Resource utilization decisions for integrated container companies

Robert W. Haessler

A wide variety of new and old decision support methods can be organized into a coherent framework to improve decision making and resource utilization for the integrated producer of corrugated containers.

Every integrated producer of corrugated containers is aware of the complex set of highly interrelated resource utilization decisions that must be made on a regular basis. In total, these decisions have a significant impact on productivity, costs, customer service, and profitability. The challenge is to develop a structure and framework for dealing with these decisions in an effective and manageable fashion.

This paper describes a hierarchical approach for identifying ten key decision points in an integrated container company. Each of these decision points is discussed, along with the tools that are currently available for dealing with them. Because several of the major decisions for the integrated producer cross over two or more of these decision points, approaches for dealing with them from a more centralized viewpoint are discussed.

Decision hierarchy

Ten easily identifiable decision points, five on the mill side and five on the box plant side, can be arranged in a hierarchical fashion based on the sequence in which choices must be made in the operation of the business. These points encompass both planning and scheduling issues and in total have a very significant impact on the profitability of the integrated producer of corrugated containers.

The first five decision points deal primarily with mill issues:

1. Paper machine loading—allocating forecasted product demand to paper machines on the basis of production efficiency, freight costs, available capacity, and trading options
2. Master scheduling—determining the run sequence and cycle time for each grade assigned to each paper machine
3. Shipment planning—sizing the order and selecting the desired mix of railcars that will minimize freight cost for each order
4. Trimming—specifying how many production rolls must be produced and how each is to be slit to satisfy a set of current production requirements
5. Vehicle loading—determining the sequence in which rolls are slit and loaded into the available railcars.

Decision points 6 through 10 deal with box plant issues:

6. Stock size selection—determining the roll stock sizes to be inventoried for the corrugator
7. Inventory replenishment—specifying the timing and quantity for replenishing the stock sizes that are to be inventoried
8. Shipment planning—establishing the time and method of shipping an order to a customer as part of the promising process to establish a due time at shipping
9. Corrugator combining—determining the least-cost method of producing the corrugated blanks required to fill a set of current order requirements
10. Finishing scheduling—determining the sequence in which individual orders will be sequenced through the finishing operations to meet the planned shipment time.

These 10 decision points are discussed in the next two sections. A quick check of the points will verify that they are not independent of one another. Important crossover effects must be dealt with to avoid suboptimization. The following major interactions are considered in the section of the paper on system interactions:

1. Trimming and railcar loading to minimize material handling
2. Corrugator combining and finishing scheduling
3. Master scheduling and inventory replenishment
4. Impact of stock size selection on machine loading, trimming, and freight cost.

Solution methods for mills

Over the last 25 years, a great deal of work has been done to develop models and systems to deal with the 10 decision areas listed above. The purpose of this section and the next

Haessler is associate professor at the School of Business Administration, University of Michigan, Ann Arbor, Mich. 48109-1234.

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

The decision on paper machine loading can be easily and accurately modeled as a large-scale linear program (*1, 2*). The decision variables identify the tons of a grade to be produced on a paper machine in a given time period to meet a demand at a customer location for the same or a later time period. The objective is to maximize the total contribution for the system. The primary constraints of the model relate to machine time and raw materials available for each period and to 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 planning short- to intermediate-term mill operations.

In this model, contribution and machine hours required to produce a ton of each grade are based upon assumptions about trim yield that depend upon both master scheduling and trimming. The yield on any trim 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 described 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 sequence in which the grades are run is 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, algorithms for solving the traveling salesman problem (*3*) make it possible to find a run sequence that will minimize grade changeovers for a given set of grades. In addition, there is a software package (*4*) 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 causes an impact on the 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 for a given grade is partitioned into more subsets, the combining options are reduced and trim loss can increase. Procedures for solving the economic lot-sizing problems for *n* products on one machine (*5*) 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 overall supply-demand relationship for each grade. Imbalances one way or the other may necessitate modifying the master schedule.

Shipment planning

Most liner and medium mills have very limited storage space, and they are often located a significant distance from their customers. It makes sense in most situations to size the orders sent to the mill to ensure that the whole order can be shipped and that use is made of all the available space and weight-carrying capacity of the shipping vehicles available. If railcars are used, and especially if more than one size of railcar is available, this gives rise to an interesting question as to how many rolls loaded in which car sizes will minimize freight cost per ton by shipping as much tonnage as possible at the incentive rate that is triggered above some weight level in each car size. The weight at which the incentive rate applies generally can be reached only by loading rolls horizontally in the second level of the railcar. A procedure for solving this problem is based on linear programming (*6*).

This problem must be solved at order entry so that an order of appropriate size is trimmed and sent to the mill. With limited storage space, it is important not to produce rolls that cannot be shipped immediately. This is especially true for roll widths, grades, or diameters that are ordered infrequently.

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 20 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 (*7, 8*). A number of authors (*9–12*) developed SH procedures in an attempt to overcome some of the difficulties with 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 or underruns. To some extent, this can be dealt with by controlled pattern generation techniques (*13*). A new approach (*14*) has been proposed for solving trim problems in which LP and SH procedures are used jointly to find solutions with relatively few slitter changes.

In addition to the factors considered above, 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. More detailed discussions of these issues are available (*15, 16*). In large trim runs, order contiguity is an important issue because it makes an impact on the opportunity to load rolls directly into railcars without having to stage them first.

Vehicle loading

Two separate issues interact in vehicle loading. The first is that the choice of trim patterns and the sequence in which they are run determines the arrival of rolls at the shipping dock. The most effective way to load the rolls would be directly into the vehicle without their being staged or even touching the mill floor. This requires that the trim patterns be sequenced so that the rolls to be loaded first are produced first. This can be done reasonably easily by observing that most rolls are interchangeable. The only exception is the narrower widths that form the base for rolls to be loaded on the second level. These typically are the rolls that must be produced first.

The second issue has to do with a change in loading plans because:

- Railcar sizes available may be different than expected.
- Rolls in inventory for the customer may need to be shipped with current production.
- Trimming or quality problems may have changed the number of rolls of each size available to be shipped.

Any one of these may necessitate a replanning of the loads. The shipment load planning system described above can be used for this purpose also. One of the most interesting uses is to allocate a limited number of high-capacity cars to obtain the maximum benefit from their use. This problem can be solved by systematically increasing the threshold weight required by a high-capacity car until the number used equals the number available.

Solution methods for box plants

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 width roll, most plants also stock several narrower widths. 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 stock size selection. 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 that changes in the set of sizes stocked have on the controllable costs of corrugator operation. 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 procedure for corrugator combining is available (see section on corrugator combining). If such a program is available, it is possible to combine the orders produced over a period of time by using a variety of sets of roll stock 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. The general rule of thumb that the amount of inventory increases as the square root of the number of sizes provides a reasonable first approximation to the relationship between the amount of inventory and the number of roll stock sizes.

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 large 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 that 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 cyclical nature of the master schedules for the paper machines.

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 in the section on master scheduling and inventory replenishment.

Shipment planning

The promising of an order to a customer is essentially the specification of when that order can and must be at the shipping dock ready to load for shipment to the customer. In some instances, a desired shipment time may be stated and the issue is to see if the order can be at the dock by that time. In other instances, it may be a matter of finding the earliest time at which the order may be reasonably expected to arrive at the shipping dock. In either case the answer depends on a number of interrelated issues:

- Other orders that have already been accepted and for which times due at shipping are known
- Backlog at each work center
- Crewing schedule currently in place
- Reliability of processing times and equipment.

In many situations, an order can be accepted and a reliable delivery promise made based on backlog information and the lead time available on the order. In other cases, it may not be clear whether or not a given order can be produced on time without changing the work schedule or possibly delaying one or more previously accepted orders beyond their promised shipment time. Under these circumstances, it may be necessary to simulate the operation of the plant over the near term in order to understand both the consequences of accepting a given order and the alternative ways in which those consequences can be lessened. The plant scheduling system discussed in the following section can be used in a simulation mode to help deal with this important problem.

Corrugator combining

Early attempts to develop computer-based programs for corrugator combining closely paralleled the development of procedures for trimming paper machines. Both linear programming (*17*) and sequential heuristic (*18*) procedures were developed. Unfortunately, the corrugator combining problem turned out to be much more difficult than the paper machine trim problem. This is due to the costs associated with slitter and stock size changes and the desire to minimize the amount of order splitting that takes place.

For the two-knife corrugator, an integer programming approach to order combining (*19*) is capable of dealing explicitly with the cost and order-splitting issues. It is a two-stage approach to the problem. In the first stage, solution elements are generated along with an estimate of the production cost of each element. 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:

1. Producing one order by itself. An example is cutting three 25-in. blanks from a 77-in. stock size.
2. Producing two orders from a single cutting pattern. An example is 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 10% above the order quantity.
3. Producing two orders from two cutting patterns from a single stock size. An example is 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 three across.
4. Producing three orders from two cutting patterns from a single stock size. An example is 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 a set-partitioning problem which guarantees that each order is produced once and only once in a manner leading to the lowest overall cost solution for all orders.

For the three-knife corrugator (*20*), there is a combination linear programming and sequential heuristic procedure that takes advantage of the strengths of each approach to generate good solutions from a single roll stock size.

Finishing scheduling

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 Mill (*21*), it has had little impact on industrial scheduling. The focus of all the academic research has been on measuring the operating performance of simple local dispatching rates that ignored the issue of bottleneck operations. The inadequacy of this academic research has been discussed (*22*).

It was not until the development of OPT (*23*), which focused on bottleneck operations, that any real progress was made on scheduling practice. As a result of the recognition of the importance of bottlenecks and the rapid improvement and decreasing cost of computer hardware, it is relatively easy to outline the primary elements of a scheduling system for the finishing operations in a box plant:

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

A discussion of a box-plant scheduling system, along with a sample schedule, was presented at the 1988 TAPPI Corrugated Containers Conference (*24*). The real value of such a system is the ability to simulate the operation of the box plant over the near term. A simulation of the plant based on its current status provides an invaluable look into the future that will identify when each order should finish and what the utilization of each work center will be over the next few days.

If these results are satisfactory, no special action need be taken. When these results are not satisfactory, plant management may want to use the simulation capability of the system to assess the consequences and effectiveness of various options that are available. The options may involve such things as replanning shipments, changing the work schedule, changing the corrugator schedule, or recombining orders on the corrugator.

System interactions

Because tools and techniques are available for dealing with each of the 10 decision areas discussed in preceding sections, the next step is to identify important issues that overlap these 10 areas and to 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 10 decision areas.

Areas where decisions overlap can be placed in two categories. The first category contains issues that overlap decision levels within either the mill or box plant subset but do not overlap both areas. These are the most straightforward to deal with from an organizational standpoint and usually can be handled by using the tools in an iterative fashion or by developing more sophisticated tools. The second category of system interactions contains decision issues that involve both the paper mill and box plant.

Two of the most important intra-area interactions are described in the next two sections.

Trimming and railcar loading

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

1. Quantities are checked at order entry to make sure that each order completely fills an integer number of railcars. If it does not, order quantities are adjusted up or down so that planned railcar utilization is improved.
2. When the orders for a given run are trimmed, overruns and underruns should be avoided on the orders that have been sized for railcar loading. The trim solution may also need restriction 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 railcar is to be loaded to maximize the number of rolls that can be direct-loaded into the railcar.
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.

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 railcars 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 algorithm described in the section on corrugator combining has the ability to consider factors other than direct operating costs of the corrugator when a solution is generated. Every solution element that is considered in the second-stage selection model is explicitly generated in the first stage.

If two orders should not be combined because doing so would overload the storage space available in front of a finishing machine, elements containing those two orders can simply be rejected. 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 an economic advantage in finishing, that can also be handled in the costing of any element containing those orders. In fact, it is feasible at this point to develop a sophisticated system for job shop scheduling for finishing and shipping operations that controls the release orders into the shop through a corrugator-combining algorithm that responds directly to the requirements of the finishing and shipping operations.

The second category of system interactions—decision issues that involve both the paper mill and box plant—can be more difficult to deal with organizationally because they require a higher degree of centralized control than most integrated box producers are ready or able to exert at this time. The issues nonetheless are extremely important and worthy of significant attention.

Master scheduling and inventory replenishment

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

1. The inventory items to be replenished from the same production runs 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 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. Tentative order quantities are determined by using a periodic replenishment model. In this model, each inventory replenishment must be large enough to last until receipt of the next replenishment order.
6. The tentative orders can be matched against capacity in the master schedule to determine the overall supply-demand relationship by machine.
7. The expected inventory status can be determined for each joint replenishment category to indicate 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 a 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 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 a systematic fashion to correspond to the available time.

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

Selection of roll stock sizes

As discussed in the section on stock size selection, the determination of roll stock sizes for the box plant involves a difficult trade-off between inventory carrying costs and corrugator operating costs. The decision becomes even more complex when the impact on paper machine trim and freight costs is considered, as it should be. Clearly there is no realistic algorithm that can be used to directly determine what the "best" sizes would be. It is possible, however, to use the algorithms available for trimming, carloading, and corrugator combining for development of some meaningful measures of the impact of changing stock sizes on paper machine trim yields, freight costs, and corrugator operating costs. Methods include:

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 one size by a fraction of an inch can result in a dramatic change in trim yields.
2. Railcar loading 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 roll stock sizes that are uncovered by an analysis of trim and railcar loading solutions can be easily evaluated by simulating the corrugator combining process. Results using actual orders with the new roll stock sizes can be compared with those obtained from the current roll stock sizes.

Conclusion

The 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 effectively requires the use of information systems and management science techniques. This is the only certain way to realize the efficiencies of production required to remain competitive.

This paper has focused on 10 decision areas where techniques are readily available to help solve important resource utilization problems. The techniques are computationally feasible and used to some extent by virtually every organization in this 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.

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 address broader issues that have tended to be dealt with on an ad hoc basis. No significant unsolved hardware or software problems appear to stand in the way.□

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