Scheduling and line balancing in a multi-product assembly line using tabu search

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Abstract

This paper presents a real-world industrial application of the multi-product and multi-objective scheduling and assembly line balancing problem, for a company involved in the production of four models of a product. Two objectives are considered: production rate maximization and minimization the dispersion of worker tasks on each one of the different models. An integrated approach for the scheduling and line balancing problem is presented. It is based on four heuristics cited in the literature and it is improved using a tabu search algorithm.

1. Introduction

The studied company is involved in the production of white good products and located in Spain. Since its foundation, the company has undergone continuous growth in variety and quantity of its products.

At present, the company manufactures four models (M1, M2, M3 and M4) of the same product in a unique line, giving rise to 120 references depending on the country of destination and the technical features. These models are classified into two groups according to their production rates (M1 and M2 in the first group and M3 and M4 in the second). This difference leads, on average, to two changes in the production rate every day [4].

Production capacity is approximately of 90,000 units/year and the manufacturing process is as follows: the foil is shaped in a press to make the chassis of the appliance; next, the foil is folded to give it three dimensions; then the appliance is manufactured on the assembly line; the next stage involves testing it in a test bank and, if it is found fault-free, it is then packed and sent to the warehouse; if it is found to be defective, it is repaired and sent again to the test bank.

The aim of this work is to improve the current task assignment and the balancing of this multi-product assembly line. In Section 2, the current situation of the line and the special features of the problem to be solved are described. Section 3 describes the resolution process followed. Finally, the results of the work are summarised in Section 4.

2. Problem analysis

When the study started, there was an independently obtained task assignment for each model manufactured. Analysis of real data leads to the detection of two problems: the cycle time of every model is different (which causes waste of time when changing from a high production rate model to a low production rate one); and the workloads of the stations are not uniform (a situation that could lead to labour conflict). There are also additional constraints imposed by the available space in each station and by the tools available.

Specifically the objectives are as follows. Firstly, to maximize the production rate (to cope with a future increase in production demand from the main client) for a given number of workstations. Secondly, to achieve an equal cycle time for all the models (in order to eliminate waste of time occurring at present when changing from one model to another), to achieve an equal workload for the different workstations (thus avoiding possible labour conflicts) and, finally, to minimize the dispersion of worker tasks in each of the different models (assign the same task of the different models to the same workstation).

From the previous analysis one can see that the problem to be solved involves scheduling and balancing a multi-product assembly line (4 models requiring approximately 100 tasks each), with a fixed number of workstations (10 stations), a number of different constraints and a set of objectives.

In fact, the problem is a General Assembly Line Balancing Problem (GALBP, according to [1]), where the main objective was to maximize the production rate (to minimize the cycle time) for a given number of workstations.

Also, there were a number of different constraints in the problem:

- No workstations in parallel are permitted and a task cannot be split between two or more stations.
- It is a multi-product line with four variants and a production mix of 35%, 25%, 10% and 30% for each model, respectively.
- Intermediate buffers exist with a maximum capacity of three units each.
- Known task duration independent of the workstations and known precedence between tasks.
- There are tasks that must be performed on specific stations, since the necessary tools are located on a specific station and cannot be easily moved.
- Space constraints: the available space to deposit the components to assemble is restricted on each station; depending on the size and the shape of these components, they can be located in packing cases (incorporated in the vertical space of the line and without taking up m2), on shelves, on medium-size pallets and on large pallets.

3. Resolution process

The resolution diagram below was used to solve each model balancing (see Figure 1):

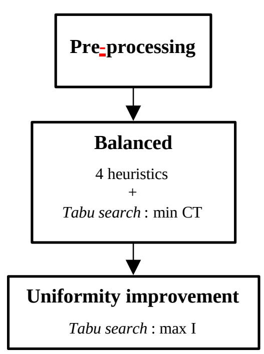

Figure 1. Diagram of the resolution process

After a data pre-processing, four heuristics were used to balance the line:

- Longest Processing Time, LPT: candidate task of greatest processing time [3].

- Greatest Processing Time divided by Upper Bound, G(PT/UB): candidate task of highest ratio : processing time divided by an upper bound at the station to which the task may be assigned [3].
- Boctor: the candidate tasks are assigned as a function of whether four hierarchical decision rules are executed or not [3].
- Bhattacharjee & Sahu, HMTT: a heuristic that combines the heuristics of Helgeson & Birnie, Moodie & Young, Tongue, and Talbot et al. [2].

The solutions obtained using the heuristics were improved used a tabu search routine trying to minimize the cycle time. Finally, a second tabu search routine was used trying to minimize the next index:

$$I = \alpha \cdot P + (1-\alpha) \cdot U$$

Where,

α, parameter (fixed to $\alpha = 0{,}8$ after several tests).

P, total production.

U, uniformity index:

$$U = \sum \forall i \ (ci / Ti)$$

i, common task index in several models that is not pre-assigned.

c_i, highest number of times that task i appears in the same station.

Ti, total number of times that task i appears.

The manufacturing processes of the different models involve tasks requiring the same resources: tools and/or components. Before balancing the next model, the common tasks requiring special tools, mobile bookcases or particularly specific components were fixed. Thus, the order in which the different models are balanced is important. Because there are certain critical common activities that are fixed at the workstation where they appear for the first time, and they are also fixed for the balancing of the remaining models.

The similar production rate models were grouped reducing the problem size from the 24 feasible permutation of models. Experiments were only performed on the results of combining: the M1 and M2 models, on the one hand, and the M3 and M4, on the other. Consequently, the following permutations M1-M2-M4-M3, M2-M1-M4-M3, M3-M4-M2-M1 and M4-M3-M2-M1 were used.

The balancing process and the first tabu search procedure can be used to balance simple assembly lines on which only one model is manufactured. As has already been mentioned, the process followed to balance the multi-product assembly line is described graphically below (see Figure 2).

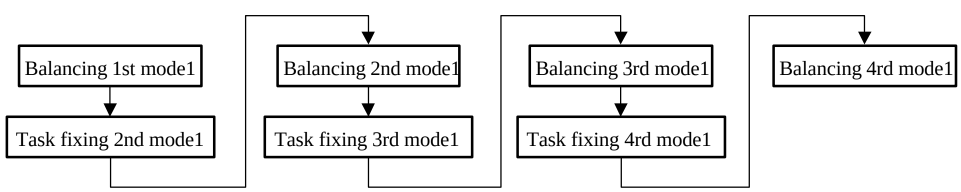

Figure 2. Multi-product line balancing process

When the line balancing of the four models is carried out, a different heuristic can be employed for each model or the same for all of them. If the models are balanced with different heuristics, there are 4! possibilities of balancing the line for each permutation of models. In this work, several tests were carried out using different heuristics. It has been concluded that using different heuristics does not improve the results. Therefore, the same heuristic is always used to balance all the models.

As has already been mentioned, the main objectives of the company are to maximize the production rate and, secondly, to equal the cycle times of all the models.

For the second purpose, two approaches were taken. The first allows certain activities to be "given up" from one model to another, and the second one allows these tasks to be performed off the line. There are some tasks that are performed outside the chassis: these tasks are called pre-assembly. To equal the cycle times of the different models, some pre-assigned tasks are "given up" from the models with high cycle time to the other models. After analysing the tasks, we see that there are seven pre-assembly tasks.

4. Experimental design and results

About two hundred feasible solutions were obtained. These solutions resulted from a full factorial experimental design. Every experiment consisted on a combination of three factors:

The first one was the pre-assignation of task (Factor P). Three possibilities were tested (P1 if the pre-assigned tasks stayed in the respective models, P2 if the pre-assigned tasks are carried out off the line, P3 if the pre-assigned tasks are "given up" from certain models to another and P4 considers the P2 and 3 situations at the same time.

The second factor was the order of the models. As it has been explained in section three, four possibilities have been considered namely O1 (M1-M2-M4-M3), O2 (M2-M1-M4-M3), O3 (M3-M4-M2-M1) and O4 (M4-M3-M2-M1).

The last factor was the heuristic employed to balance the line. The possibilities were H1 (LPT), H2 (G(LP/UB)), H3 (Boctor) and H4 (HMTT).

Every solution was evaluated throughout some values: P (production rate per hour), U (uniformity rate), I (rate of the second tabu search), and Δ% (percentage of improvement in P, U and I from initial solutions with no improvement throughout the second tabu search in comparison with the improved solutions).

As a conclusion, improvement using the the second tabu search approach always increases the uniformity of the tasks performed by the line workers, although it usually has the effect of slightly decrements in the production rate.

If the proposed solutions are compared with the initial line balancing, the improvements are between from 20% to 38% in the production rate.

Furthermore, the average saturation is greater than 96% from the initial solution in all the proposed solutions. The minimum dispersion is also around this value.

Finally, a solution with production improvement of 27.93 % was selected by the company to be implemented on its assembly line, because the production rate was high enough to deal with the forecasted increase in demand. Moreover, the cycle time was made equal for all models and no extra personnel were required although it was necessary to "give up" certain pre-assembly tasks from some models to others.

References

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