

Production Planning and Scheduling for an Integrated Container Company*

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An overview of the hierarchy of decisions indicates the control resource utilization and profitability for the integrated container producer and the tools available to assist in the decision-making process.

Key Words—Paper industry; optimization; computer applications; heuristic programming; linear programming; management systems; modelling.

Abstract—This paper describes a hierarchy of models and information systems being developed by integrated producers of corrugated containers to aid in the process of planning and scheduling their operations. The initial focus is on eight easily identifiable decision areas and the tools available to deal with them. The eight decision areas are paper machine loading, master scheduling, trimming, boxcar loading, stock size selection, inventory replenishment, corrugator combining, and finishing and shipping scheduling. The remainder of the paper identifies the major interactions among these decision areas and the systems required to deal with them.

INTRODUCTION

THIS PAPER describes a hierarchy of models and information systems being developed by integrated producers of corrugated containers to aid in the process of planning and scheduling their operations. Although directed toward a particular industry, many of these topics are relevant for other industries such as steel, glass, aluminum and plastic extrusions. The initial focus is on eight easily identifiable decision areas and the tools available to deal with them. These eight decision areas are given below. The first four are primarily paper mill issues and the last four are box plant issues.

1. Paper Machine Loading—allocating forecasted product demand to paper machines on the basis of production efficiency, freight costs and available capacity.
2. Master Scheduling—determining the run

- sequence and cycle time for each product assigned to each paper machine.
3. Trimming—specifying how many production rolls must be produced and how each is to be slit to satisfy a set of current production requirements.
4. Boxcar Loading—determining which boxcars should be used for an order and how each is to be loaded to minimize total freight cost.
5. Stock Size Selection—determining the roll stock sizes to be inventoried for the corrugator.
6. Inventory Replenishment—specifying the timing and quantity for replenishing the stock sizes that are to be inventoried.
7. Corrugator Combining—determining the least-cost method of producing the corrugated blanks required to fill a set of current order requirements.
8. Finishing and Shipping Scheduling—determining the sequence in which blanks for customer orders will be sequenced through the finishing and shipping operations.

The second section of the paper identifies the major interactions among these decision areas and the systems required to deal with them. The interactions considered are:

- A. Master Scheduling and Inventory Replenishment
- B. Trimming and Boxcar Loading to Minimize Material Handling
- C. Impact of Stock Size Selection on Machine Loading, Trimming and Boxcar Loading
- D. Corrugator Combining and Finishing Scheduling

DECISION AREAS

Over the last 25 years, a great deal of work has been done to develop models and systems to deal

* Received 8 June 1984; revised 10 January 1985. The original version of this paper was presented at the 5th IFAC/IMEKO Conference on Instrumentation and Automation in the Paper, Rubber, Plastic and Polymerisation Industries which was held in Antwerp, Belgium during October 1983. The Published Proceedings of this IFAC Meeting may be ordered from Pergamon Press Limited, Headington Hill Hall, Oxford OX3 0BW, U.K. This paper was recommended for publication in revised form by Editor A. Sage.

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with the eight decision areas listed above. The purpose of this section is to define more fully each of these decision areas and to identify the models and systems that are available as decision aids.

Paper machine loading

This decision can be easily and accurately modelled as a large-scale linear program (Godfrey, Spivey and Stillwagon, 1967; Haessler, 1979a). The decision variables identify the tons of a grade to be produced in a given time period to meet a demand at a customer location in a given time period. The primary constraints of the model relate to machine time and raw material available each period and forecasted requirements at customer locations by time period. The product allocations provided by these models consider production and distribution costs as well as the inventory carrying costs for production smoothing. This type of model can also be used to evaluate trade and purchase opportunities. The output of this model, which is a specification of the quantity of each grade to be produced on each paper machine in each time period, is the starting-point for short-to-intermediate-term mill operations planning.

A mathematical statement of this problem is given below:

$$\text{Max } \sum_g \sum_m \sum_p \sum_c \sum_s C_{gm pcs} X_{gm pcs} \quad (1)$$

$$\text{s.t. } \sum_g \sum_c \sum_s A_{gm} X_{gm pcs} \leq H_{mp} \text{ for all } m, p \quad (2)$$

$$\sum_m \sum_p X_{gm pcs} \leq D_{gcs} \text{ for all } g, c, s \quad (3)$$

$$X_{gm pcs} \geq 0 \quad (4)$$

where

g identifies a grade of paper,
 m identifies a paper machine,
 p identifies a production period,
 c identifies a customer location,
 s identifies a sales period ($s \geq p$),

$X_{gm pcs}$ = the tons of grade g produced at mill m in period p for sale to customer c in period s ,

$C_{gm pcs}$ = the contribution per ton defined as sales price less variable production, distribution and holding costs,

A_{gm} = the hours required per ton of grade g on machine m ,

H_{mp} = the hours available on machine m in period p ,

and D_{gcs} = the demand in tons for grade g by customer c in sales period s .

It should be noted that $C_{gm pcs}$ and A_{gm} are based upon assumptions about trim yield which depend upon both master scheduling and trimming. The

yield on any problem is determined by the mix of sizes and quantities ordered and the width of the paper machine. In general, historical experience can be used to estimate yields, although it may be necessary in special cases to use an iterative procedure of allocation and trimming to overcome the inability of the model given above to explicitly consider trim.

This linear programming model is a variation of the well-known product mix model that is used to plan production in a wide variety of industrial situations. It clearly should be used on a rolling horizon basis. The model considers multiple periods so that the loading in the present period is done in light of future requirements. At the end of each period, the model is resolved using the most up-to-date information.

Master scheduling

Once an allocation of grades to a paper machine has been set, the next step is to sequence and cycle the grades to be produced on each machine. Although this can be a very difficult technical problem because of the interaction of sequencing and cycling considerations, the issues are straightforward. The sequences in which the grades are run are important because changeover costs are sequence-dependent. Because most machines run a limited number of grades, it is generally possible to develop a natural sequence for a machine that minimizes the impact of grade changeovers. If that is not satisfactory, recent advances in algorithms for solving the traveling salesman problem (Lin and Kernighan, 1973) make it possible to find a run sequence that will minimize grade changeovers for a given set of grades. In addition, Brown, Northup and Shapiro (1981) have recently developed a software package that will generate a short-term run schedule for a mill based on changeover costs, order dates and pulp draw constraints.

The cycle, or run frequency, for a given grade on a machine impacts inventory levels, customer service, replenishment lead times and trim yields. The advantages of frequent runs of a grade are less box plant inventory and faster response to changes in demand for a given grade-size item. The disadvantages of frequent runs are higher changeover costs and possibly more trim loss as the set of required sizes and quantities is partitioned into more subsets, thereby reducing combining options. Recent advances in solving the economic lot sizing problems for n products on one machine (Haessler, 1979b) provide an effective way to deal with the trade-off between changeover and inventory carrying costs.

The master schedule provides the starting-point for short-term run planning. Promise dates for delivery of customer orders can be quoted from the master schedule. The master schedule is also the

place to monitor the supply–demand relationship. Imbalances one way or the other may necessitate modifying the master schedule.

Trimming

Prior to the start of a production run of a specific grade on a paper machine, the orders assigned to that run must be trimmed. Computer-based trim procedures have been in widespread use for over 15 years. Two basic approaches are used: linear programming (LP) and sequential heuristic (SH) procedures. All LP procedures can be traced back to the pioneering work of Gilmore and Gomory (1961, 1963). A number of authors (Pierce, 1964; Johns, 1966; Haessler, 1971) developed SH procedures in an attempt to overcome some of the difficulties with the LP procedures. Two of the most important of these difficulties are the number of slitter changes and order fulfillment. LP theory indicates that the number of cutting patterns will be equal to the number of sizes being trimmed and that pattern usage need not be integer valued. Trying to round an LP solution to integer values may cause serious problems with overruns and/or underruns. To some extent, this can be dealt with by controlled pattern generation techniques (Haessler, 1980b). If that is not satisfactory, then SH procedures may be required. A discussion of LP and SH procedures and the number of slitter changes can be found in Haessler (1975).

As a practical matter, the most effective trim procedures are those that combine LP and SH procedures. Two possible combinations follow:

1. Use an SH procedure to get a solution which is used as the initial basis in an LP procedure. Minimize trim loss with the LP procedure using a controlled pattern generation approach. Round the LP to integer values. Generate patterns for any residual rolls using an SH procedure.
2. Use an LP procedure to obtain a minimum trim loss solution. Use the results of the LP solution as a guide to how sizes should be combined in an SH procedure that provides the final solution.

A minimum definition of the roll trim problem is given below. It is assumed that the production requirements are for R_i rolls of width W_i , $i = 1, \dots, n$, to be cut from production rolls of usable width W .

$$\text{Min } C_1 \sum_j T_j X_j + C_2 \sum_j \delta(X_j) \quad (5)$$

$$\text{s.t. } RL_i \leq \sum_j A_{ij} X_j \leq RU_i \quad (6)$$

$$X_j \geq 0, \text{ integer valued,} \quad (7)$$

where

A_{ij} is the number of rolls of width W_i to be slit from each production roll that is processed using pattern j . In order for the elements A_{ij} , $i = 1, \dots, n$ to be a feasible cutting pattern, the following restrictions must be satisfied:

$$\sum_i A_{ij} W_i \leq W \quad (8)$$

$$A_{ij} \geq 0, \text{ integer;} \quad (9)$$

X_j is the number of production rolls to be processed according to pattern j ,

T_j is the number of units of trim loss incurred by pattern j . If W is the usable width, then

$$T_j = W - \sum_i A_{ij} W_i$$

C_1 is the dollar value of trim loss per unit,

C_2 is the cost of changing patterns in dollars,

$\delta(X_j)$ is 1 for $X_j > 0$ and 0 otherwise,

RL_i, RU_i are the lower and upper bounds on the requirements for customer order i reflecting the general industry practice of allowing overruns or underruns within specified limits.

In addition to the factors considered in the above trim model, it may be necessary to incorporate other issues into a trim program such as: roll position, order contiguity, varying order specifications, optional sizes, multiple machines and roll welding. A more detailed discussion of these issues can be found in Haessler (1976, 1980c).

Boxcar loading

In most situations the volume/weight relationship of rolls of paper is such that volume is the key factor in loading boxcars. This gives rise to a three-dimensional packing problem which must be solved to answer one of the following questions:

1. Does a given order completely fill one or more boxcars of known size?
2. How should a given set of rolls be loaded into boxcars so as to minimize freight costs?

The first question should be asked and answered at order entry time. If an order does not fully utilize an integer number of boxcars, it may be possible to modify the order prior to trimming so that planned boxcar utilization is increased.

The second question must be dealt with after the rolls are produced. The answer may be different from the answer to (1) for a number of reasons:

- the boxcar sizes available may be different than expected
- there may be rolls in inventory for the customer that should be shipped with current production

—trimming or quality problems may have changed the number of rolls of each size available to be shipped.

By knowing the general type of loading scheme to be used, it is possible to adapt trim programs to solve the boxcar loading problem to maximize the volume utilization of a boxcar. A common loading scheme used in the United States is to load rolls on end in the boxcar. The minimum number of rolls to be placed in a boxcar is the number of floor spots available. The maximum number depends on how well space between the floor rolls and the top of the car can be utilized. In most cases, it is possible to stack rolls vertically up to the top of the boxcar, or to lay a minimum of two rolls horizontally on a base of at least four rolls of equal size in what is commonly referred to as a rollback or combination load. Special restrictions usually hold for the floor spots in the boxcar doorway. No rollbacks can be placed in the doorway and stacks are usually restricted or prohibited. A simplified model to maximize utilization of a single boxcar by minimizing the floor spaces required is shown below:

Assume that the original order calls for R_i rolls of width W_i for $i = 1, \dots, n$, where all the rolls are for diameter D . Let BCH , BCW , BCL be the inner boxcar height, width and length dimensions, respectively.

$$\text{Min } \sum_j XS_j + \sum_j XD_j + 2\sum_j XR_j \quad (10)$$

$$\text{s.t. } \sum_j AS_{ij}XS_j + \sum_j AD_{ij}XD_j + \sum_j AR_{ij}XR_j = R_i \text{ for all } i \quad (11)$$

$$\sum_j XD_j \geq DS \quad (12)$$

$$\sum_j XR_j \leq RC \quad (13)$$

$$XR_j = 0 \text{ or } XR_j \geq 2 \text{ for all } j \quad (14)$$

$$XS_j, XD_j, XR_j \geq 0, \text{ integer} \quad (15)$$

where

XS_j = number of non-doorway stacks using pattern j ,
 XD_j = number of doorway stacks using stacking pattern j ,
 XR_j = number of rollbacks using pattern j ,
 AS_{ij} = number of times order i is in stacking pattern j such that $\sum_i AS_{ij}W_i \leq BCH$ and $AS_{ij} \geq 0$, integer,
 AD_{ij} = number of times size i is in stacking pattern j for the doorway with clearance, CL , such that

$$\sum_i AD_{ij}W_i \leq CL \text{ and } AD_{ij} \geq 0, \text{ integer}, \quad (16)$$

AR_{ij} = number of times size i is in rollback pattern j such that

$$\sum_i AR_{ij} = 3 \quad (17)$$

$$\sum_i \delta(A_{ij}) = 2 \quad (18)$$

$$\text{where } \delta(a) = \begin{cases} 0 & \text{for } a = 0 \\ 1 & \text{for } a > 0, \end{cases}$$

DS = number of floor spots in the doorway,
 RC = maximum number of rollbacks that can be put in the car.

A detailed discussion of a procedure for solving this problem can be found in Haessler (1980a).

Stock size selection

The maximum width roll of liner and medium that can be processed by a corrugator at a box plant is a function of the design of the corrugator. In addition to the maximum size roll, most plants stock a number of rolls of narrower width. This decision obviously leads to an increase in box plant inventory and a reduction in corrugator productivity. The primary motivation for stocking multiple roll widths is to reduce side trim generated at the corrugator. Because side trim is such an easily measured factor, it generally dominates in the stock size selection process. This can easily lead to a proliferation of stocking sizes. The costs associated with increased inventory and reduced corrugator utilization are more difficult to isolate and measure. This inhibits making an economic trade-off to determine the number of sizes to stock.

The key to making this trade-off is to be able to estimate the impact on controllable corrugator operating costs of changes in the set of sizes stocked. This can be done only through a computer-assisted simulation of the corrugator scheduling process. This is a practical undertaking if, and only if, a reliable computer-based corrugator combining procedure is available (see section on corrugator combining below). If such a program is available, it is possible to combine the orders produced over a period of time using a variety of sets of stocking sizes and to estimate the differences in controllable corrugator costs. This information can be used in conjunction with estimates on the relationship between inventory levels and number of items stocked to arrive at a better-balanced decision on the number of sizes to stock.

Although there is no direct algorithm for determining the best set of stocking sizes, the economics of the problem make it clear that a small number of wide sizes would be preferred. In existing plants with a wide range of sizes, it is generally easy to demonstrate that many of the smaller sizes can be

eliminated with a resulting increase in width utilization of the corrugator. Furthermore, there is increasing evidence that corrugators with triple length cut capabilities can be run with a single stock size. When only one stock size is to be selected, it is easy to enumerate all the alternatives and select the best.

Inventory replenishment

Given the set of sizes to be stocked, current inventory levels, forecasts of future roll stock consumption by grade-size, and estimates of replenishment lead times, box plants can determine inventory replenishment quantities and safety stock which are appropriate for their operations. Most plants order once or twice a month on a periodic basis. Continuous review systems are not appropriate because of the nature of the production process.

The great advantage that the integrated producer has is the opportunity to develop a system that directly links master scheduling for the mills with inventory replenishment for the box plants. This linking is advantageous because it can provide the mill with an idea of what the box plant will order from a production run while at the same time permitting the box plant to wait until the latest possible time before specifying exactly how many rolls of each size are to be ordered. An outline for this system is presented later in this paper.

Corrugator combining

Early attempts to develop computer-based corrugator combining programs closely paralleled the development of computer-based procedures for trimming paper machines. Both linear programming (Marley and Mahoney, 1963) and sequential heuristic (Van Wormer, 1963) procedures were developed. Unfortunately, the corrugator combining problem turned out to be much more difficult than paper machine trimming because of the more severe nonlinearities due to slitter and stock size changeover costs and the desire to minimize the amount of order splitting that takes place.

A new integer programming approach to corrugator combining developed by Haessler and Talbot (1983) is capable of dealing explicitly with the non-linearities mentioned above. It is a two-stage approach to the problem. In the first stage, solution elements are generated and costed out. A solution element is a specification of the way in which one or more orders can be completed from a single stock size. The four types of solution elements considered are listed below.

1. Producing one order by itself—for example, cutting three 25-in. width blanks from a 77-in. stock size.

2. Producing two orders from a single cutting pattern—for example, cutting two 20-in. blanks and two 18-in. blanks from a 77-in. stock size. This can be done if, and only if, the quantity requirements are such that both orders are simultaneously completed within the allowable quantity tolerances. Typical industry practice in the United States is to produce an amount that is in an interval between the order quantity and the order quantity plus 10%.
3. Producing two orders from two cutting patterns from a single stock size—for example, cutting one 25-in. blank and one 51-in. blank from a 77-in. stock roll until the order for 51-in. blanks is filled, and then finishing the order for 25-in. blanks by cutting them three across.
4. Producing three orders from two cutting patterns from a single stock size—for example, cutting two 25-in. blanks and one 26-in. blank from a 77-in. stock size until the 26-in. order is completed, and then cutting one 25-in. blank and one 50-in. blank until these two orders are completed. This again requires a specific relationship among the quantities required.

After all possible elements are generated, the subset that produces the order requirements at minimum total cost is selected in stage 2 by solving the following integer programming problem.

$$\text{Min } \sum_j c_j x_j + \sum_k s_k y_k \quad (19)$$

$$\text{s.t. } \sum_j a_{ij} x_j = 1 \text{ for all } i \quad (20)$$

$$\sum_j u_{jk} x_j \leq A_k y_k \text{ for all } k \quad (21)$$

$$x_j = 0 \text{ or } 1 \quad y_k = 0 \text{ or } 1 \quad (22)$$

where

x_j is 1 if element j is used and 0 otherwise,
 Y_k is 1 if stock size k is used and 0 otherwise,
 a_{ij} is 1 if order i is completed in element j and 0 otherwise,

u_{jk} is the feet of stock size k required by element j ,

A_k is the feet of stock size k available in inventory,

c_j is the total cost of using element j exclusive of the cost of changing to the required roll stock size. It includes the cost of corrugator time and paper used plus the cost of pattern changes. If any order is not produced at the maximum quantity, this value is adjusted to reflect the cost of producing the whole order,

s_k is the cost of loading stock size k onto the corrugator. It is assumed that if two or

more elements use the same stock size, they will run sequentially so there will be only one setup for each stock size.

The solution procedure for this 0–1 model is an adaptation of the set-partitioning algorithm introduced by Garfinkel and Nemhauser (1969). This approach is a list-processing, implicit enumeration technique that has very low core requirements and has been shown to be a relatively fast method for optimally solving the set-partitioning problem, which is a subproblem of this 0–1 model. In addition, this approach is attractive because of the ease with which inventory constraints and change-over costs can be included without significantly increasing core requirements.

The major advantage of this two-stage procedure for solving the corrugator combining problem is the ability to generate multiple elements in stage 1 that contain an order and then to select the one in stage 2 that gives the best overall result with all economic factors considered.

Scheduling finishing and shipping

After the rectangular blanks required by any order are produced on the corrugator, they generally must be processed through a small number of finishing operations before being shipped to the customer. Although there has been a great deal of academic research on scheduling job shops since the topic was first studied systematically by Conway, Maxwell and Miller (1967), it has had little impact on industrial scheduling. The focus of all that academic research has been on measuring operating performance of simple local dispatching rates that ignored the issue of bottleneck operations. It was not until the development of OPT (Fox, 1982) which focused on bottleneck operations, that any real progress was made on scheduling practice. As a result of developments such as OPT and the rapid improvement and decreasing cost of hardware, it is relatively easy to outline the primary elements required to schedule the finishing operations in a box plant.

1. Monitor status of each finishing operation.
2. Compute work backlogs at each operation.
3. Identify how manpower should be assigned to equipment.
4. Identify the jobs available to be processed next on each machine.
5. Identify when alternative routings for jobs should be considered.
6. Select job to be processed next.

SYSTEM INTERACTIONS

Given that tools and techniques are available for dealing with each of the eight decision areas identified above, the next step is to identify

important issues that overlap these eight areas and indicate how these issues can be dealt with by linking these tools. Each of the following sections develops an approach for dealing with issues that overlap the decision areas identified above.

Master scheduling and inventory replenishment

One of the best opportunities to increase operating efficiency for the integrated container producer is to link the mill master scheduling and box plant inventory replenishment systems together. The key elements of the linkage between these two systems are listed below.

1. The inventory items to be replenished from the same production run are grouped into a joint replenishment category.
2. A forecasted weekly consumption rate is determined for each inventory item in the joint replenishment category.
3. A master schedule that is consistent with the projected timing and quantity requirements for each joint replenishment quantity is established before the start of each month.
4. At any point in time a tentative replenishment order can be generated on the basis of the best available information for each joint replenishment category and each run in the master schedule.
5. The tentative order quantities are determined using a periodic replenishment model so that enough inventory replenishment will last until receipt of the next replenishment order.
6. The tentative orders can be matched against capacity in the master schedule to determine supply/demand relationships.
7. The expected inventory status can be determined for each joint replenishment category to determine if serious shortages are projected.
8. Problems highlighted in points 6 or 7 can be reported on an exception basis so that corrective action can be taken. This might involve changing the master schedule or replenishing all or part of the replenishment group from some other source.
9. Proposed changes in the master schedule can be evaluated by using the tentative ordering process in simulation mode so that the impact of the proposed changes can be determined as in point 8.
10. Actual replenishment orders can be generated at the latest possible time just prior to trimming so that the best available information on current inventory levels and forecasted consumption is used.
11. If the available production is too large or small for a replenishment order, the replenishment quantities can be automatically

scaled up or down in an optimal fashion to correspond to the available time.

The benefits of this linkage between master scheduling and inventory replenishment systems should be reduced inventories and improved service due to better use of the available information.

Trimming and carloading

If trimming and carloading are viewed as separate activities, the net result may well be increased material handling and lower-than-expected boxcar utilization. If, on the other hand, the two activities are viewed on an integrated basis, it is possible to link the trimming and carloading algorithms to reduce material handling and increase boxcar utilization. An integrated trimming-boxcar loading might operate as follows.

1. Quantities are checked at order entry to make sure that each order completely fills an integer number of boxcars. If it does not, order quantities are adjusted up or down so that planned boxcar utilization is improved.
2. When the orders for a given run are trimmed, overruns and underruns should be avoided on the orders which have been sized for carloading. The trim solution may also need to be restricted to limit the spreading of orders over a long period of time if the run is large.
3. The patterns in the trim solution are sequenced on the basis of knowledge of how the car is to be loaded to maximize the number of rolls that can be direct-loaded into the car.
4. A loading diagram is created for the shipping department that indicates how each car should be loaded so as to be consistent with the sequence in which the rolls are produced.

Roll stock sizes

As was stated earlier, the number and sizes of roll stock inventory involve a difficult trade-off within the box plant between inventory carrying costs and corrugator operating costs. The decision becomes even more complex when the impact of a box plant's stock sizes on paper machine trim and freight costs is considered, as it should be. Clearly there is no realistic algorithm that can be used to tell us what the "best" sizes would be. It is possible, however, using the algorithms available for trimming, carloading and corrugator combining, to develop some meaningful measures of the impact of changing stock sizes on paper machine trim yields, freight costs and corrugator operating costs.

1. Trim solutions can be analyzed to identify either the sizes that are causing high trim losses or the sizes that could be used to complement the troublesome sizes and reduce trim loss. With a computer-based trim procedure it is an

easy matter to change or add a few sizes and obtain a new solution to determine the impact of the change. In some cases, reducing some size by a fraction of an inch can result in a dramatic change in trim yields.

2. Carloading solutions can also be analyzed to determine new sizes or changes in existing sizes that will have a significant impact on freight costs by permitting increased utilization of incentive rates.
3. The impact of proposed changes on stocking sizes uncovered by analysis of trim and carloading solutions can be easily evaluated by simulating the corrugator combining process using the actual orders with any possible configuration of roll stock sizes.

Corrugator combining and finishing

The combining of orders for the corrugator can be done without regard to the status of the finishing operations, just as a paper machine can be trimmed without regard to the way in which boxcars are to be loaded. However, this may also lead to increased operating costs relative to what might be accomplished if the two are considered jointly. The two-stage corrugator-combining algorithm described earlier has the ability to consider factors other than direct corrugator operating costs when a solution is generated. Every solution element that is considered in the second stage 0-1 selection model must be generated in stage 1. If two orders should not be combined because doing so would overload the storage space available in front of some machine, that can be handled easily by simply rejecting elements containing those two orders. If the orders could be combined but only at an increase in finishing costs, that can be dealt with in the process of estimating the total cost for an element containing those orders. Similarly, if combining two orders results in some economic advantage in finishing, that can also be handled in the costing of any element containing those orders. In fact, it is possible to conceive of a sophisticated job shop scheduling system for finishing and shipping operations that controls the release of jobs into the shop through a corrugator-combining algorithm that responds directly to the requirements of the finishing and shipping operations.

CONCLUSION

The extremely high operating and capital costs of modern paper mills and box plants provide a very powerful incentive to utilize labor and equipment in an efficient and effective fashion. Any attempt to obtain high levels of resource utilization forces management to deal with complex trade-offs and interactions. Dealing with these issues is beyond our mental capacity. We must have information systems

and management science techniques to help us realize the efficiencies of production required to remain competitive.

This paper has focused on eight decision areas where techniques are readily available to help solve important resource utilization problems. These techniques are computationally feasible and used to some extent by virtually every organization in the industry. No company, at the present time, has all the techniques and, indeed, some organizations may have little to gain from some of them. Each organization must focus on those areas which have the greatest potential cost/benefit relationships. As impressive as these techniques may be, however, they are not enough. Many of the important management issues span two or more of these areas. The need and opportunity, therefore, is to find ways to use these systems in concert to move onward in the never-ending quest for improvement.

In the systems era, it is necessary to continually update and modernize the systems used to run the business. It is now time to focus on the cost/benefit relationships of being able to integrate these techniques to be able to get at the broader issues which have tended to be dealt with on an ad hoc basis. There do not seem to be any significant unsolved hardware or software problems that stand in the way.

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