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A NEW WAY FOR FMS LOT STREAMING: THE JOINABLE SCHEDULE APPROACH

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ABSTRACT
Quality solution of scheduling is one of the key factors to make FMS profitability high. The scheduling problems may be solved by sophisticated operational research approaches and as well with simple heuristic methods. Having a solution for a scheduling problem it is a natural wish to improve it. On some stage, at the original formulation of the problems, these improvements become very difficult or impossible. so, new planning principles should be formulated. One of these is the use of lot streaming.
In the present paper an attempt is outlined for improvement of FMS schedules by "joining" sub-schedules. For that the schedules should be "joinable". Joinability conditions are given. For joinable schedules the optimal improvement of scheduling problems solutions may be formulated and solved. The results are schedules which provide close to the global minimum completion times
Keywords: Scheduling, FMS, Bottleneck, Minimum of completion time, Lot streaming, Setup time, Job shop, Joinable schedules

1. INTRODUCTION
For the solution of FMS scheduling problems similar approaches can be used as for usual problems of manufacturing scheduling. The literature on this topic is enormous. The publication of J. M. Proth [1] is one of the last survey papers on this topic. For quality solution of FMS scheduling problems one issue should be very seriously taken into account. This is the fact that for these systems the times necessary for setups are much less than the processing (manufacturing) times. This is trivial fact because in other case the systems hardly would be named flexible. This fact gives special importance to the use of lot streaming. In the present article we will not go very deeply into details of scheduling methods. We concentrate on lot streaming issues. The only performance criterion used here will be the minimum of maximum completion times.

1.1 State of the art
As it was mentioned, the manufacturing scheduling is one of the topics most widely discussed in technical literature. Lot streaming is not as popular in literature as the general problem of scheduling with fixed batches. In this field, an attempt was made to formulate the problem from the point of view of inventory control by Szendrovits [2]. Dauzere-Peres and Lasserre [3] proposed computation aspects for lot streaming in job-shop scheduling problems. Genetic algorithms for the above problem were proposed by F.T.S. Chan, Wong, and P.L.Y. Chan [4]. Many other works discuss the problem, too. The topic, lot streaming in flow shop problems is widely discussed in [5]. In [6] the use of the, so called, Brute Force Method **(**BFM) was proposed for lot streaming.
The present paper is concerned with the so called "Joinable Schedule Approach". In this line in [7, 8], for special cases, (joinable schedules, and job shop problems), optimal lot streaming policies were developed. In [9] the Joinable Schedules approach was extended for flow shop scheduling problems.

1.2 The contents of the paper

In the present paper, part 1 is an introduction. In part 2 a mathematical model for FMS scheduling is described. In part 3 an example is given. In part 4 the idea of joining schedules is formulated. In part 5 Joinable Schedules for job shop problems are analyzed. In part 6 conclusions are given.

2. MATHEMATICAL MODEL FOR FMS SCHEDULING

The mathematical model for FMS scheduling is outlined in details in [6, 7, 8, 9]. Here only some basic information on it will be given. So, the model consists of:

- **Part types, machine groups**
- **Production time periods**
- **Processing time data**

The processing time is determined as $\tau_{i,j,k}$ where i indicate what part type on which machine group (with index j) has the given manufacturing time. The integer k expresses the order number of the given sequence. In the following, only $\tau_{i,j}$ will be used (k – is omitted) because for the discussed topics the order number of operations does not have any role. One more data is the number of items of the parts to be produced n_i *(i=1, 2 ....I)*

It is remarkable, that here, on the processing time, we understand, processing capacity needs which can even contain handling times and others, too.

- **Setup times**

The setup times are indicated as δ_{ik} when the processing is switched from part with index i to part with index k (the machine-group is not indicated).

- **Scheduling task**

As it was mentioned, in the present paper, to estimate the goodness of schedules only the values of the completion times will be considered.

2.1 Machine group loads and the global minimum of completion time

From the above data the machine group's loads can be computed as follow

$$tl_j = \sum_{i=1}^{I} \tau_{ij} n_i \qquad \text{j} = 1,2,\dots\ \text{J} \tag{1}$$

Where, the quantities are described above. The tl_j values are the components of the machine load vector. The maximum of tl_j values belongs to the bottleneck machine group. This value forms the processing time part of the global minimum of the completion time. Clearly, it is impossible to construct any order of processing which could result less than this processing time. The global minimum of completion time differs from this value by the sum of setup time values. Of course, the sum of setup time values may depend on the order of processing.

Let us introduce the following notations

$$Ntl = Max\ tl_j \qquad \text{... (2)}$$

Here, not considering the effect of setup times, we assume Ntl as reference value for the global minimum of completion time.

2.2 Suitable schedules

In the present paper we formulate the planning goal as to construct scheduling sequences which satisfy the following condition:

$$C_r = \frac{t_{pr}}{Ntl} \le \eta \qquad \text{... (3)}$$

Where: C_r is named as ***excess time coefficient*** and η is a suitably chosen value which is more than one ($\eta \ge 1$).We propose $\eta = 1.15$ in normal case, $\eta = 1.1$ for extreme quality requirement cases and $\eta = 1.2$ for lower quality requirement cases. One can recognize that these values seem very much satisfy practical goals. If the above condition is satisfied the completion time is close to the global minimum and this can be a good criterion for the systems performance.

3. AN EXAMPLE

Let us consider an example where 4-part type is produced on 5 machine-groups. The engineering database for this example is visualized on Figure 1.

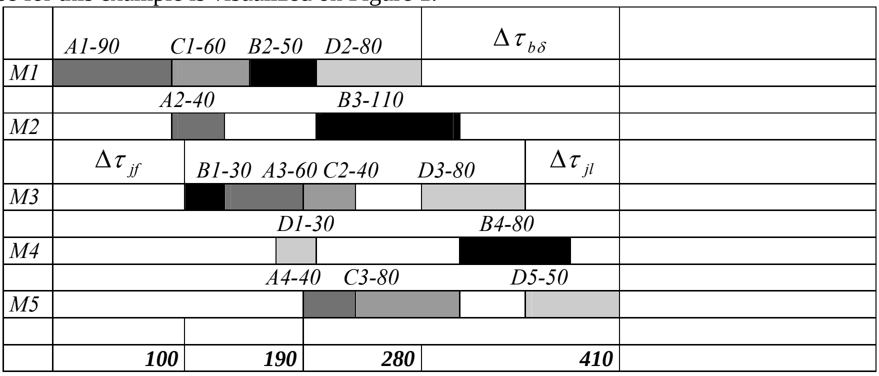

Figure 1: A scheduling example

The processing capacities needed are indicated on the Figure in hours.

The global minimum value is: *Ntl =280 [h].*

A feasible schedule is as it is indicated on the Figure1. We emphasize here that it is not analyzed how good this schedule is. At this stage, we do not consider setup times.

The completion time for this case is: t_{pr} *=410 [h]*.

So, $C_r = \frac{410}{280} = 1.46$

This value for excess time coefficient is not very good.

3.1 Joining schedules and the Joinable Schedules approach

Now, let us realize the following construction. Decrease the "lengths" of the operations to half. That is, divide the lots into two equal sublots. The result is given on Figure 2.

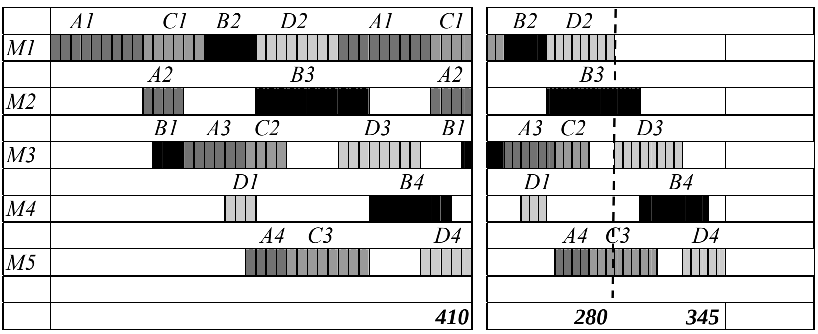

Figure 2: The joined schedules

It can be recognized that the completion time has significantly decreased. Because, t_{pr} *=345 [h]*, the excess time coefficient decreases to

$C_r = 1.23$

This is a much more favorable value.

Going on with this procedure to *W=3, 4, 5, 6,* etc. values, the completion time becomes

$$t_{pr} = 280 + \frac{130}{W} \quad [h]$$

That is: t_{pr} *=323,3; 312,5; 306,0; 301,7;* and C_r *=115; 1,12; 1,09; 1,08;* etc.

In this way the completion time goes closer and closer to the global minimum.

3.2 Definition of joinability

A schedule is joinable if a.) It has no idle times involved on the bottleneck machine-group (including the *t=0* moment), and b.) If moving together the "active sections" of the schedules on the bottleneck machine-group no overlapping of the active sections on other machine groups occur. The mathematical conditions for joinability are given in [8].

3.3 Optimal number of sublots

If the schedules are joinable it can be proved that the optimal number of sublots is:

$$W_{opt} = \sqrt{\frac{\Delta\tau_{b0}}{p_b \delta}} \quad \text{... (4)}$$

Where: $\Delta\tau_{b0}$ is the quantity shown on Figure 1.

p_b is the number of setups on the bottleneck machine-group

δ is the maximum of setup times values for bottleneck machine-group

But the number of sublots should be an integer. Candidates for that are:

$$\mathrm{I}W1_{opt} = \mathrm{Int}\{W_{opt}\}$$

and ... (5)

$$\mathrm{I}W2_{opt} = \mathrm{Int}\{W_{opt}\}+1$$

Equations (4, 5) give an opportunity to investigate the lot streaming solutions obtained in this way.

4. CONCLUSIONS FOR JOINABLE SCHEDULES FOR JOB SHOP PROBLEMS

When looking for the solution of scheduling problems for an FMS problem we can use a number of different approaches and devices (standard software). In some of the cases (depending on the database of the task) we can find some (at least one) feasible schedules which give very close to the global minimum completion time. If the schedule is suitable from other point of views, too, the planning may be finished. If the completion time do not satisfy the requirements, and one can find joinable schedules, the outlined above can be used to find suitable schedules. The success of the methodology given above depends on the values of the setup times. Of course, when the setup time values are big the given approach may not be used. What is big and what is small is always an open question. We have the conjuncture that when the setup times sum on the bottleneck machine-group is less then a hundreds of the net manufacturing time on this machine-group the given approach gives good results.

The outlined above are valid for job shop problems. Successful attempt to extend the method to flow shop systems was made in [9].

The real strength of the method proposed in the present paper can be estimated by extended case studies a part of which is on the way.

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