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**Comparing RCT and STFI  
TEST METHODS** p. 163

**Zero Discharge  
PROGRAMS** p. 171

**Maximizing Yield to Increase  
OPERATING EFFICIENCY** p. 180

Also in this Issue:

**PRODUCTION ROUNDTABLE** p. 160

**Plant Story: Metsä-Botnia's Kemiart** p. 185

# A joint analysis of box plant roll-stock sizes and paper machine yield

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*How to maximize yield on the paper machine while increasing operating efficiency in the box plant.*

THIS PAPER EXPLORES THE ISSUES INVOLVED IN SELECTING THE ROLL-STOCK sizes to be used by a group of corrugated box plants. The project was carried out with the twin objectives of maximizing trim yield on the paper machine(s) supplying the roll stock while increasing box plant operating efficiencies consistent with the current customer order mix. The methodology developed to meet these objectives is illustrated using mill data from Inland Paperboard & Packaging, Inc.'s paper mill and corrugated box plants in California.

### BACKGROUND

In the case presented here, a single paper machine supplies the majority of the roll stock used by six box plants. A significant amount of trading is done to optimize the grade mix on the paper machine, which has a maximum usable width of 255–258 in., depending on the grade being produced. At the time of the study, the yield on the paper machine was about 97%, with the six box plants receiving the majority of the paper machine's output. Each box plant has a single corrugator with a maximum roll-width capacity of 98 or 87 in. The box plants were free to order any sizes they needed to meet their in-

dividual needs, without regard to impact on paper machine yield. Consequently, it is reasonable to assume that the box plants selected roll-stock sizes that were consistent with their operating objectives without considering the impact of their size selections on the yield of the paper machine.

### EXPECTATIONS

The key expectation of this project was that it would be possible to increase paper machine yield significantly without adversely affecting box plant operating efficiency. An additional goal was to introduce the process of board grade consolidation (BGC) to the box plants by performing "before" and "after" roll-stock analyses (RSA). The objective of BGC was to increase productivity and reduce inventory carrying costs while achieving the goal of increasing paper machine yield.

### METHODOLOGY OVERVIEW

A systematic analysis was carried out in an effort to develop recommendations that would increase the yield on the paper machine without reducing the operating efficiencies of the box plants. The analysis involved the following four steps:

1. *Paper machine trimming.* The

first step was to consider current paper machine trimming practices and policies to determine if yield could be improved without any changes in the roll-stock sizes being ordered. A linear programming (LP) algorithm was used in this step to assess the maximum theoretical yield from a given pool of orders.

2. *Roll-stock trading.* The second step was to review current roll-stock trading practices to determine whether yield could be improved by changing the mix of roll sizes that were traded to other mills. Once again, the LP algorithm was used to assess the impact on yield of changes in the mix of sizes outsourced.
3. *Box plant roll-stock analysis.* The third step was to perform a roll-stock analysis for each box plant using historical orders and current roll-stock sizes to determine benchmarks for operating efficiency. These results could then be used to estimate the impact that changes in roll-stock sizes and/or combined board grades would have on plant operating efficiency and inventory carrying costs. A thorough review was then made of all combined-board grades offered at the box plant, eliminating as many as possible through consolidation. The order history was then "reassigned" to the new consolidated grades, and a second roll-stock analysis was performed. A corrugator combining program—modified to accumulate operating statistics over a large number of runs—was used to generate statistics on order completion, average width utilization, side trim, and paper and slitter changes for whatever set of roll-stock sizes was being considered.
4. *Putting it all together.* The fourth and critical step was to bring the results of the first three

steps together into a set of implementable proposals that would achieve the objective of simultaneously increasing paper machine yield and box plant operating efficiency while lowering inventory carrying costs.

Each of these steps is discussed in detail in the following sections.

### PAPER MACHINE TRIMMING

For the sake of discussion, assume that the paper machine width is 255 in. The majority of the order sizes required by the box plants are in the interval from 66 to 98 in. A quick calculation indicates that this is primarily a three-out machine, which means that the typical slitter pattern will contain three rolls. It follows that if every slitter pattern contains three rolls, the yield can be determined by calculating the average roll width as long as the average width does not exceed 85 in. For example, if a trim run contains 300 rolls with an average width of 83 in. and no widths less than 255 divided by 4 (i.e., 63.75 in.), then the run will require exactly 100 machine sets, and the yield will be 3 times 83 divided by 255, or 97.65%. A review of historical trim runs indicated that most large runs required some rolls that were less than 63.75 in. and, therefore, slitter patterns containing four rolls were possible. However, because of minor material-handling considerations, the mill had asked that the number of four-out patterns be minimized. The following example demonstrates how expensive this request was in terms of paper machine yield.

Suppose that in addition to the 300 rolls mentioned above, an additional 12 rolls, all of them 61 in. wide, are needed. If these rolls were mixed in with the others and produced in three-out patterns, 104 machine rolls would be needed, reducing the yield to 96.65%. A better solution would be to use a four-out

pattern, which would produce the additional 12 narrow (61 in.) rolls using only three machine rolls. In this case, the yield would be 97.59%. An even better solution can be obtained by specifically attempting to maximize the number of four-out patterns that are generated. The impact of this is easy to see. Three four-out patterns will produce as many rolls as four three-out patterns while consuming one less machine roll. In the proposed example, if the 12 additional 61-in.-wide rolls can be combined with 12 rolls whose average width is no more than 66.5 in., then six machine rolls can be slit using four-out patterns. This will reduce the number of machine rolls by one relative to the previous solution, where only three machine rolls were slit using a four-out pattern. Because only 102 mill rolls are then required to produce 312 rolls, the yield will be 98.55%. [Note that  $(6 \times 4) + (96 \times 3)$  gives the required 312 rolls.]

The important observation here is that trimming practices and policies can have a detrimental impact on paper machine yield. Thus the first step in improving paper machine yield is to make sure that the current order pools are being trimmed as efficiently as possible. Even the use of a computer-based trim system is no guarantee that the maximum possible yield or lowest possible cost solutions are being obtained. In this case, the simple act of maximizing rather than minimizing the number of four-out patterns resulted in a one-point increase in paper machine yield from 97% to 98%.

### ROLL-STOCK TRADING

It is common in the corrugated box industry to trade sizes and grades with other producers in an attempt to improve mill profitability. In the case at hand, Inland was trading out significant amounts of some large-volume commodity grades in order to maintain capacity for more

profitable grades or grades that could not be procured economically from other mills. For products that are not specifically manufactured for outsourcing, this raises the question of balancing the sizes that should be traded vs. those that should be kept for internal production. A review of sizes traded out to other mills for production again showed the possibility of improving yield without changing the roll-stock sizes ordered by the box plants. The sizes being traded away at the beginning of the study were a cross section of all the sizes being ordered by the box plants. However, the LP analysis of the theoretical paper machine yield potential performed in Step 1 indicated that yield could be improved by either increasing the number of four-out patterns or increasing the average width of the rolls produced from three-out patterns so they are closer to the theoretical optimum of 85 in. This could be accomplished in this setting by identifying specific roll sizes to be outsourced to other producers. The roll sizes that increase the yield loss are those that are too wide to be trimmed four-out and too narrow to trim well three-out. In this case, roll widths in the range from 67 to 84 in. are the logical sizes to trade out. Based on the scenario presented in Step 1, it makes no sense to trade narrow sizes that can be used in four-out slitting patterns. It also makes no sense to trade away the wider sizes that help three-out patterns achieve the desired average width of 85 in. Using the same arguments as before regarding the fixed rela-

tionship between the number of rolls required and the number of three-out sets, trading twelve 73.5-in rolls rather than a weight-equivalent nine 98-in. rolls will result in a trim loss saving of one complete machine roll (i.e., 255 in.). The recommended modifications of the rules for determining which sizes to trade further increased the yield by 0.7 points to 98.7%.

Care must be taken to ensure that the application of this strategy does not cause the average roll width to become too wide. If the average roll size in this example exceeds 85 in., the trim yield will start to go down again because it will be necessary, at least theoretically, to use some two-out slitting patterns to deal with the fact that the average roll size has gone from too small to too large. This possibility can easily be avoided by using an LP algorithm to calculate the maximum

theoretical yield of the remaining order pool before releasing the trade sizes.

### BOX PLANT ROLL-STOCK ANALYSIS

Unless a systematic analysis has been performed to reduce the number of roll-stock grades and sizes carried in inventory at a box plant, the list of inventory items is likely to be very long, and many will have a low usage. This raises the possibility of significantly reducing inventory carrying costs by paring the number of grades and sizes stocked. This is a complex task requiring sophisticated tools to process large amounts of data in order to identify strategies allowing the box plant to consolidate its mix of grades and sizes while continuing to serve its customers efficiently.

This portion of the study was carried out using a roll-stock analysis system developed by Corrugated Technologies, Inc. (CTI), a San Diego, CA-based firm specializing in scheduling and information-processing applications in the corrugated box industry. CTI had previously performed stand-alone roll-stock analysis for Inland at other plants with significant benefits realized. The analysis in this situation was a little more complex because of the desire to select roll-stock sizes that would increase box plant operating efficiency while also increasing the yield on the paper machine. Based on the analysis done in Steps 1 and 2, paper machine yield could be improved to 99.5% if the average roll width produced could

GLOBAL ANALYSIS RESULTS					
Analysis Group: Inland Paperboard & Packaging				Plant: Inland Plant	
Period:	From 6/12/1997		To 6/12/1998		
Width	M28	M45	K	L70	L120
87.00	14957	15825	58481	21201	8218
86.00	19278	3788	35890	15138	14185
85.00	9317	3684	20920	13748	8761
84.00	13401	6118	14085	6658	16193
83.00	13532	1718	43654	7162	6334
82.00	5937	856	5650	9064	1350
81.00	4398	948	6418	3038	2505
80.00	2275	1360	2001	2675	678
79.00	10184	372	14162	1212	1730
49.00	180	5344	184	8017	176
48.00	28	...	...	55	240
47.00	...	...	...	...	...
46.00	264	...	528	...	141
45.00	15	...	175	...	...
44.00	166	...	...	7	141
TOTALS:	186491	118416	355390	160950	50528
PERCENT:	12.05	7.65	22.96	10.40	9.73

1. Initial LP output is termed the "natural distribution" for the plant's specific order mix

be increased by as little as 0.75 in.

Roll-stock analysis was carried out using specially modified computer algorithms from the set of solution methods in CTI's CorrTrim<sup>®</sup> corrugator scheduling system. Their "Dollar" or Cost Minimization solution method—modified to accumulate operating statistics on order completion, average width utilization, side trim, and paper and slitter changes—performs a detail/cost-based analysis using baseline or present-case data, and was used later in a variety of "what if" scenarios. CorrTrim's LP (linear programming) method was used to perform a global analysis using 1-in. (25-mm) increments of roll stock with the entire historical order database to determine the "natural distribution." The LP analysis is used as a guideline during detail/cost-based simulations. **Table I** shows a sample printout of LP analysis.

We obtained a database of each Inland plant's production order history covering an entire year. We then scrutinized the database to eliminate grades of paper that are not essential to plant operations. This not only led to an inventory reduction, but it also eliminated the problem of sourcing these low-volume items. We also excluded orders with preprint stock or special processes (where these orders couldn't be combined with other orders and/or the roll stock for these orders couldn't be eliminated for various other reasons). The remaining orders were organized into order pools consistent with the frequency their flutes/grades run on the corrugator. For example, a grade such as 200C is run every operating day, so the "pull-ahead limit" for 200C was set to 1 day, whereas the parameter for 500BC, which was run weekly, was set to 5 days. As a result, the order database, consisting of thousands of orders, was organized and shrunk into hundreds of scheduling/analysis order pools.

RSA™ Summary Of Results				From 6/12/1997
				To: 6/12/1998
	Present	New	Difference	Percent
Roll Stock Sizes	182	88	-94	-51.6%
Paper Changes	7583	6690	-893	-11.8%
Slitter Changes	9024	8862	-162	-1.8%
Lineal per Paper Change	26,467.69	28,875.73	2,408.04	9.1%
Lineal per Slitter Change	22,241.19	21,798.53	-442.65	-2.0%
Corrugator Hours	8,357.20	8,043.80	-313.40	-3.8%
Area per Hour	144.64	148.26	3.61	2.5%
Side Trim Percentage	2.5%	3.0%	0.5%	21.0%
Average Width	72.27	74.08	1.81	2.5%
Production Cost	\$4,889,657.98	\$4,623,460.93	(\$266,197.05)	-5.4%
<b>Total Cost &amp; Savings</b>	<b>\$4,889,657.98</b>	<b>\$4,623,460.93</b>	<b>(\$266,197.05)</b>	<b>-5.4%</b>

Prepared by Corrugated Technologies, Inc.

II. Results for one of the study plants, showing before and after board grade consolidation

We then determined each plant's cost and control parameters—corrugator operating costs per hour, single facer speeds, cost of side trim, cost of paper and slitter changes, maximum number out, etc. Once those figures were in hand, we performed the first detail/cost-based analysis using each plant's scheduling/analysis order pools with their present roll-stock widths in order to establish a present-case benchmark of results before grade consolidation.

Working at each plant with a team consisting of sales, production, and design personnel, we sought to identify opportunities to eliminate as many grades as possible. Using a special board-grade consumption report—sorted by usage, by grade, and by customer—the team was able to move orders from the bottom 10–20% (i.e., where there are very few orders per grade) to other grades. The consolidated order database was adjusted to re-

flect the board grade consolidation, and the revised scheduling/analysis order pools were run through a second cost-based analysis to create a present-case benchmark of results after grade consolidation. The roll-stock analysis results in **Table II** show the data before and after board grade consolidation for one of the plants.

A global analysis was then run on the consolidated order database. The result was a table with columns listing all of the paper grades used within the time period being studied. The rows in the table list possible roll-stock widths in 1-in. (25 mm) increments. Each cell in the table shows the usage by roll-stock components and widths, where the LP algorithm has trimmed each order pool to maximize the width of the corrugator and produce minimum side trim (see Table I).

The results of the global analysis at each plant provided guidance in selecting alternative sets of roll-

stock sizes in the subsequent detail/cost-based runs, which simulate the corrugator combining operation for the plant and show the relative cost of using a hypothetical set of roll stock sizes. The selection of candidate roll widths was also influenced by the paper machine trimming study, which identified widths that would achieve box plant goals while increasing paper machine yields.

After a series of simulations, a final set of recommended roll-stock sizes was selected. The effects of the recommended changes were then quantified in a summary of results for the old and new roll-stock widths, showing lineal per paper/slitter changes, area per hour, average width and side trim, and total production costs for the old and new setups. (See Table II.)

In addition to comparative results, an estimate of the impact on inventory was generated for each grade using a variation of the square-root rule. This relationship—which can be derived from a standard continuous review inventory control system under random demand—states that the amount of inventory required to provide a consistent level of service increases as the square root of the number of individual stock items. For example, if four items in different colors replace one standard inventory item, the amount of inventory will have to double to provide equivalent service. Conversely, if four inventory items (roll-stock sizes) are consolidated down to one, the inventory can be reduced by half. Because most box plants replenish inventory on a periodic rather than a continuous basis, the relationship between the amount of inventory and the number of stocking items has been modified to be one-half plus one-half the square root of the number of items. Using this relationship, increasing the number of items inventoried from one to four

would increase the amount of inventory required by one-half. Decreasing the number of items from four to one would lead to an estimated one-third reduction of required inventory.

### PUTTING IT ALL TOGETHER

The previous discussion might appear to suggest that the proposed optimization strategy is a linear process, but that is not the case. Yield on the paper machine is a complex function of:

1. Paper machine trimming policies and procedures
2. Rules for determining which roll-stock sizes to trade away
3. Modifications to the list of grades and sizes of roll stock carried by a box plant

Optimal results depend on concurrent analysis of Steps 1–3, with frequent feedback among the steps to distinguish between perceived needs and technically feasible options. Provisional decisions in each step are required before assessing the ultimate impact on paper machine yield.

The final integration step requires multiple trials to determine the best mix of roll-stock sizes that will meet both the box plant's requirement for customer service and operating efficiency as well as the mill's requirement for high paper machine yield.

### RECOMMENDATIONS AND RESULTS

The analysis described here generated a number of recommendations, and we can report some early results. At the paper mill, the scheduler began looking for and recognizing opportunities to maximize the number of 4-out patterns. This alone accounted for a gain of 0.5–1% in trim efficiency. As a result of the efforts at the box plants to reduce board grades through consolidation—and to select fewer, more advantageous widths from the per-

spective of paper mill trim—the mill began to see a steady increase in average order width, with attendant improvement in trim efficiency. The last example we were given prior to handing off this project to the Inland Paperboard & Packaging West Coast Yield Optimization Team was a net total gain of 1.32% in paper machine width utilization for January 1999, said to represent a savings in excess of \$750,000 per year.

Some box plants experienced delays in achieving the benefits identified by the analysis due to the need to use up obsolete inventory. Two specific examples of expected gain were cited prior to project handoff: For Inland's RK grade, the suggested new standard widths should have resulted in a total increase of 0.82 in. across the plants, which would represent an increase of 2.46 in. at the mill. For their RM grade, they expected an increase of 0.52 in., which would increase mill yield by 1.56 in. After that initial stage, most plants experienced higher average widths and longer wet-end runs, although some also reported an increase in side trim. For most schedulers trained in years past to avoid side trim at almost all costs, this issue seemed daunting. Also mentioned were the problems introduced with National Account business requiring specific grades that were not on the consolidated "approved" list, and therefore not subject to the plant's local control. For the most part, however, the box plants realized significant improvement in operating costs by implementing the recommendations. **CI**

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