PRODUCTION SCHEDULING ON MULTIPLE LINES WITH SHARED RESOURCES

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ABSTRACT
In the research area of scheduling, many simulation models were developed to test solutions, generally establish by optimization algorithms or heuristics. In the paper is presented is a simulation model for scheduling problems of orders in the case of a multiple production lines with shared resources. The studied problem deals with the management of a specific number of work teams available for many operations, with skills to consider in the assignment of the workloads.
Moreover, the simulation model needs to consider the work teams' efficiency that depends on the season and on the production level. These characteristics are managed by software to test alternative solutions for the scheduling of the multi-product productions, where the lot size and the due dates changes order by order.
To verify the simulation model, it was tested to a real case of a motorcycle production plant, where different scheduling rules were considered and assessed measuring the performances and their effect on a specific objective function based on lateness.

1. INTRODUCTION AND BACKGROUND

Manufacturers nowadays often face the challenge of providing a rich product variety as lower cost as possible. This typically requires the implementation of cost efficient, flexible production systems on multiple lines, since by using single model assembly lines, manufacturing companies were able to efficiently produce big quantities of a product, that nowadays are rarely required.
Thus, production processes in a wide range of industries rely on modern mixed-model assembly systems, which allow an efficient manufacture of various models of a common base product on a flexible production system. However, the observed diversity of mixed-model lines makes the planning of sequence essential for exploiting the benefits of this production organization.
This scheduling problem is often called mixed-model assembly line scheduling (Leu *et al.*, 1996) and can be also referred to the permutation flowshop scheduling problem. In such a production system, the managers want to sequence the different products, thus obtaining a high service level (product mix) without delays in products delivery while respecting the constraints of capacity.
The variability on the final product involves production variables to be considered, as human resources flexibility, production line capabilities to work on specific products, set-up times depending on the adopted scheduling, therefore the production sequence of the products becomes important as a central issue. Hence, after an assembly line has been balanced (work has been spread out over the line stations), the order in which units have to be introduced into the assembly line must be considered by taking into account certain criteria.
To sequence mixed-models in assembly lines some criteria have been considered in the literature (Scholl, 1999), two main sequencing objectives are the constant rate of part usage (Monden, 1983; Miltenburg, 1989; Bautista et al., 1996), and the leveling of work load (Yano and Bolat, 1989; Xiaobo and Ohno, 2000). More than one criterion has also been considered simultaneously (Aigbedo and Monden, 1997; Kotani et al., 2004).
In addition to the long- to mid-term assembly line balancing problem (see Baybars, 1986; Scholl and Becker, 2006; Becker and Scholl, 2006; Boysen et al., 2006), mixed-model assembly lines give rise to a short-term sequencing problem, which has to decide on the production sequence of a given number of model copies within the planning horizon, like a day or a week.
With this background, the paper present a simulation model for the analysis of the short term scheduling in a mixed-model lines production.
In the simulation two general objectives are targeted:

- *Workload related objectives*. The manufacture of varying models typically leads to move human resources (operators) on different machines or lines. The flexibility asks for continuous changes but those can bring to decrease in the workload times and in delay on productions.
- *Just-in-Time objectives*. Since the flexibility is a target this cannot be paid with excessive lateness on due date, back orders or high level

of stocks of finished products and consequent immobilization losses and risks. With this in mind every scheduling has to be assessed in its capacity to be just-in-time with the established due date.

2. CASE STUDY DESCRIPTION

The case study regards an Italian motorcycle company, where different products are realized on multiple production lines and where a significant issue is the typical mixed-model scheduling problem.

The productive capacity of the studied plant is around 1800 units per day in high season, using eleven assembly lines: the first four are devoted to motorcycles, while the remaining seven are for scooters. The Company has decided to adopt a "multi-model" lines strategy, assigning a limited number of models in each line, thus ensuring short set-up times, thanks to the affinity of the models worked on the same line.

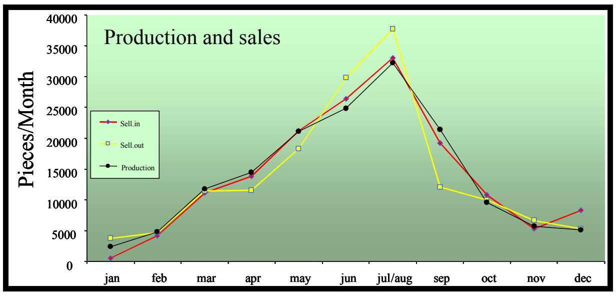


Figure 2: Seasonality in motorcycles' production

The criticality of the situation is however reflected in the low season, e.g. in winter and autumn seasons (Figure 2), when the market demand is low, the number of active production lines decreases, the workteams are halved and, therefore, forced to move between the lines, from a minimum of two to a maximum of three, following a chessboard logic. An example of this situation is shown in Figure 3, where the team X moves periodically between the lines I and J, where different models are assembled.

The main aim is, in fact, to propose and compare different short-term (weekly and daily) production plans, built around the availability of effective human resources, in order to identify the most effective solutions in terms of time and cost.

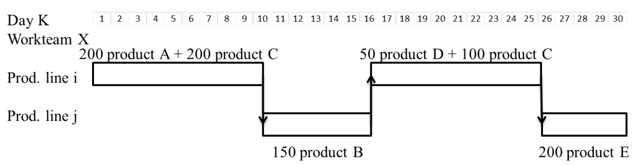


Figure 3: Example of chessboard between two lines

2.1. Objective

The minimization of time and costs is carried out considering a target function (T.F.), expressed by a weighted sum where the weights are provided in collaboration with the company's planner:

$$T.F. = \alpha_i \cdot \sum CB_i + \beta_i \cdot \sum SU_i + \gamma_i \cdot \sum T_i \qquad (1)$$

Where:

CB_i = time lost in the chessboard for the i-th batch;

SU_i = time spent in the set-up of the line for the i-th batch;

T_i = advance or delay of the i-th batch compared to the due dates;

a_i, β_i, γ_i = related weights.

Through the use of quantitative indicators can be determined the quality of a scheduled plan, using an evaluator module capable of expressing a "vote" for the scheduled plan, using a series of cost's indicators , expressed in the target function:

- Costs for the Set-up of the lines;
- Costs of chessboard between the lines;
- Costs of delay or advance compared with the date agreed for the delivery.

The data input for the evaluator module are:

- ***Lots*** ordered according to a specific scheduling to test;
- ***Status Team***: last line the team has worked on;
- ***Status Line***: last worked model (line and model have the same index *i* since each one is related to the other);
- ***Release dates***: the date of actual start of production;
- ***Due dates***: the date agreed for delivery;
- ***Cycle Time*** to assemble the models, with differences from model to model.

2.2. Complexity of the problem

The complexity of the problem is linked with the orders that day by day are added to the production plan and have to be scheduled with the lowest impact on costs and service levels.

Therefore it becomes necessary a proper management of the available resources, through the study of the chessboard and scheduling problems.

The way the workteam has to shift between the lines depends on the two ways the line can be left:

- Leaving the line "full" after it stopped will leave semi-assembled models on the line: this method is useful when it is expected that the team will be back soon on that line and the same model;
- Leaving the line "empty" the workteam finishes to assemble all the provided models: this is worth it when it is expected that in a few days the team will assemble a different model on that line.

Considering the real configuration of the line and the convenience in not immobilizing items upon them, the most appropriate solution, among the two above, is the second one: moving the team to a blank line to another, with loss of time due to the shifting of the team that are still small. In this situation the operators, as they move, can begin assembling the new model, but the faster line must be adapt to the slower one, so the loss of time will depend on the speed of both lines (Figure 4).

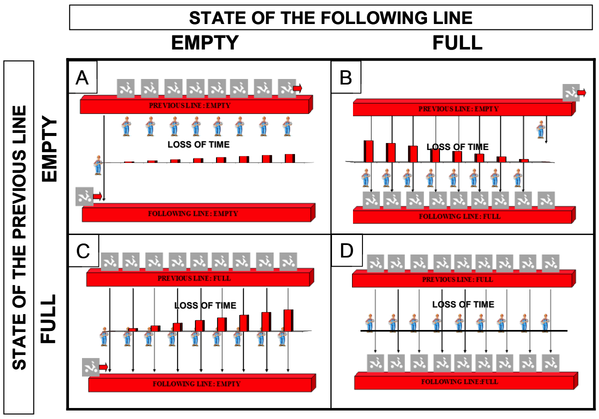


Figure 4: Time lost in the four shifting choices

The time lost in the empty-empty chessboard configuration is:

$$\text{LOST TIME} = TC_{reached} \times (N_{reached} - 1) / 2$$

In the evaluation of the time lost in chessboard are considered:

- CT = cycle time;
- ΔTC = difference, positive, between the cycle times of the two lines;
- N = number of operators on the line.

As regards the calculation of the time lost for the set-up, it's possible to proceed as follows: if the line of the batch i is the same of the batch i-1, the time spent for the set-up is calculated according to two based situations: if the model is the same, the time lost in the set-up of the line is zero, otherwise the set-up time of the line is equal to a motorcycle and two clamps free, i.e. at the time of execution of a task multiplied by three.
Figure 5 summarizes the loss of time, when the lot changes, due to the two issues of setup and chessboard:

	Time losses	
	Fixed	**Variable (depending on models production times)**
Chessboard	Time needed for the team shifting	Shifting strategy between lines (empty-empty, full-full, …)
Job changes on the same line	Time needed for the movement of two free clamps	Adaptation to the slowest present model

Figure 5: Loss of time when the lot changes

2.3. Simulation approach

To study better the complexities discussed so far, the choice was to model and develop a methodology to handle the incoming data of the different scheduling tested, to process the results, and analyze them in relation with the targets of the company, or in relation to the results obtained with other scheduling.
This approach has been applied to the problem called Permutation flow shop sequencing problem which consists in having to process (in the same order) on M machines, N job, which identify, in the case of the production lines, with different batches. The input data are the main orders MPS, which correspond to the batches to be produced, planned in the medium term.
The case study has in fact provided the information to realize a simulation model, tested with a four month production plan on two assembly lines, which are handled, in low season, by one workteam. The model has been developed through the use of SIMUL8 simulation software and the Microsoft EXCEL program.

3. MODEL DESCRIPTION

The simulation model was built by a combination of a object oriented software (SIMUL8) and MS Excel. The integration was obtained by using the specific simulation language called Visual Logic, which allows the full customization of the simulation objects and the communication with other software.
The construction of the graphical structure of the model and of its functional characteristics was based on input data supplied by the company; input data and constraints of the real production are transmitted on the simulator through the interface with the MS Excel file or Visual Logic on the Simulator .
The information on the Orders provided directly by the company are:

- Work calendar of the workteam;
- Quantity of the lot;
- Delivery date of the order;
- Line which the model will be worked on;
- Total processing time of a job (in relation to different models);
- Efficiency of the workteam (98%).

The model can simulate in a few moments the real operating conditions established in advance; dynamically simulate different types of scheduling, by changing from time to time the sequence of orders received as a function of the variables mentioned above, obtaining results that are transcribed in the MS Excel sheet of process and analysis of results. The outputs of the simulation are of two types: those related to the whole system performance (i.e. percentage of use of the machines of the two lines and of the resources) and those related to the minutes of start and end of production, crossing times of the batches, delays or advance on delivery dates, and time lost in the chessboard and set-up. Specifically, the results are: delay / advance max, average delay / advance, number of orders late / early, total days of delay / advance, average flowtime, makespan, total time lost in the chessboard, total time lost for the set-up, target

function.
These results refer to the use of the simulation model to see and measure the effects of scheduling heuristically planned through different combinations of the input data, related to the orders. The scheduling rules and heuristics used with the simulation model were based on the real options for the easy scheduler available in the enterprise plus the use of a genetic algorithm, implemented by the authors but not yet optimized for the specific case study. The basic rules, the results of are showed later, process orders with one of the sequent logic:

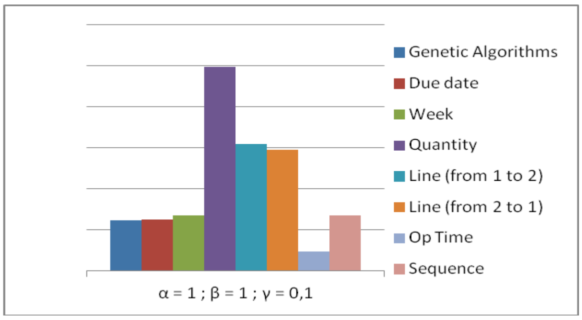
- start from the first to be satisfied (*due dates*);
- before the more little lots (*quantity*);
- just schedule depending on the arriving order (*week*);
- gather together the orders of a specific line reducing the chessboard (*line*);
- sequence by the operation time for one product (*op time*);
- choose just to balance the load of the lines in a specific time window (*sequence*).

Through the use of the MS Excel macro functions, it was possible to record several scheduling, and selecting and testing them quickly and easily.

4. RESULTS

The results of analysis and comparison of different scheduling tested are facilitated by the use of histograms that allow a more immediate graphical display of the results and can lead the company to strategic considerations. The histograms show all the heuristic scheduling tested, each one is related to his respective value of a specific performance parameter. The performance parameters considered are presented.

4.1. Target function

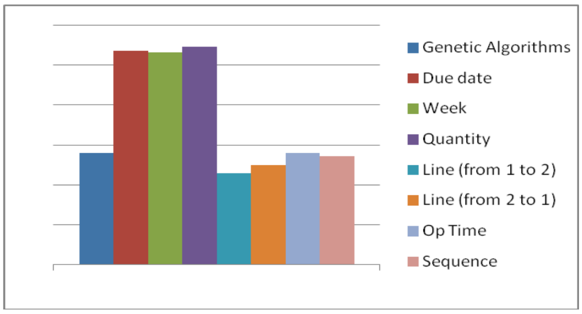


$$T.F. = \alpha_i \cdot \sum CB_i + \beta_i \cdot \sum SU_i + \gamma_i \cdot \sum T_i$$

related weights: ai; βi; γi = 1; 1; 0,1

The Scheduling that minimizes the target function is the one that better meets the needs of the company since it takes into account more variables of interest established by the company itself and how these variables affect in terms of cost and time.

4.2. Flowtime



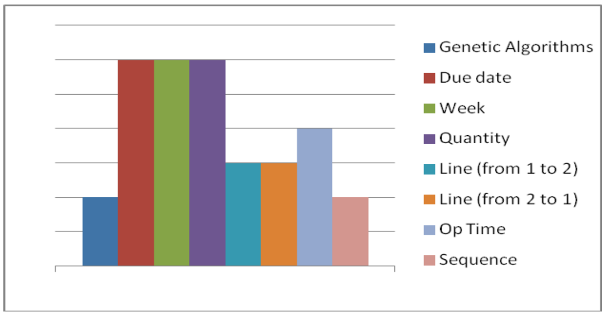
This parameter indicates how much time is elapsed, on average, from the moment a job enters the production to the time is completed:

$$F_{med} = \frac{\sum_{j=1}^{N} F_j}{N}$$

Where:
N: jobs total number

To minimize this delay means increasing the number of operations the company performs in the range of time considered because it leads to an increase in remaining production capacity. This principle however must be used only in case of real need (speed of response to the customer), as if the volumes of requests remain constant, the saturation level of the machines would be decreased,

4.3. Makespan



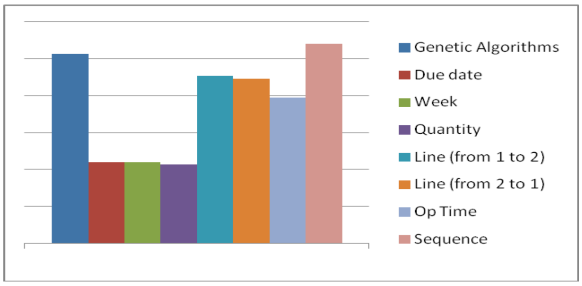
This parameter is similar to the completion time of the last job being processed, i.e. the extent of time necessary to complete all tasks.
Similarly to the case of the minimization of flowtime, a solution which minimizes the makespan should be adopted in all those cases where it is desired to increase the residual capacity of the existing resources with the aim of increasing the production volumes. The evaluation in this case is on a parameter that does not aggregate average values (such as the flowtime average) but retains the total impact

$$MAK = \max(C_j) - \min(I_j)$$

Where:
C_j: Job j production completion date;
I_j: Job j production starting date.

The makespan depends on the scheduling since a bad operative planning may repeatedly cause the occurrence of the phenomenon of "bottlenecks". that is the slowing down of a faster lot that enters in the production line after a slower lot, with the line that takes the rate of production of the slower lot and the value of the makespan which therefore increases.

4.4. Average saturation coefficient of the system



This parameter indicates how long, compared to the makespan, the M machines at issue were engaged in the processing of different orders:

$$S_{med} = \frac{\sum_{i=1}^{M} \sum_{j=1}^{N} t_{i,j}}{MAK}$$

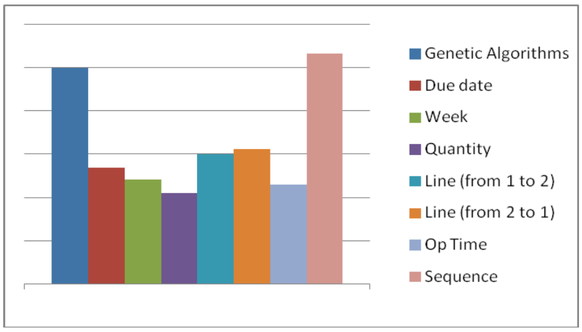
Where:

$t_{i,j}$: Job j production time on the machine i.

The situations which is convenient to use this policy are when every start and stop of the machine brings inefficiencies and significant periods of not added value, or when it is particularly expensive the purchase and maintenance of the resources.

In the case study considered the choice of the scheduling affects for only a few percentage points on the saturation of the system that is relatively low (with a range that varies from 42% to 45%) because of the choice made by the company to maintain operational policy of mixed-model lines, even in low season. The main advantage of this choice is the ease of configuration of the line and of its arrest, with expense, however, in the saturation of the lines themselves.

4.5. Average coefficient of human resources



This parameter indicates the percentage of time the operator is engaged in manufacturing, and large inefficiencies of this type can not be accepted by the company since brings clearly a loss of competitiveness.

5. CONCLUSION AND FUTURE RESEARCH

Simulation study showed that the scheduling process in the mixed-model production strongly effects global performances of just-in-time and workloads.

The develop tools are robust in its application and can be a decision support tool to assess specific scheduling solutions, taking into account multiple production parameters, from the production times, to the operators efficiency.

The natural development of the model allows not only to investigate the effects of variability on the production times and of other characteristics. Moreover a link to optimization algorithms can be introduced to fast assess available solutions and see their global effects.

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