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"BUILT TO ORDER" MANUFACTURING WITH FLEXIBLE PRODUCTION

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Abstract: One of the main problems that manufacturers are now facing is how to adapt to the market requirements with regard to customization and delivery date. One answer to this problem is to find and utilize flexibility within the work organization.

The aim of this work is to find a mathematical representation of these methods and to find the optimal result, or the best possible result in a reasonable time, using an economy based function of evaluation. *Copyright © 1998 IFAC*

Keywords: production management; scheduling; inventory control; manufacturing systems; optimization; mixed integer programming.

1. INTRODUCTION - PRESENTATION OF THE PROBLEM

This study deals with the production of large assemblies, characterized by their high value at process end, the low throughput of assembly lines and particularly long production cycle, in a highly competitive environment and under strong seasonal variations. The general problem is to meet delivery deadlines while avoiding a large stock of finished products by finding the best schedule (the meaning of "best" will be discussed later on). The production organization resembles a flow shop, with some differences.

The seasonal fluctuations of the deliveries have strong consequences on the workload: a regular workload all year long is only possible if some of the products are built up long before their delivery dates and others being possibly delayed. The latter should be avoided because of the competition between the major companies; so a given firm has to handle inventory of finished products.

After looking at several methods of flexibility, various criteria and heuristics to optimize the workload schedule will be discussed. Then some aspects of the mathematical formulation of the problem will be looked at.

2. OBJECTIVES - FLEXIBILITY - CRITERIA

The goal is to find organizational solutions that minimize the storage time, while at the same time avoiding strong variations in the workload schedule. In effect, the challenge to manage is to come up with the best balance between "Just in Time" production and social stability.

The scheduling problem is, as usual, characterized by the tasks and the constraints of the production process (GOTH, 1993).

An example of delivery planning over two years is shown in Fig. 1., and is characterized by two high delivery rates period each year.

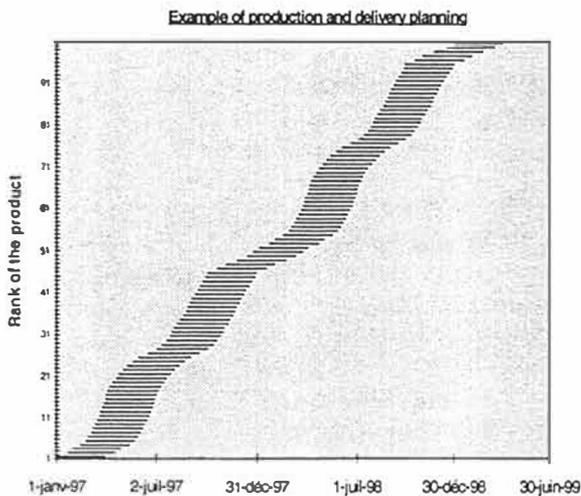


Fig. 1: Example of production and deliveries planning

2.1 Objectives

The aim is to provide scheduling solutions with very low inventory level, short production cycles and acceptable perturbations of the workload schedule. Unfortunately the evaluation of the third term is quite difficult and cannot be easily measured neither as a cost nor as a duration.

To avoid the financial cost incurred by the storage of finished products, the final part of the production process must work using a « Just In Time » policy. If intermediate storage is located prior to the final assembly line, any preceding process can still obey a fixed rate policy (Benouhiba-Zelfani F. *et al.*, 1997).

2.2 Smoothing, leveling and adaptation

This part deals with the presentation of several methods, which are called *flexibility tools*. The use of these methods should allow "Just in Time" production while avoiding high perturbations level on the workload schedule. In addition to *smoothing* and *leveling* methods, the principle of *adaptation* will be described.

In most cases, there is a conflict between flexibility and stability. But, in fact, stability is needed to ensure the success of flexibility and to avoid chaotic and confused management: the flexibility is the intermediate response between the rigidity and the overreaction (Volberda H. W., 1996).

Leveling and smoothing allow the schedule of the tasks to be modified and (with or without altering the deadline, respectively) the workload to the workforce available to be adapted. The method called « adaptation » relies on the methods available to reduce the gap between the mean and the needs.

Let's explain these two concepts by the use of two simple diagrams, showing the curve of the means and the curve of the needs as a function of time. Three different situations may occur:

1. The level of the means exceeds the level of the needs: under capacity and wasted resource;
2. The level of the needs exceeds the level of the means: overcharge, external manpower is needed;
3. The level of the means equals the level of the needs: that is the kind of situation that every firm wishes to face.

On one hand, methods such as smoothing and leveling aim to flatten the curve of the needs to remove the peaks (high activity period), which would require extra manpower, and the gaps (low activity period), that would lead to wasted resource capacity (Fig. 2).

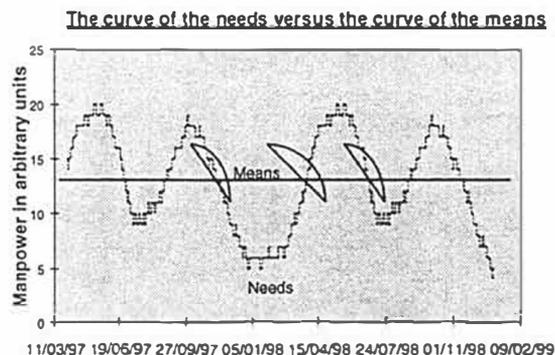


Fig. 2: The curve of the needs vs. the curve of the means

On the other hand, adaptation acts on the curve of the means. The simultaneous use of these two kinds of methods (Fig. 4) can reduce the discrepancy between needs and means at the least cost.

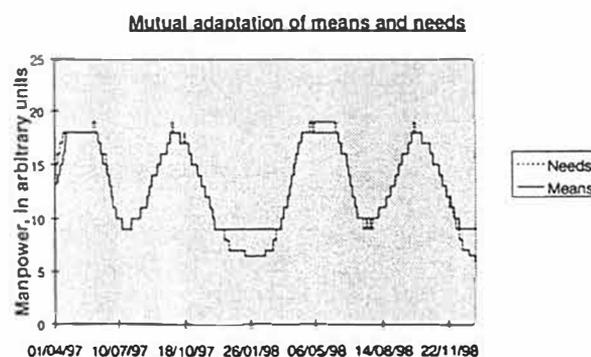


Fig.3: Mutual adaptation of means and needs

Some ways in which a workforce can be smoothed or leveled are listed below:

- A slight modification of some delivery dates;

- Choice of the duration of the holiday's closures;
- The number of working days per week (i.e. to decide if work must be done on week ends, and on which workplaces);
- The modulation of the assembly cycle on each workstation (the manpower needed is inversely proportional to the assembly cycle);
- The organization of shifts: operating two shifts, three shifts, etc.

The second category has many more social influences, because these methods deal with the number of workers, the working hours and the skills; then, it is possible to:

- Increase the number of workers by hiring an external workforce;
- Adjust the daily (or weekly) working hours depending on the workload;
- Use the ability of the workers to perform several different types of tasks.

2.3 Criteria

Two kinds of criteria have been defined to evaluate each solution (Rosenblatt, M. J. and H. L. Lee, 1996). First of them are financial criteria:

- Financial cost of storage and work in progress;
- Cost of the work that has been done;
- Cost of inactivity (low activity period of the workload schedule);
- Cost of utilization of each flexibility tool.

But each of the consequences can not be measured with currency unit. Some of the social implications are much more difficult to appreciate. For example, let's consider the perturbations of the workload schedule; a manager would define some constraints to keep it as smooth as possible:

- by limiting the variations of the manpower between two consecutive days, that can be measured with the mean daily variations of the manpower;
- by avoiding high inactivity rates; the inactivity rate can be defined as the ratio between average manpower and the maximum manpower;
- by modifying the work organization as seldom as possible.

As a consequence, the result will be a combination of the financial evaluation (the "cost" of the solution) with some constraints placed on the level of the perturbations.

3. LOOKING FOR HEURISTICS

Because of the industrial aspects of this problem, the number of data that have to be processed can be especially high (for example, two years of production including deliveries and production cycles); then the computational time to find an exact solution to the optimization problem can easily exceed reasonable limits. That is why the separate use of heuristics for each method of flexibility seems to be a good solution. Some authors have already envisaged the case of using heuristics for the job shop problem (Agrawal A. and al., 1996).

The main data are:

- The delivery planning;
- The upper and lower limits on the production cycle for each workstation;
- The workload for each workstation;
- The cost of the product at each step of the process;
- The interest rate for the storage and the work in progress;
- The constraints on the level of perturbations allowed;
- The cost of each method of flexibility.

A sequential and "manual" (i.e. using computers only to compute the planning and the workload schedule) process to solve the problem has been developed: each method is applied successively to obtain a solution close to the optimum, with the possibility of repeating a method in the process. The best sequence of application was found by studying the effect of different combination on some industrial cases.

One of the main difficulties with the problem is the nature of the optimum which is partly quantifiable (cost of the work in progress, production cycles, number of belated deliveries, sum of the lateness, etc.) and partly unquantifiable (perturbations on the workload schedule, social consequences, etc.).

These heuristics have given good results and now must be "automated" using such methods as genetic algorithms, Tabu search, simulated annealing (Lee, J. K. and Y. D. Kim, 1996).

A study of the sensitivity of each solution should be conducted. The results of this study will be obtained by comparing each method to a benchmark situation (delivery planning, constraints, etc.). The results will provide the cost and the efficiency of each method, as well as the effects of the combination or two methods or more.

Fig 4. shows an example of an objective function, computed using the profit from reducing storage and the cost of the methods as a function of the flexibility.

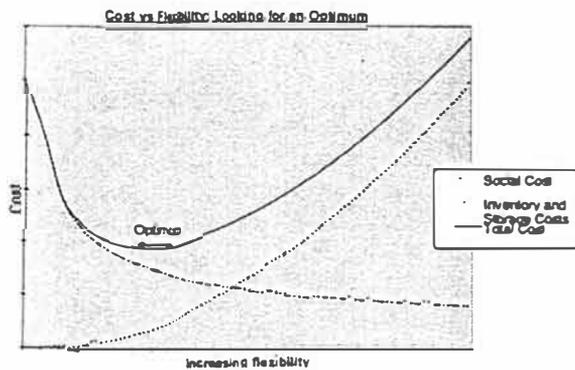


Fig. 4: Costs versus flexibility: Looking for an optimum

The heuristics should provide a good solution, which combines modifications to the delivery dates, production cycles, and the use of human resource, etc., when the total cost curve reaches its minimum value.

4. MATHEMATICAL FORMULATION OF AN EXACT SOLUTION

In order to confirm the solutions that have obtained using heuristics, an exact formulation is being developed to describe the model. The results will then be compared with the solution of the heuristics, and, hopefully, will prove that the loss in accuracy can compensate for the calculation time profit.

Due to the continuous nature of the production cycles, a first decision has been taken to use a continuous representation of time instead of the more usual discrete representation.

Two models based on nonuniform time discretization (Pinto J. M. and I. E. Grossmann, 1995; Mockus, L. and G. V. Reklaitis, 1997) have been chosen, allowing the timing of tasks to be described as a function of the events. Each problem is then formulated as a mixed integer linear programming problem (MILP), using both binary and continuous variables.

The nonuniform time discretization can outperform the usual discrete approach when the time intervals have low value. In association with a time representation based on events, rather than directly on the time, the data and the results may be more suitable for further handling.

5. CONCLUSION

The first results of the on going "nonuniform time discretization" will be achieved soon.

The comparison between the different formulations and the heuristics will then allow the differences between the various methods to be evaluated.

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