average Workload Design Method (see section 2) in the cells, players can proceed to the next step.
- *Queuing Theory*: when this button is clicked, an Excel dialog box lets the player set inputs for the running of a Fortran module which calculates the manufacturing system throughput. Once this task is over, control returns to the Excel front-end screen;
- *Simulation*: this is the most interesting and complicated part of the game. Sixteen different models were designed to give players maximum flexibility and availability of choices. These sixteen models result from the combination of 2 machine type options, 2 buffer type options and 4 loading rule options.

When the simulation button is clicked, a first dialog box lets the player set the configuration which he/she wants to run on the model. Once the configuration has been selected, a second dialog box is displayed, enabling the player to set the required simulation entries (i.e. number of machines, number of buffers and max. number of pallets allowed by the system). This dialog box varies according to the configuration which was selected.

When the selected choices are confirmed, the simulation run starts writing results to a pre-selected output file. Once the run simulation ends, control of the game returns to the front-end screen. The player is now able to display the simulation outputs by clicking *Show Results.*

The sixteen models were designed in a parametric way: once a configuration type has been selected, players can enter different numbers of machine, buffers, pallets by means of dialog boxes. An Excel Macro reads the values entered and writes a batch file which is recognized by the selected Witness models and reflects the choices made by the player. Fig. 2 shows one of the available simulation models.

- *Evaluation:* this button introduces players to a dialog box that allows them to enter values for the evaluation of the designed manufacturing system. Then control goes back to the Excel macro sheet front-end screen.

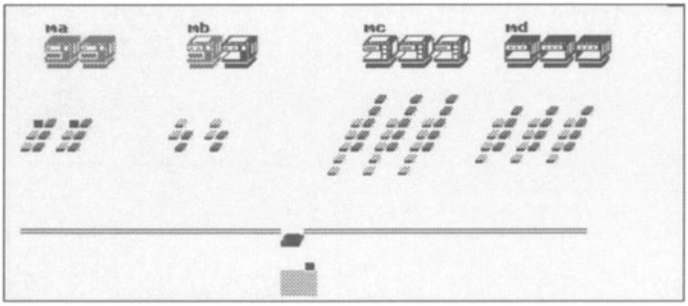

Figure 2 Example of the FMS DESIGN GAME simulation model.

6. EXPERIENCE GAINED BY USING THE GAME

For some years now the use of software tools has been a quite developed approach used in university classes in the area of Production System Design and Management at Politecnico di Milano. As a matter of fact, a lot of practical lessons have been computerized in the last few years.

By designing the FMS DESIGN GAME we wanted to test a new approach to practical lessons by adding some specific game-like features, the main one being the competition among students. In our game, players (students) have to design a project which is not the best in absolute terms, but which is better than those designed by the other students. The competition created by the game among students helps teachers keep their alertness and involvement high.

Moreover, a big improvement in comprehension was experienced through the adding of graphics facilities to the simulation package.

According to the classification method suggested in [4] by Riis et al., the educational purpose of this game is also to make students aware of the influence of a number of loading and dispatching rules on the performances of the FMS short term production scheduling and to make them more involved in the proposed design process. As to the kind of player, our game falls into the single decision-maker category.

7. CONCLUSIONS

This paper introduced readers to the FMS DESIGN GAME, which has proved a powerful tool for the teaching of the FMS design process.

Due to the complex correlations to be found in Flexible Manufacturing Systems, traditional teaching approaches have not proved to be very effective, whereas the game approach makes students much more involved in the comprehension of this topic.

Game as a teaching method has proved a very effective tool to enhance students involvement and comprehension.

SOFTWARE AVAILABILITY

The FMS DESIGN GAME can be obtained free of charge. The software package includes the following files: the Excel Macro Sheet, a compiled fortran module and sixteen simulation models.

A license for Microsoft Excel release 4.0 or later and a license for WITNESS release 4.0 or later are required to run the software.

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