Flexible Production Planning in a Printing Shop

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Abstract: The paper presents a concept of flexible product and production planning in a printing shop with practical implementations, and discusses in particular the issues relating to production planning. The characteristics of products and processes that must be taken into account when selecting the methods and algorithms for production planning are clarified, and the most important similarities and differences between printers are pointed out. The implementations are based on the models of processes and products, and they include inference mechanisms to manage the multitude of production alternatives during the selection of the production method and enable automatic scheduling viewed as an optimization task. Various opportunities of enhancing the scheduler are discussed.

Introduction

Concepts and systems for product and process related planning tasks have been within the scope of our research for the past three years under the VTT research programme 'Product Models in Design and Product Planning'. Our objective was to provide a fountain for systems tools to manage planning tasks that require a profound knowledge of the printed products, their production methods and production processes. The product planning concept was presented at the 1994 TAGA Conference in Baltimore (Bäck et al., 1994), and it is currently being commercialized. The emphasis of this paper is on the issues of production planning, but it also shows how the two areas should be linked together to give the printers effective tools to manage their production planning tasks.

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The term 'production planning' is employed to include the resource and the time allocation of orders made before their production is initiated. The purpose of production planning is to make sure that

- the orders can be produced to meet the time and quality requirements,
- the production resources are used effectively,
- the work in process is kept at a low level, and
- that materials and other necessary resources are available as needed.

Scheduling is an essential function in production planning, dealing with the timing of orders and their allocation to individual resources. Scheduling does not change the production method (such as the size of the sheets to be used in printing), but it can choose between several interchangeable - but not necessarily identical - resources, all of which are capable of carrying out the required production operation. The selection of the production method is called 'product planning' in our paper.

The term 'production control' or 'reactive scheduling' refers to the tasks and functions needed to manage the orders during their production. The time scale of the production control is typically from a few minutes to some hours or shifts, whereas in production planning the time scale is from several days to some weeks, or even to some months, depending on the processes. The term can be used synonymously with the term 'production control'.

The production planning tasks are handled in printing companies with a variety of methods. In the simplest stage there is no distinct planning function, but the incoming orders and materials are given more or less immediately to the production, if the capacity is assumed to be sufficient. Priority is usually given to orders with the closest deadlines, or to those of the most important customers. Wall charts, work lists and other similar tools may be used as an aid to keep track of the production load.

With a computerized production planning system the production load may be calculated and its development predicted. The accuracy of the prediction depends on several factors: how well the production routes have been described in the system, how well the resource time requirements are known in advance and how well the total production load, i.e. the mutual interaction of several orders is taken into consideration. The most typical solution is to plan the orders to unlimited capacity, using so called planning lead times to make some allowance for possible queues and those operations which are not calculated specifically on the basis of order-related data. In this approach, it is the task of the production planning personnel to level out any overloading situations.

Scheduling has been a controversial area in computer applications. Several arguments are presented against it: real-life problems require too much computing time to be of any help, too much work is required to provide the scheduler with up-to-date data on the available processes, current orders and their status, and, besides, the results of computerized scheduling need to be corrected manually.

Despite this argumentation, we concluded that there will be an increasing need for production planning tools, including automatic scheduling, for three main reasons. Firstly, the processes will be more automatic, requiring an efficient use to guarantee their cost-effectiveness, and automatic processes also offer better ways to gather status data automatically. Secondly, with the reduced run lengths, the number of orders will increase and computer-aided support for decision-making on production-related problems will be more important than before. The automatic and manual methods need not be regarded as mutually exclusive, but they should be used as complementary tools. Thirdly, the development of scheduling methods and algorithms as well as the more effective and cheaper computing power open new possibilities to bring automatic scheduling to real-life applications.

The Basis for the Selection of Production Planning Methods

The choice of suitable methods and tools for production planning largely depends on the company's products and processes, on the requirements set by their customers, and on the market situation. The types of the production processes and products determine the kind of problems that occur frequently, and if these problems can be solved effectively and with good results, the requirements can be met and the company can financially benefit from the system.

As far as the products are concerned, there are two relevant aspects: how many different product groups can be identified within the company and what the characteristics of each of these product groups are.

The term 'product group' can be used to refer to those final deliverable products which are similar in structure, e.g. soft-cover books and hard-cover books. The products in a group are produced using the same production resources in the significant parts of the production chain.

In each product group the relevant characteristics of production planning are

- the characteristics of input material/information,
- the number of required production operations, and
- the required and the average throughput times.

The number of different product groups does not necessarily mean that production planning becomes more complicated in direct relation to the number of different product groups. If the product groups have more or less their own production resources, the production plans can be made separately for each of these groups, but the more the different product groups share the same resources the more complicated the planning problem tends to become.

Relevant characteristics of the production resources regarding production planning problems and applicable methods are e.g.

- the availability of interchangeable production routes and resources,
- the reliability of the capacity requirement estimates,
- the length of the change-over times,
- production speeds/ typical time requirements for resources, and
- the ease of increasing (and decreasing) capacity at short notice

A classic way of categorizing production processes is to distinguish between job shops, batch shops and flow shops. Job shops produce unique orders with unique routings. Operations are performed sequentially on a single lot of parts, which travel together through the shop. Batch shops have many similar characteristics with open jobs, but orders consist of batches instead of single items. The make-ready times of the machines are typically long from batch to batch, and it is possible to take advantage of grouping orders according to their characteristics. The routings are typically not so complex as in job shops. (Morton & Pentico, 1993)

The third type, the flow shop, is basically a batch shop with linear material flow and fixed routings. Flow shops in different variations are common in the industry. The significant characteristic of the flow shops regarding production planning is the fixed order of the recurrent production operations. This process type may be seen in the industries which produce very different kinds of products, liquids as well as piece goods. The form of the products is thus not decisive in this classification. There are several variations of this production type: the sequence of the operations can be fixed, yet all batches do not use all the operations but skip some of them. There may also be groups of resources and the batches use all the groups, but not all the resources in the groups. Assembly shops are often regarded as a separate type. Basically, they are job shops or batch shops, depending on the lot size, but assembling is the main operation performed on the parts. (Morton & Pentico, 1993)

Some Characteristic Features of the Printing Processes

When the production processes of a typical printer, starting with the prepress and ending with the binding, are looked upon as a whole, they can be classified as being of the flow type. There is a large number of recurrent production operations, and their order is well-known and fixed in advance, and in most cases the variety of products is not too large if only the physical structure of the deliverable products is taken into consideration.

If, however, the different parts of the process are investigated more closely, some other characteristics can be found. In the prepress or repro processes, tens or even hundreds of elements are gathered to make up one final item, which can be used to make plates, or even to be printed directly on paper. The prepress phase is like an assembly shop producing single items.

Also the bindery process has an element of the assembly shop but the operations are not performed on single items as the production is batch-oriented. The batch is made of a single order, consisting typically of at least thousands of identical copies of the final deliverable product. The characteristics of the subsequently produced orders determine how much time is spent on the make-ready.

The sheets that belong to an order can be printed regardless of each other. Of course, the setup times may be shortened and the level of the work in process can be kept at a lower level, when the sheets are printed in succession or simultaneously using different presses, but there is no process-related necessity to do so.

The product parts produced to make up the copies of an order do not travel through the processes together, but may have different routes, and are brought together only in the final production operation. This requires a good coordination of the different items to make sure that the deadlines are met and to keep the level of work in process at as low a level as possible. Figure 1 illustrates the different features of the various production phases in the printing shop.

The following common features relevant to production planning can be identified in most companies that make printed products:

- there are no major routing problems
- parts or intermediate parts are order-specific, and
- the coordination and timing of the parts produced by the different routes is an important issue.

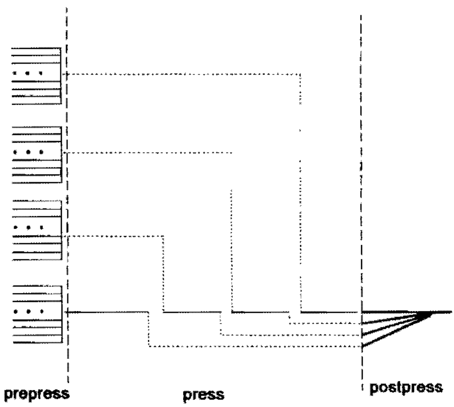

Figure 1. A schematic representation of the printing processes showing the different nature of the different production phases.

In practice there may, however, be significant differences between the companies in regard to the problems of production planning. Some major differences can be identified if we compare a typical magazine printer and a typical book printer. Typical magazine production has large volumes and the number of signatures making up a copy is not so great. Production schedules are tight, and expensive, high-capacity presses need to have high utilization rates.

Book production tends to be less time-critical, the run lengths are typically much shorter, and the number of different signatures/copy is larger than in magazine production. Several different production resources (e.g. a press, a gathering line, a sewing machine, a casing-in line) are required and the use of them all may have to be planned in advance.

The differences may, however, diminish. Book production is becoming more time-critical and the trend in magazine production is towards greater variation and selectivity, which increases the number of items to be managed during the production.

Regarding production planning important characteristics, which vary from one printer to another are such as

- the scale of the production volume
- the run lengths and the speed of the make-ready
- the time-criticality of the orders
- the number of time-critical production resources.

The scale of the production, the run lengths and the make-ready times together determine at which level the scheduling of orders is rational to do, and if it is important group similar orders to be produced after each other.

Our Approach to Product and Production Planning

In our approach, product planning and production planning are regarded as two separate functions. The product planning covers the selection of the production method and produces one or several cost estimates based on the requirements set on the final deliverable product (Bäck et al., 1994). We have implemented a system prototype, which is capable of suggesting the user alternative and relevant production methods for a specified printed product in a known printing shop. The product planning system is based on detailed models of the available resources and on inference mechanisms which can use these models to deduce the valid production methods. The system advises the user on the selection of the most appropriate production method. This selection can be facilitated, for example, by giving as a set of figures indicating the effectivity of the use of paper, or by informing the user of the production costs calculated in a way which allows to compare the company's own production costs.

Production planning has the required production operations (the process plans) as input and gives the user a production schedule. We find that both automatic and interactive scheduling methods should be available to the user. Automatic methods are needed to make the planning of the increasing number of orders effective. It is, however, practically impossible to model the production planning task so comprehensively that the results as such always satisfy the user. Therefore the user has to be provided with both interactive and automatic methods. The user should actually have several alternative automatic methods, because the nature of the scheduling problem and the goals of the scheduling tasks may vary from day to day.

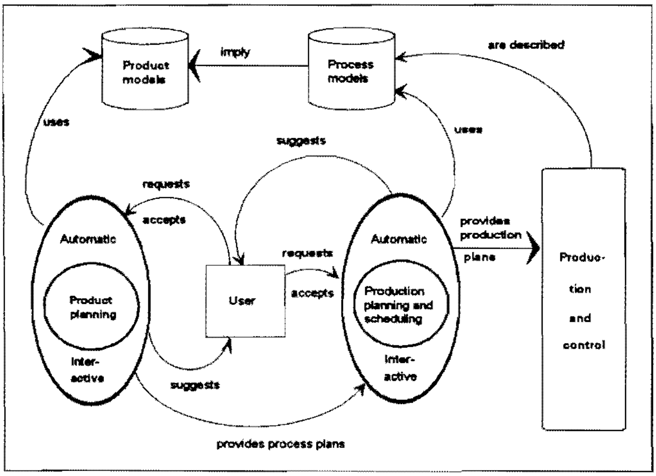

Figure 2. A conceptual representation of the links between product planning and production planning.

In our approach, both product planning and production planning deploy the common models of processes and products. These two applications require this information in slightly different ways and both of them need their own enhancements in the common data content. The product planning module sees the production processes mainly through the available product structures, whereas production planning sees the products primarily as process plans giving the required work phases (Figure 2). Product planning is not concerned with the time aspect of the processes but it can complete its task using time-independent information. It needs to know all the available routes, which differ from each other in such a way that it has an effect on the obtainable final deliverable product. The number of identical resources is irrelevant to it. In contrast production planning requires time-related data of each single resource, which can be used in the planning period.

The scope of this paper is to discuss more in detail the automatic scheduling of orders, which should be included in a future planning system of a printer. The foremost information requirements of scheduling are described, as well as the principal ways of processing this information and the results of scheduling as implemented in our schedulers. The time scale of the scheduler is one week and upward. The scheduler is object-oriented both in the design and in the implementation. The implementation language is Common Lisp augmented with CLOS, the Common Lisp Object System.

Scheduling Methods

When the aim of scheduling is to create a schedule that meets the predefined requirements, an optimal solution can be expected to be found only if the problem is small or otherwise restricted (e.g. Johnson's algorithm for one to three machines). The time needed to solve most scheduling problems by the currently known algorithms grows exponentially in relation to the number of orders and resources. This, of course, puts strict constraints on the methods that can be used to solve real-world problems and one must often be content with a good solution which is not necessarily the best.

Scheduling methods can roughly be divided into two categories: simple methods and advanced methods. Simple methods do not typically require any extensive computation and they cannot usually address major problems. The resulting schedules may not be close to an optimum. Simple methods include, for example, manual scheduling, simulation used as a decision aid for human decisionmakers, and simple heuristic schemes such as the use of priority rules. Advanced methods have been developed to overcome these deficiencies.

Advanced methods for scheduling and routing can be divided into four groups (Morton & Pentico, 1993): those employing mathematical programming methods, heuristic methods for global search, bottleneck methods and methods based on artificial intelligence, neural networks or other similar technics. Naturally, there are hybrid systems that combine several of these approaches.

The solving of scheduling problems requires mixed integer programming with mathematical optimization. If the problem is linear, i.e. if both the cost function and the constraints set on the variables are linear, the problem can be solved by some method based on linear programming. Also dynamic programming methods can be used. An advantage of the mathematical programming methods is that they always produce an optimal solution if the underlying model is correct and they are run with appropriate computing resources. A drawback of the mathematical programming methods of scheduling is the large number of variables needed to model real-size problems. Consequentially, the amount of time and computer memory may be huge. For a review of the mathematical programming methods, see (Shapiro, 1993).

The main heuristic methods for global search are based on socalled intensification-diversification strategies. Intensification means that a method seeks a better solution in its immediate surroundings. If one is not found, the intensification is over for the time being, and either the current solution is accepted as optimal or another try is made elsewhere. Diversification means that try. An essential point is that the search is directed to areas of the problem space that do not seem to produce a better solution than the one found by intensification. Another common feature of the heuristic methods for global search is that they are socalled meta-algorithms: they use an algorithm designed for intensification as a part of their optimization.

The best-known heuristic methods for global search are taboo search (Glover, 1990), simulated annealing (Laarhoven van et al., 1991), genetic algorithms (Davis ed., 1991), and beam search (Ow & Morton, 1991). There is some evidence that simulated annealing is best suited for solving certain scheduling problems (Aarts et al., 1994), but more research still needs to be done.

Bottleneck methods, the most widely known of which is OPT®, try to pinpoint the critical resources and/or jobs of the planning period, and then arrange the orders in such a way that the critical resources are used to their maximum potential.

Knowledge-based systems have also been constructed in the past ten years to solve scheduling problems. Their advantage, when compared with the mathematical methods, is that it is possible to manage both numerical and qualitative data, and the cost function need not be formulated in a precise mathematical manner. Their principal deficiencies are that collecting the necessary knowledge requires a lot of work and the systems may show low adaptivity if they face unexpected situations.

The Scheduling View on Printed Products and Printing Processes

We implemented two schedulers. The implementation modeled a web-offset printer and the process included page-output, platemaking, printing with two alternative web-offset presses and stitching with three alternative stitching lines. Both schedulers are based on simulating the schedule forward after each scheduling decision is made, and calculating the cost of the resulting (partial) schedule. The current cost function is the maximum lateness of single orders.

The first method enumerates all the possible resulting schedules, and chooses the one with the lowest cost. The method is, of course, quite archaic, and is not suitable for real-world problems due to its slowness. The method was mainly implemented to test the data models and structures, to double-check the results of the other scheduler, and to provide a lower limit for the cost function in simple examples.

The second method is a variant of the branch and bound heuristics (Pearl, 1985). It can be classified as a mathematical method, and could be considered for use with small to medium scheduling problems. The branch and bound heuristics was selected for the implementation because it is simple, relatively effective, and can be combined with methods for global search.

The algorithm is currently based on going through all the relevant alternatives. Any decision that would result in a higher cost than the best solution obtained so far is rejected, and this way some alternatives can be eliminated, and the calculation time reduced.

The scheduling problem has two views of the production: that of the orders (i.e. the products to be made), and that of the printing house resources (and the external resources if required). The main thing the scheduler needs to know of the orders is the work phases required to produce them. A work phase is, for example, the four-colour-printing of a B1 sheet. The work phases are given to the scheduler as a directed graph with precedence. If a company has several resources which are capable of doing the required work phase, the scheduler needs to know the resource requirements for all the alternative resources in order to make the final decisions on machine allocations.

In addition to the work phase information, the earliest and latest due dates for each publication are needed, as well as the earliest starting date for the order. The different signatures of a publication may have different starting dates.

The scheduler's view of the printing house resources shows the resources which are available in the time period covered by the scheduling, and the sequence-specific setup times. The setup times can be divided into two groups: product-specific and sequence-specific. The product-specific setup times depend only on the characteristics of the product, such as the number of plates to be changed, and can be calculated in the product planning phase. The sequence-specific setup times are determined by the production order of the items. If the production sequence has significance to the setup times, the scheduler must be provided with data on those characteristics of the orders which determine these times and conversion tables indicating their lengths.

If the scheduler cannot be provided with the required information, a preprocessor is needed to calculate it from the available data. For example, the calculation of sequence-specific setup times would typically be in the domain of a scheduler preprocessor.

The scheduler also needs calendar-related time information. This allows the preprocessor to calculate, among other things, the number of working hours in the planning period and the due dates relative to the beginning of the planning period.

With the above information, the scheduler can determine the resources that are used to complete the orders, and when this processing should take place. The publication is considered complete when the last required work phase is completed. To better judge the quality of the schedule, different key figures can be calculated, such as the number or invoicing value of late orders, used capacity, the setup costs, or the throughput times.

Concluding Discussion

The different parts of our approach are currently in different stages of maturity and implementation. The product planning concept has led to a product development project, whereas in the production planning part further development is needed to make the concept and algorithms ready for practical use.

One of the arguments against computerized production scheduling is the large amount of data needed of the production environment and the orders. Our work with the product planning application has produced the mechanisms to establish the available production methods and routes for a particular order with a good accuracy and with a reasonable amount of basic data. After the selection of a particular production method for an order, the product planning application can output the corresponding process plan for the scheduler with its resource requirements. If there are several routes capable of making the final deliverable product from similar components, the process plans for all these routes could be transferred as an input to the scheduler. If these alternative routes are not equally acceptable, their priorities should be deduced from the process plan information either by the scheduler or by the scheduler preprocessor. If this is not possible, some general rules or user-specified preferences must be used.

The scheduler is currently focused on solving the scheduling problems of flow-type production processes, producing batches for which reliable production time estimates can be made. The production planning task of prepress operations would, in many cases, be only insufficiently scheduled with the present implementation, unless the processes conform to the flow-type assumption. The development in the graphic arts technology is, however, leading to a clear division of operations between the printers and the publishers. The printers will deal with the operational or industrial tasks starting with the output of pages. The publishers will deal with the creative part of the production chain and there scheduling assuming a flow-type production process is inappropriate. As the publisher is - or will soon be - able to give the printer the input in the digital form, the printer's processes can be streamlined.

In our approach, the scheduling task was regarded as an optimization problem. The object-oriented implementation method makes it possible to gradually enlarge and tailor the implementation for different purposes. The implemented branch and bound heuristics could easily be extended to handle even big scheduling problems. The main enhancement would be to make the heuristics able to estimate the cost of the complete schedule from the information that is available on the partial schedule. Such heuristics should give a cost estimate lower than or equal to the actual final cost of the schedule, equal to or higher than the current cost of the partial schedule, and as close as possible to the final cost. In this way, only irrelevant alternatives would be eliminated.

As noted above, printing companies have both common and different characteristics in regard to production planning problems. Therefore, the implemented basic models and their functionality need to be enhanced to better meet the requirements of individual companies. An example is automatic partitioning of work phases into smaller units (e.g. in large-volume production the printing of a sheet in two separate work phases, either using different machines or on two different occasions), and the handling of mergeable work phases (e.g. in small-volume production combining similar orders). These two enhancements would increase the level of automation, and the system would be developed towards a knowledge-based system.

The current cost function (the maximum lateness of single orders) is an important measure, but not the only relevant conceivable one. Other cost functions could be incorporated into the program.

Another enhancement would be to develop scheduling towards reactive scheduling. This requires continuous monitoring of the status of the orders and resources. The monitoring data should also be employed to reliably analyse the performance of the processes. In this way dependable resource requirement estimates could be produced and the accuracy of the cost estimates improved in the product planning module. The development toward reactive scheduling is necessary because in most production environments planning periods are getting shorter and production plans need to be adapted to unexpected changes without losing the control of the overall coordination of the production.

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