Division of Research
Graduate School of Business Administration
The University of Michigan

May 1981

SHORT TERM PLANNING AND SCHEDULING IN A PAPER MILL

Working Paper No. 268

Robert W. Haessler

The University of Michigan

Abstract

This paper describes an alternative approach to short term production planning and scheduling in a paper mill. Instead of first allocating grades to machines and fixing a master schedule, this approach first looks at trim and then uses the trim results in making the allocation decision. The new approach is discussed in the context of a multi-machine newsprint mill where it was developed. The input to the system is the set of orders to be produced during a week and the output is a running list indicating what is to be produced on each machine.

Introduction

The classical approach to production planning and scheduling in the paper industry as described in [3] involves an hierarchical disaggregation of the problem. The first step is the solution of the machine loading problem. This is generally a large scale linear programming model in which the decision variable is the number of tons of a grade to be produced on a machine in a time period for a given destination. The constraints limit the total tons that can be produced on each machine and the tons of each grade that can be shipped to each destination. The objective function coefficients are based on production contribution for each feasible grade-machine combination and freight costs from the producing mill to the shipment destinations.

The second step is the development of a master schedule for each paper machine. The production sequence and cycles for the grades assigned to each machine are based on grade changeover costs and customer service requirements. As orders are received from customers, they are assigned to production runs based on the master schedule.

The third and final step in the process is the trimming of the orders to be produced from a given production run on a paper machine. This involves specifying the number of production rolls to be made and the way each is to be slit to obtain the number of rolls of each customer width ordered. A primary objective here is to minimize the amount of trim loss. For example, if three 65 inch wide rolls are slit from a 200 inch production roll, 5 inches of trim loss would be generated. It should be clear that the profitability of a run is very much dependent on obtaining solutions to trim problems with low levels of trim loss. It is not unusual for the annual value of one inch of side trim to be in excess of $100,000 for a modern paper machine.

The classical approach to production planning and scheduling described above has a number of advantages. The fixed master schedule permits reliable customer service and economic run lengths on the paper machine. It also provides a means to constantly monitor supply/demand relationships to determine when the overall production plan must be adjusted because of changes in supply or demand.

The major disadvantage is that trim is not considered explicitly in the machine loading or master scheduling process. The production costs for a grade on a machine used in the LP model are based on historical trim yields. The order mix of sizes and quantities required may vary from run to run and therefore may result in substantial changes in trim loss. It may be argued in some situations that trim is not considered until it is too late. The purpose of this paper is to characterize those situations in which trim should be considered earlier in the production planning process and to present a procedure for explicitly considering trim in the machine loading process.

Production Environment

In general, the production environment where the classical approach does not work well can be characterized as follows.

1. Multiple paper machines of varying widths.
2. Relatively homogeneous products.
3. A great deal of production flexibility (i.e., most products can be produced on several machines.)
4. Significant trim problems probably due to the fact that the ordered sizes are wide relative to the paper machines.

Two types of paper, newsprint and containerboard, typically fit these characteristics. The following more detailed description of a large newsprint operation should make it clear why a new approach is needed.

The company has five paper machines at a single location. The maximum width production rolls that the five machines can produce range from 256 to 363 inches. The production capacity of the mill is approximately 9000 tons/week of newsprint. The widths ordered by their customers range from 13 to 66" with heavy concentrations of demand at standard newspaper sizes such as 58 inch wide rolls. Although only one kind of paper is being produced, customers do require different diameters, core sizes and winding direction. Rolls with different specifications can be thought of as being different grades because they cannot be slit from the same production roll. In addition to differences such as diameter, customers are also able to specify which subset of machines their order must be produced on. This is due to a customer perception of differences in the quality of the rolls produced on different machines.

In this situation there is no real basis to assign orders to a specific paper machine other than trim. It should be noted that the allocation cannot be done by solving a multi-machine trim problem because of the requirement that rolls for an individual order cannot be produced on more than one machine because of differences in the paper machines. The classical approach of machine loading, master scheduling, and trimming provides no help in this situation. The fundamental planning constraint is that the mill is capable of producing 9000 tons/week. Assuming for the moment that the five machines can be balanced (i.e., there is enough that can be produced on each machine to keep each busy during the week), there is no need to do any initial resource planning other than to limit the orders to be shipped during the week to 9000 tons. The machine loading and trimming must be done jointly once the customer requirements are known.

Paper Machine Trim Problem

Let Q_i and W_i be the quantity and width required for order i for i = 1,..., m, and D be the maximum usable width of the production roll. The single-machine roll trim loss minimization problem can be formulated as follows:

$$\text{Min } \Sigma_j T_j X_j$$

$$\Sigma_j A_{ij} X_j = Q_i \text{ for } i = 1,\ldots,m$$

$$X_j \geq 0, \text{ integer}$$

where

X_j is the number of production rolls to be slit according to pattern j.

A_{ij} is the number of times size i appears in pattern j. $(A_{1j}, A_{2j}, \ldots A_{mj})$ is a legitimate pattern if

$$\Sigma_j A_{ij} W_i \leq D$$

$$A_{ij} \geq 0, \text{ integer}$$

T_j is the trim loss associated with pattern j

$$T_j = D - \Sigma_i A_{ij} W_i$$

If trim loss is an important consideration, the LP relaxation of this problem can be solved by the delayed pattern generations technique of Gilmore and Gomory [1,2]. The integer restriction can be handled by rounding the LP soultion down and heuristically generating patterns to complete any residual items as described in [3]. If the objective is simply to determine how well a set of orders will trim on a given machine, it is sufficient just to estimate the trim loss from the LP solution as

$$\Sigma_j T_j X_j / \Sigma_j X_j$$

or equivalently as

$$1 - \Sigma_i Q_i W_i / D\Sigma_j X_j.$$

Proposed Approach

The proposed approach to short term planning and scheduling assumes that the whole system will be considered for a short period of time. In the newsprint mill this would be one week. The assumption is that 9000 tons of orders have been accepted for production and shipment in a one week period of time. The issue is to simultaneously load orders onto machines and trim them to obtain high yields. A five step procedure for doing this is described below.

1. Group all orders having identical diameters, core sizes, machine windings, and machine preferences.

2. Find the trim loss if each group defined in Step 1 is trimmed using the Gilmore-Gomory LP-based approach for each machine on which the group can be made.

3. Assign a "cost/ton" of making each group on each machine. This cost can be based on the actual fraction of trim loss or can be scaled to indicate relative preference.

4. Allocate groups to paper machines using the costs, C_{ij}, determined in Step 3. In the case of the newsprint mill a simple transportation model can be used.

$$\text{Min } \Sigma_i \Sigma_j C_{ij} X_{ij}$$

$$\Sigma_j X_{ij} = R_i \quad \text{for all } i$$

$$\Sigma_i X_{ij} \leq C_j \quad \text{for all } j$$

where

X_{ij} is the tons of group i assigned to machine j.

R_i is the tons required in group i.

C_j is the capacity in tons of machine j.

The requirement that individual orders be produced on only one machine causes a problem if a group is allocated to more than one machine. The set of orders must be partitioned on a trial-and-error basis so that appropriate tonnage is assigned to each machine and so that the expected yields are obtained. Guidance on how to do this can be obtained by noting which orders trim together on each machine. Small partial assignments of a group to a machine can usually be ignored because the machines need not be perfectly balanced.

5. Trim together all orders having the same specfication that are assigned to each machine in step 4. At this point there is the possibility that the trim loss will be less than expected because of the intertrimming of orders that were in different groups originally because they could be produced on different subsets of machines. If orders that are identical in every respect except machine preference are assigned to the same machine, they can be trimmed together. Other considerations such as order contiguity or minimizing slitter changes in generating the final trim solution or running list for each machine can be handled as described in [43].

If there are problems with the solution at this point, it must be due to the mix of orders that have been accepted. In certain cases it may be possible to overcome the problem by getting permission from the customer to make his order on a new preferred machine or by producing one or more of next weeks orders in this run. If the problem persists over time, the only time solution may be a change in the customers served.

Summary

The early development of large scale LP-based resource allocation models in the paper industry led to a disaggregation of the production planning problem by machine. This clearly can be an ineffective way to look at the problem in those situations where there is a great deal of production flexibility with relatively homogeneous products and significant trim problems. In these cases it is more effective to disaggregate by time period and to focus directly on determining the most effective manner in which to produce the order requirements over a short time period. This works quite well in products such as newsprint because the demand is relatively stable in terms of tonnage and continuous.

The disaggregation by time period rather than machine permits trim loss which is an ubiquitous problem in the paper industry to be explicitly considered before the machine assignment decision is made. This eliminates the need for a large scale multiperiod LP model to do detailed planning. What is needed in its place is a smaller resource allocation procedure in subroutine form that can be executed at the middle stage in a preliminary trim-allocation-final trim procedure.

References

1. R. C. Gilmore and R. E. Gomory, "A Linear Programming Approach to the Cutting-Stock Problem," Operations Research 9, 849-859 (1961).

2. P. C. Gilmore and R. E. Gomory, "A Linear Programming Approach to the Cutting-Stock Problem - Part II," Operations Research 11, 863-888 (1963).

3. R. W. Haessler "The Disaggregation Problem in the Paper Industry" reprinted as chapter 16 in Disaggregation Problems in Manufacturing and Service Organization edited by Larry Ritzman et.al. (Boston: Martinus Nyhoff, 1979).

4. R. W. Haessler, "Single-machine Roll Trim Problems and Solution Procedures." 59, 145-149 (1976).