AN HORIZONTAL APPROACH TO BATCH SCHEDULING
Using the Simultaneous Manufacturing philosophy

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Abstract: This paper is concerned with Batch Scheduling in job-shop like manufacturing systems. The Horizontal Scheduling approach is used, assuming that full scheduling of a simple or complex job, based on the job routing network of operations, from the first operation to the last, is performed before another job is considered for scheduling, having in consideration existing manufacturing processors and their availability. We follow this approach because we aim at compressing job flow time to a minimum as a strategy to meeting job due dates. To further enhance this objective the idea behind Simultaneous Manufacturing through, the widespread use of batch overlapping with Job Scheduling Patterns, which proved particularly effective in reducing job throughput time, maintaining operating simplicity and requiring reduced coordination

1 INTRODUCTION

A job as defined in this work, is typical of reality but untypical in theoretical scheduling problems addressed in the literature. Our approach considers a job to be a manufacturing order for a number of identical products. These may be simple, i.e. having a set of operations to be carried out in a given sequence in a batch of identical parts, called simple products. The products may also be complex products, having a set of operations carried out in a given sequence in a batch of products, each one made of several different parts. The manufacture of these complex products is typical of industries of type A and T as defined in (Chase and Aquilano, 1998). It is mainly, but not only, for these types of industries that the scheduling approach and methods presented in this paper are most appropriate. A job is specified by the quantity of products necessary, i.e. it's batch size, the manufacturing operations and their precedence relationship, processing times of operations and the manufacturing processors to be used. Processing times include auxiliary time elements such as set up time and time for parts handling at a machine.

We strongly explore the possibility of different batch overlapping and batch splitting schemes for finding good schedules. Actually, we focus the quality of scheduling in shortening job throughput times and meeting job due dates. The reason is that this has a positive contribution to both profits and customer service. To further enhance this multi-objective we adopt a strategy to scheduling known as horizontal scheduling (Vollman *et al.*, 1996). Under Horizontal Scheduling, a job is scheduled first in all the required processors before another job is considered for scheduling. Therefore, again, priority to execute a job already started is given and consequently flow time further reduced. The scheduling approach combining all or some of these factors for reducing job throughput time has been named as Simultaneous Manufacturing (Almeida *et.al*., 2003).

2 PROBLEM DEFINITION

The problem under consideration can be included in the job-shop class with renewable resources. Because it assumes the existence of alternative

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resources to process the task we can say that is a flexible job-shop problem (Brucker and Schlie,1990). Besides that, it is considered a variable number of operations per task, so it is not restricted to the pure job-shop problem but it refers to the general job-shop problem (Conway *et al*., 1967).

Additionally, it is more general than this because any task may be processed on more than one machine at the same time. This happens not only because several parts, to be fabricated and assembled, belong to the same task, but also because batch overlapping strategies may be adopted. This scheduling problem scenario includes a much general case than the basic JSSP, typically addresses in JSSP literature, and is more realistic and in line with what happens in practice We call the scheduling problems of the type defined as Extended Job-Shop Scheduling Problems (EJSSP).

3 BATCH SCHEDULING

In traditional batch production, a job is considered as a set of identical parts that are always processed as a whole, i.e. the full batch must be processed in a processing stage before it can be transferred to another to carry out further processing. In cases where the batch size is large, this can become a too great penalty to the full duration of the job processing. So the performance of the manufacturing system, mainly regarding job throughput time and accomplishment of job due dates can become highly poor. This operating weakness can be highly reduced through Horizontal Scheduling, batch overlapping and batch splitting. We explore these strategies in our approach to solve the EJSSP.

3.1 Batch Overlapping

Batch overlapping means transferring work from a machine, which is processing an operation of the job, to another machine, for processing the next operation, before the entire batch has been finished on the previous machine. This is very common, in practice, sometimes done randomly, with different amounts of overlapping, and other times under a well defined overlapping procedure. In this case, transfer batches are clearly defined. These are batches, normally smaller than the total job batch size, transferred between two successively required machines. When a transfer batch is equal to the total job batch size batch overlapping does not take place. In the extreme, when trying to fully implement Simultaneous Manufacturing we should seek maximum overlapping, i.e. the transfer of work between processors should be continuous, which means transfer batches of size one.

Batch overlapping does not necessarily changes the processing batch size at a processing stage. A processing batch size is the amount of units of a job processed in a machine continuously before it takes another job.

3.2 Horizontal Approach

Horizontal Scheduling (Vollman *et al*., 1996), have in consideration that jobs are manufacturing orders of products, resulting from fabrication of parts and their assembly. The scheduling process is focused on the job, in such a way that all the operations are scheduled in all the required re-sources or processors before the next job is considered for scheduling. Using this approach it is possible to have a good perception of the state of each job during the scheduling time horizon and easily establish the scheduled job completion date, which permits verifying if job due date is likely to be accomplished.

Horizontal Scheduling implements the concept of Simultaneous Manufacturing in batch production of complex product manufacturing orders. In this work this is achieved, through the widespread use of batch overlapping. The main purpose is to reduce job throughput time as a strategy to meet due dates.

3.3 Simultaneous Manufacturing

The Simultaneous Manufacturing (SM) philosophy aims at the complete manufacturing of each single product of a product order in the minimum possible time. The intention is to take the minimum time to manufacture the whole job, i.e. the product order. To achieve this, each set of parts belonging to each product of the order must flow in a coordinated way through the sys-tem, i.e. in a way such that they are processed before any other parts, and arrive simultaneously to where they are needed for assembly. This assembly must be performed immediately, according to available processors. In this way, the throughput time for the complete manufactured and assembly of each product of the product order is minimum, and therefore the full job throughput time is minimum too. Additionally, the work-in-process is likely to be low (Almeida *et al*., 2003). In our scheduling approach, mechanisms were developed for implementing SM in a user-controlled manner.

4 JOB SCHEDULING PATTERNS

One of the main mechanisms, which allow implementing Horizontal Scheduling and SM in our work, is what we call Job Scheduling Patterns (JSP). A JSP is a virtual schedule of a given job, based flexible batch transfer sizing, batch overlapping and/or batch splitting (Almeida, 2002). A JSP is one of several possible alternative schedules, for a given job, under an empty manufacturing system, i.e. with all processors considered available, in an unspecified time horizon. A job can have several JSP, which can be generated for better exploring the utilization of manufacturing processors or machines.

A requirement for establishing a JSP is the job operation plan. This specifies all operations and their precedence interrelationships of each single product, simple or complex, of a job order. It may be expressed as graph as the one shown in figure 1.

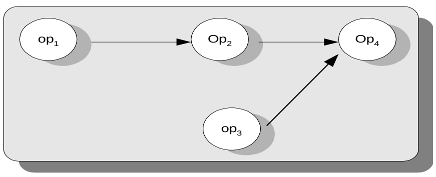

Figure 1: Precedence graph representation of a Job operation plan.

The computation procedure determines the starting and finishing time instants for all the operations of a job on each processor or machine depending on transfer batch size, on the job operation plan adopted and on machines to be used. This establishes a JSP.

Overall computing procedure

Compute the duration of each graph path and store the sequence of operations for each one

For the critical paths
From the operation of level one until the last level operation
If $prec(op_i)$ = { } and op_i is the first operation (level one)
Then
compute $t_{start(opi)}$ and $t_{fin(opi)}$
store the obtained values at the list of processed operations
Else
make $a = op_i$ and $b = succ(op_i)$
compute the displacement $\Delta ts_{(a \succ\succ b)}$
compute $t_{start(b)}$ e $t_{fin(b)}$
store the obtained values at the list of processed operations
For the non-critical paths
From the last level operation until the operation of level one
If op_i $\notin$ to the highest duration graph path
make $a = op_i$ and $b = succ(op_i)$
compute $t_{fin(a)}$ e $t_{start(a)}$
compute the displacement $\Delta ts_{(a \succ\succ b)}$
store the obtained values at the list of processed operations

Where:

prec( )	precedence operator
succ( )	succession operator
$a \succ\succ b$	represents a precedence relationship, meaning that *a* directly precedes *b*
$lt_{(a \succ\succ b)}$	transfer batch between *a* and *b*
$\Delta ts_{(a \succ\succ b)}$	displacement or overlapping time between the starting time instants of two operations *a* and *b*
$t_{start(op_i)}$	instant of processing start for operation *a*
$t_{fin(op_i)}$	instant of processing end for operation *a*

4.1 Illustrative Example

Supposing that we intend to manufacture a batch with 8 product units within a deadline, *td*, of 70 *tu*, being the release date, *rk*, the instant 0, we have: n = 8, *td* = 70 and *rk* = 0. The precedence graph is represented in figure 1.

Considering the data of the example and a unitary transfer batch, the result obtained by the job scheduling pattern generator mechanism, is illustrated in figure 2 where the batch displacement between *op1* and *op2*, and between *op2* and *op4* is shown.

We point out that operation *op3* could start anytime between instants 0 and 10. By starting at instant 10 a late start JSP is used. If had started at instant 0 we were adopting the earliest start JSP.

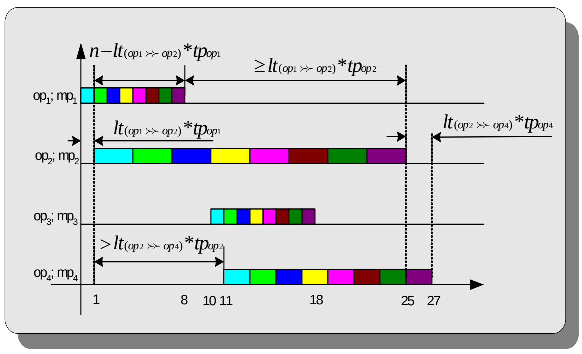

Figure 2: Job Scheduling Pattern with batch displacement representation.

JPk ={(mp1,(op1, 0, 8)), (mp2,(op2, 1, 25)), (mp3,(op3, 10, 18)), (mp4,(op4, 11, 27))}

5 BATCH SCHEDULING THROUGH JSP

With basis on the JSP and processor agendas the Scheduling Plan Generator (SPG), which implements the horizontal approach generates a scheduling solution. The SGP draws upon a scheduling algorithm developed in previous work by the authors (Almeida *et al.*, 2002). Such algorithm involves two scheduling phases: the forward influence phase and the backward influence phase. Mechanisms for implementing these phases were reported and explained in (Almeida, 2002).

The SPG picks up information about the work and processors, related with the scheduling problem and suggests possible solutions if they exist. It verifies the time horizon of the processors associated to each operation and looks for their availability in a relevant time interval.

An important feature the SPG, when it is not possible to schedule the whole job batch to meet its due date, is its ability to suggest a split batch size that can be manufactured within the due date. This may be important for time phasing delivery and negotiation with customers.

Going back to the example, the obtained results for the scheduling of the referred job using the algorithm implemented by the SPG, are represented in figure 3.

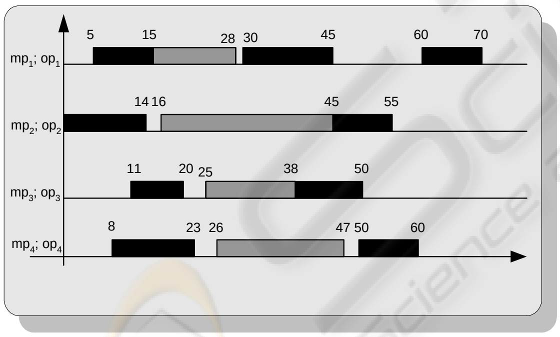

Figure 3: Results of application of the Scheduling Plans Generator.

The only solution obtained stems from some imposed restrictions on batching. By relaxing batch size, trough batch splitting, for example, it might be possible to take advantage of other available time intervals of manufacturing resources. In this case the split batches of the order could be taken separately for scheduling by the same method and, possibly provide further alternatives to scheduling.

When it is not possible to schedule a job within the MP agendas, based on a given JSP, then some strategies can be applied to obtain a solution, within the available time intervals in the MP agendas. These strategies can include trying a new JSP, considering different transfer batches sizes, and applying a batch splitting process followed by JSP generation for the split batches. The scheduling mechanisms in the SPG give suggestions about where to split a job batch. Thus, we can break one job batch in two or more smaller job batches whose sizes can fit within the available time intervals of the manufacturing processors.

6 CONCLUSIONS

Under today's highly competitive markets it is important to provide good service to customers and, at the same time, reduce costs in manufacturing. One clear contribution on these lines is to manufacture job orders within the shortest time that is reasonably possible, keeping work in process low. This has a direct effect on profitability, since fast turnover of short-term investment is achieved, and, of course, on fast deliveries, which is an important requisite for customer satisfaction.

We presented in this paper an approach oriented towards achieving very short manufacturing throughput times of customer orders. The approach uses the Job Scheduling Pattern concept, and implements a Horizontal Scheduling approach in order to achieve the Simultaneous Manufacturing philosophy. The main imbedded strategy used is what we described as Scheduling through JSP. Based on the described scheduling approach a Scheduling Plan Generator was developed, which can be seen as a powerful tool to aid users to improve detailed shop floor scheduling in complex manufacturing environments, integrating both fabrication of parts and their assembly into customer ordered products.

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