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USING SIMULATION FOR MANUFACTURING PROCESS REENGINEERING – A PRACTICAL CASE STUDY

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ABSTRACT

This paper presents a simulation study carried out to solve a problem of manufacturing process reengineering. The specific company in which the study took place is a medium size manufacturer of chest freezers, which required an in-depth analysis of its manufacturing operations in an attempt to increase its throughput and overall productivity. A simulation model of the current manufacturing system was developed to ascertain its limitations and problems. The relevant operational performance measures were analyzed in order to allow for the proposal of a set of changes to the actual manufacturing operations. In order to support the decision process concerned with the implementation of the suggested changes, these were included in the simulation model. The outcome of the simulation study was taken into account by the decision-makers and the recommendations are being implemented.

1 INTRODUCTION

The undergraduate students of the Industrial Management and Engineering program, at the University of Aveiro (Portugal), are required to take a one-year business internship in a manufacturing company, before being awarded their degree. This paper reports on the collaborative study between the Department of Management and Industrial Engineering of the University of Aveiro and a manufacturer of chest freezers carried out within the context of one of these internships.

The major goal of the study was to assess a set of changes to the company current manufacturing operations that allowed an increase in its throughput and overall productivity. For that purpose, a simulation model of the actual production process was developed, and the relevant performance measures from the simulation outputs allowed for the identification of a set of operational constraints to the manufacturing system performance. The outcome of the simulation study was then discussed with the management and a set of realistic modifications to the manufacturing system was agreed. These changes were included in the simulation model, and in view of the ensuing results obtained most of the changes were accepted and are being implemented.

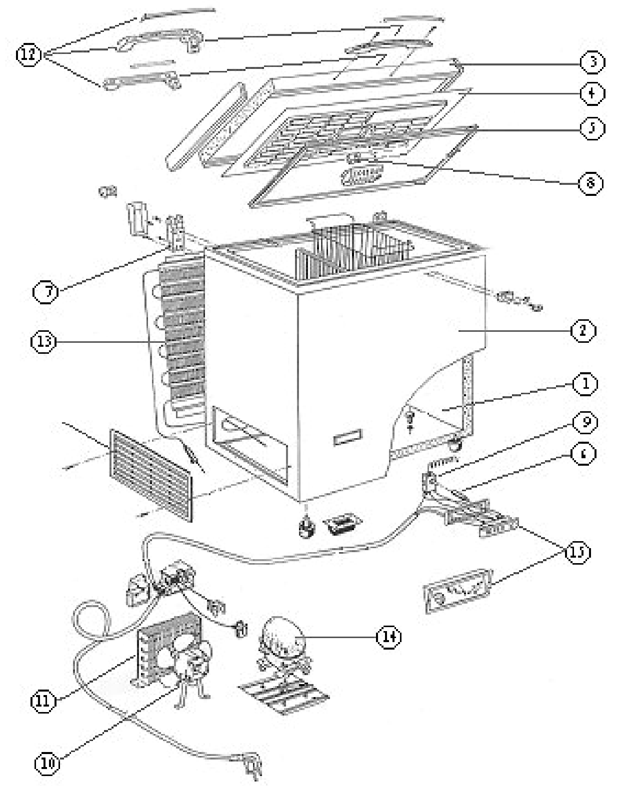
In addition to helping the company reengineer its manufacturing operations, it was our aim to use this project to show the benefits that small-medium size enterprises (SME's) can get from (i) the university business internship program and (ii) from using simulation to fine-tune their manufacturing operations.

2 THE MANUFACTURING PROCESS

The company manufactures four versions of a chest freezer with different usable capacities (HC240, HC320, HC370, and HC460). An exploded view of the chest freezer is shown in Figure 1. Some of the parts used to assemble each freezer are manufactured on the facility (e.g., internal case, external case and lid), while others are subcontracted (e.g., grids, baskets and control panel).

The main manufacturing operations for the production of the chest freezers are the following:

(i) cutting, pressing and bending of metal sheets;
(ii) internal case assembly - assembly of the bottom and side panels (to produce the internal case), attachment of the cooling worm, capillary and copper tube;
(iii) external case assembly - assembly of the bottom, back, lining and side panels (to produce the external case), attachment of reinforcements and foam filling drain;



Legend:

1 – Internal case	8 – Lamp	13 – Condenser
2 – External case	9 – Thermostat	14 – Compressor
3, 4, 5 – Lid assembly	10 – Fan	15 – Control panel
6 – Thermostat tube	11 – Brackets	
7 – Hinges	12 – Handle	

Figure 1: Chest Freezer Parts

(iv) lid assembly - attachment of the different parts that make up the lid of the freezer;
(v) internal case finishing - attachment of the thermostat tube and insulation inspection;
(vi) external case finishing - the external case is sealed with a PVC tape**;**
(vii) cabinet assembly - attachment of the internal case to the external case;
(viii) drying - the lid and cabinet are placed in a dryer (required by the foam filling operations);
(ix) cabinet foam filling - the cabinet in placed in a molding machine and filled with foam. There are four cabinet foam filling machines, one for each version of the chest freezer**;**
(x) lid foam filling - same as above, but for the lid;
(xi) lid finishing - hinges and lighting are fixed to the lid**;**
(xii) assembly of the thermostat, fan and brackets;
(xiii) assembly of the lid and handle;
(xiv) assembly of the condenser;
(xv) electrical assembly - attachment of the compressor, control panel and soldering of various parts;
(xvi) vacuum of the refrigeration system;
(xvii) gas filling - the refrigeration system is filled with gas and checked for leaks;
(xviii) final inspection - a series of standard tests are conducted;
(xix) cleaning and packaging.

The operation sequence is shown in Figure 2, and is the same for the four versions of the chest freezer.

The plant layout is shown in Figure 3. The operations that precede the drying operation are performed in the pre-drying department (operations i through viii), which is organized like a conventional job-shop being all the materials handling done manually. The succeeding operations (operations ix through xix) are performed in the post-drying department, which is organized as a paced assembly line (except for the foam filling operation), being all the materials handling done mechanically.

In the actual manufacturing system the paced assembly line, in the post-drying department, was clearly underused, and some changes were needed in the pre-drying department to increase the manufacturing system overall throughput.

3 DEVELOPMENT OF THE SIMULATION MODEL

The contrasting levels of task and material handling automation between the pre-drying and post-drying departments pose a major problem when fine-tuning the manufacturing operations. One could easily use an analytical technique for balancing the assembly line in the post-drying department, but the operational variability induced to the manufacturing system, as a whole, by the operations performed in the pre-drying department, renders the optimization of the manufacturing system performance impossible to achieve by analytical techniques.

This evidence was crucial on the choice of simulation as the tool to carry out the study reported in this work. In fact, as several authors have reported (e. g. Buzacott and Shanthikumar 1985 and Banks and Gibson 1997), the use of simulation is particularly advantageous when the complexity or operational variability of the systems under study renders the application of purely analytical models impossible. This is a consequence of the fact that simulation is the only technique able to supply a detailed and dynamic view of the systems, unlike any other analysis tools (Bell 1994).

Adding to this, the fact that simulation analysis allows access to equipment requirements and operational procedures, via construction and examination of a model relative to system performance evaluation (Law and McComas 1997), makes simulation a perfectly suitable tool to tackle the problem under study.

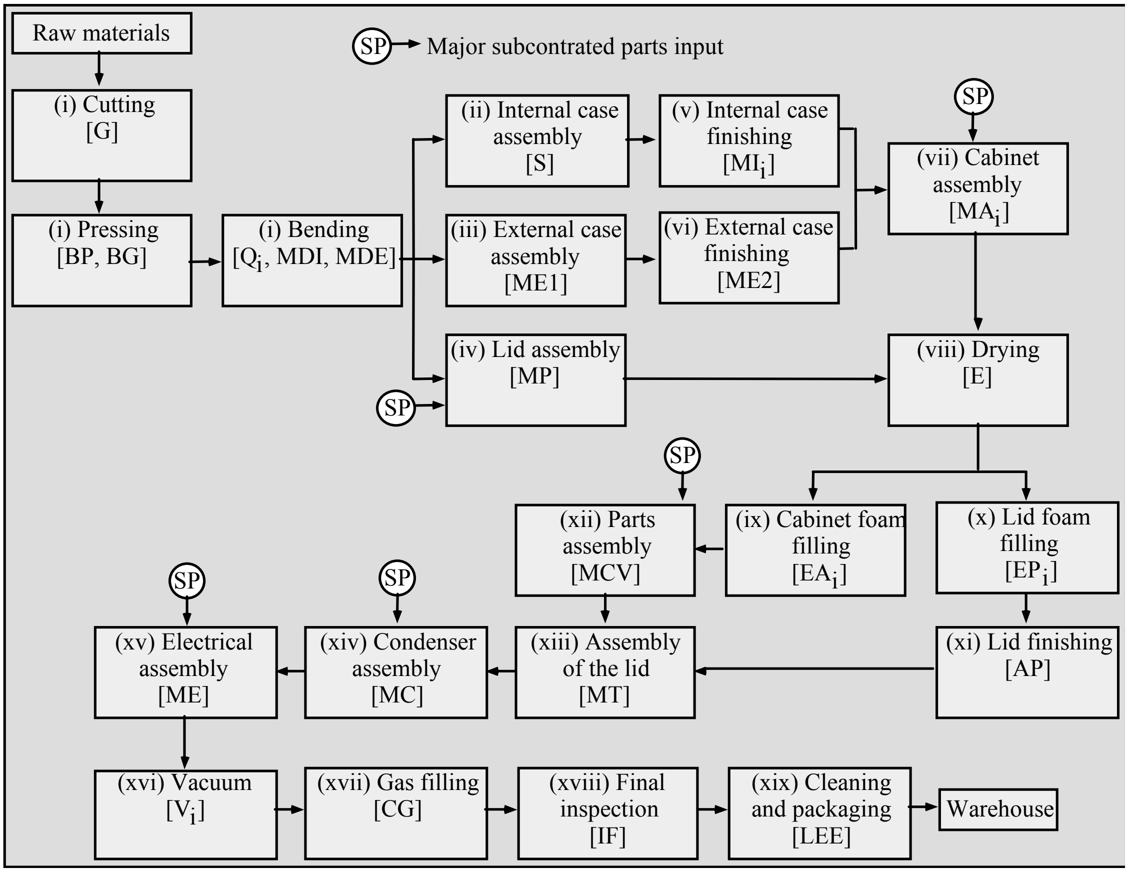


Figure 2: Operation Sequence for the Chest Freezers ([X] is the Machine or Area – Shown in the Plant Layout Depicted in Figure 3 where Operation X is Performed)

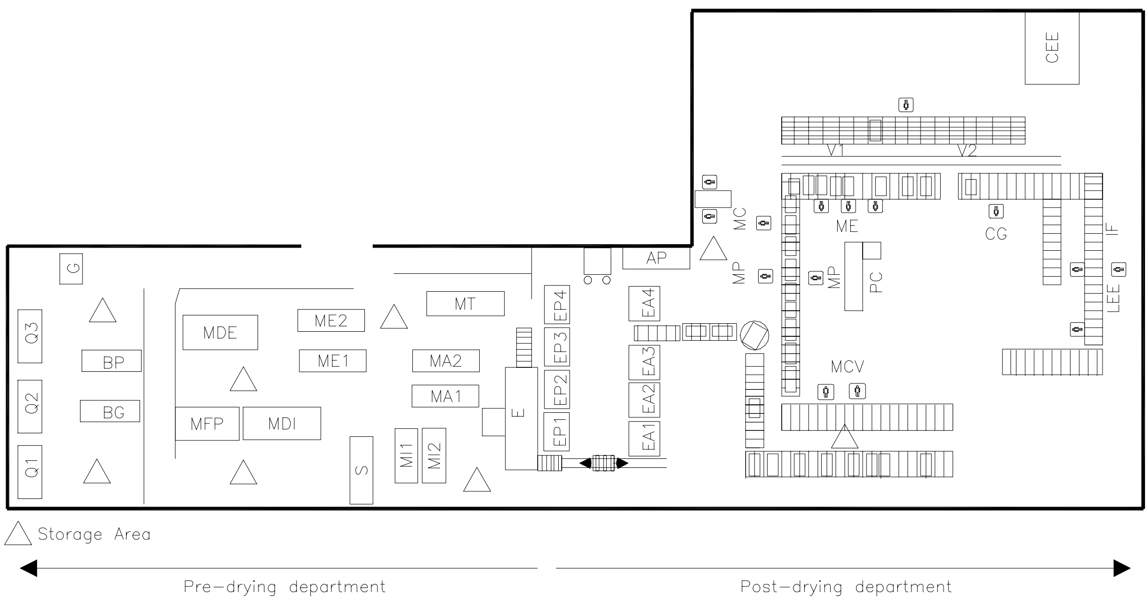


Figure 3: Plant Layout

3.1 Overview of the Modeling Process

In the first phase of the simulation study a simulation model of the actual manufacturing system was developed, using the Arena simulation software (Kelton and Sadowski 1998). This model was used to: (i) allow for a better understanding of the actual system, (ii) ascertain the critical resources of the system, (iii) gain the confidence of the decision makers regarding the used methodology and (iv) validate the assumptions made to build the simulation model.

The outcome of the simulation study, carried out in the first phase, confirmed that the pre-drying department throughput induces a low usage rate of the post-drying department assembly line. It also revealed that an increase in the pre-drying department throughput would make the foam filling operation the bottleneck of the manufacturing system. This evidence led to the proposal of a set of feasible modifications to the manufacturing system to attempt an increase of the manufacturing system throughput and of its overall productivity, namely:

- (i) manufacturing process changes;
- (ii) introduction of new equipment;
- (iii) technological upgrade of some of the equipment;
- (iv) automation of the foam filling operation;
- (v) replacement of two parts, currently manufactured in the plant, by a new one bought from an external supplier.

The goal of the second phase of the study was to analyze the impact of the proposed changes on the overall performance of the manufacturing system. The performance measures selected to evaluate the impact of these changes were the following:

- (i) throughput;
- (ii) work-in-process (queue sizes);
- (iii) utilization of resources (labor and equipment).

3.2 Modeling Assumptions and Data Collection

In developing the simulation model particular care was taken to model the production process as close to reality as possible. This was easily accomplished for several reasons: (i) throughout the duration of the project one of the team members worked fulltime on site, (ii) large amounts of historical data related to the processing times were available and (iii) the control decision rules were clearly established and posed no major modeling problems.

The wide availability of historical data for the processing times of all the tasks involved in the manufacturing process (and for each version of the chest freezer) allowed the fitting of proper distributions to this data. The distributions and its parameters were selected using the Arena's software module Input Analyzer (Sadowski and Bapat 1999). The goodness of fit evaluation limited the selection, in most situations, to lognormal distribution.

As regards material handling operations, only those that are relevant for the manufacturing system performance were modeled. Due to the unavailability of historical data for the transport times, a uniform distribution was used to model them (Hoover and Perry 1990). In material handling operations where the introduction of selective changes to the loading, unloading and transport tasks was foreseen, these were modeled separately.

As neither maintenance procedures nor equipment failures influence significantly the regular operation of the system, these were ignored.

The production is currently scheduled so that the number of units of each version of the freezer produced daily is roughly the same. So, the materials (metal sheets) enter the manufacturing system in its beginning stages (cutting, pressing and bending) in fixed size lots, and are evenly allocated to the production of each version of the freezer. The other materials entering the manufacturing system, at later stages, are subcontracted parts, which are picked from the stock only when needed.

3.3 Verification and Validation

The model was verified and validated using different techniques (Sargent, 1999): (i) animation, (ii) internal validity, (iii) predictive validation, (iv) structured walkthrough and (v) examination of model traces.

The team member who accompanied the project on site was crucial in this process, as she combined the knowledge of the simulation tool being used with the perception gained on the manufacturing process details. Not only could she easily explain to the company's staff the modeling details in structured walkthroughs, allowing for the detection of modeling errors, but also she contributed to assure that the model was faithfully reproducing the operational procedures of the actual manufacturing system, by examining model execution traces. Nonetheless, animation and the comparison of predicted performance measures with the known behavior of the current system in key operations (predictive validation), were the dominant techniques employed, as they allowed the involvement of the decision makers in the validation process.

The verification and validation process was also crucial for gaining the decision-makers' confidence in the outcome of the simulation study.

4 SIMULATION EXPERIMENT AND RESULTS

The random nature of simulation inputs renders the simulation runs to produce a statistical estimate of the performance measures not the measures themselves. In order for an estimate to be statistically precise (have a small variance) and free of bias, the following parameters were specified (Law and McComas 1998):

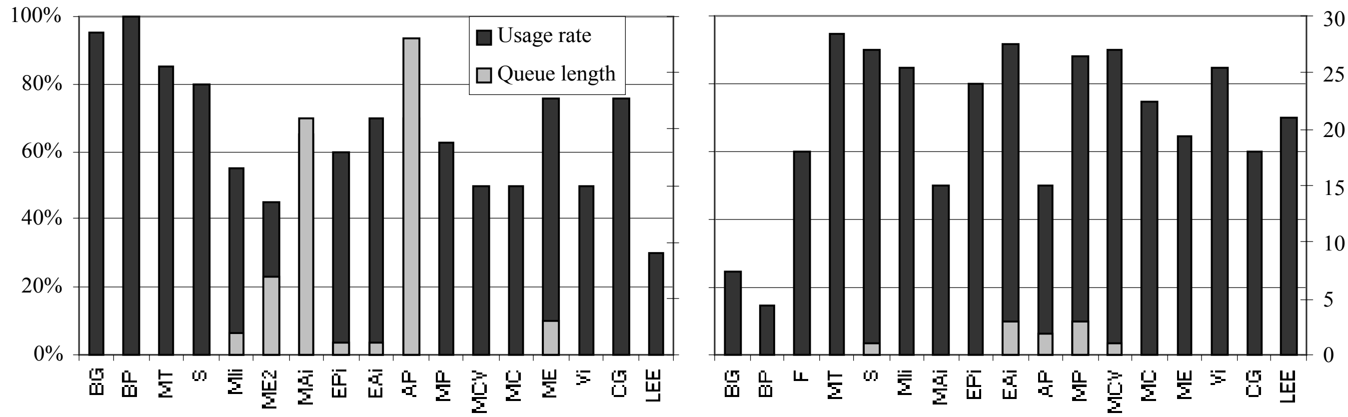
(i) Length of each simulation run = 2400 minutes (one work week).
(ii) Number of independent simulation runs = 5.
(iii) Length of the warm-up period = 480 minutes.

The outcome of the simulation study with the current manufacturing system showed that:

(i) the predicted number of units produced, for each version of the freezer, is similar to the number actually produced (on average);
(ii) two of the machines in the earliest stage of the manufacturing process are used to their full capacity - machines BP and BG in Figure 3 (see Figure 4 (a));
(iii) most of the assembly operations in the pre-drying department have usage rates in excess of 60% (see Figure 4 (a));
(iv) the cabinet foam filling machines have an average usage rate of 70%, being an important part of this rate justified by the loading/unloading operations;
(v) work-in-process is significantly high only in the lid and cabinet assembly operations. This can be mainly justified for two reasons. First, the bottleneck machines are on the earlier stages of the production process and, as these machines are supplied directly from the raw materials warehouse, they do not accumulate work-in-process. Second, WIP for the dryer and foam filling machines is stored before the lid and cabinet assembly operations. This is due to the fact that parts go through these operations only if it is assured that they can immediately proceed to the dryer and foam filling machines - due to technological constraints on these processes (WIP is shown in Figure 4 for the operations where queue length is noticeable).

To solve these problems a set of changes were discussed with the management and incorporated in the simulation model, namely:

(i) to procure a new machine to partially replace machines BG and BP (machine F in Figure 4(b));
(ii) to procure a new machine to perform part of the tasks in the external case assembly operation (in the actual systems it is a completely manual operation);
(iii) to automate the loading/unloading task in the cabinet foam filling operation;
(iv) to subcontract a new part to replace the external case bottom and lining that did not required any processing.



a) current production system

b) modified production system

Figure 4: Usage Rates and Work-in-Process for Key Operations in the Production System (Operation ME2 was Discontinued and Operation F is a New Operation)

A change in the production schedule was also taken into account. The management forecasted an increase in the demand of the smallest version of the chest freezer (HC240), so the number of units produced of this version should be the double of the others. These changes were incorporated into the simulation model, and the outcome of the simulation study revealed, as expected, a shift of the bottleneck operations to the manual assembly operations in the pre-drying department. This still constituted a problem, because the usage rate in the assembly line in the post-drying department was still low. This problem was easily solved, as it only required increasing the workforce in some operations. This modification was also introduced in the simulation model and the outcome of the simulation study showed:

(i) an increase in the throughput (from 231, 231, 231, 231 to 602, 300, 301, 301 units per day of the HC240, HC320, HC370, and HC460 versions, respectively);
(ii) a shift in the bottleneck operations from the machining ones to the manual assembly ones (see Figure 4);
(iii) a significant decrease in the work-in-process (see Figure 4);
(iv) the assembly line in the post-drying department was able to absorb the throughput increase, with minor adjustments (see Figure 4).

As one can see, the manufacturing system operation is now smoother, that is, the workload is now more evenly distributed (at least in the most demanding tasks) and WIP is considerably lower.

5 CONCLUSIONS

The development of successful projects involving both the universities and the industry is, generally, difficult to undertake. Both parties are to blame - academicians, because they usually tend to use a scientific language meaningless to managers and engineers; people in the industry because they usually concentrate on their short term concerns and so do devote insufficient time and effort to the project development. In the project presented in this paper this difficulty in communication was overcome, due to the fact that one of the university team members worked fulltime within the company throughout the duration of the project. She not only established a privileged communication channel between the university and the company, but also directed management and staff attention to the project.

The company's goals were fully attained and, to best prove it, all the suggested modifications to its manufacturing operations are being implemented, as a result of the outcome of the simulation study.

The university's goals were, first of all, to successfully complete the study, to show that companies can benefit from the business internship program offered by the university. Secondly, to get a successful case study of university/industry interaction in the simulation field, that can be used as a showcase to the benefits that SME's can get from the use of simulation.

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