AN EXAMPLE OF OPERATIONS RESEARCH IN THE DRY KILNS*

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Operations Research, or "O.R.", is the application of objective mathematical techniques to guide production decisions between alternatives. For the most part, it involves the same type of calculations you have been doing on the back of an envelope; but with computers, we can do the calculations faster and keep track of the complex interactions between decisions.

This example is simple, involving a few of the concepts used in O.R., but avoiding the more complex techniques such as linear programming and simulation.

The dry kilns are a limiting factor in many mills. Some of you have considered drying Douglas Fir dimension, but do not have the kiln capacity. An example problem would be an order from management to increase kiln capacity by faster drying without additional degrade. Because of a wide range in initial moisture content, many boards are below the maximum moisture content early in the schedule. To gain capacity, we might pull the kilns earlier than customary and gain the additional space freed by the earlier drying boards. But this must be balanced against the time lost loading and reheating the kilns and reconditioning some of the lumber (redry).

Consider the white fir dimension dried at our Anderson facilities. Because of limited sorting capacity of our three mills, the kiln input is mill run from three sources. Therefore, each charge is quite variable in initial moisture content. The kiln schedule is shown in Table 1 and includes a 7-hour conditioning period.

<table>
<thead>
<tr>
<th>Hours</th>
<th>Dry Bulb, °F</th>
<th>Wet Bulb, °F</th>
<th>E. M. C. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>150</td>
<td>130</td>
<td>8.0</td>
</tr>
<tr>
<td>20-40</td>
<td>160</td>
<td>130</td>
<td>5.8</td>
</tr>
<tr>
<td>40-52</td>
<td>170</td>
<td>130</td>
<td>4.4</td>
</tr>
<tr>
<td>52-64</td>
<td>180</td>
<td>130</td>
<td>3.3</td>
</tr>
<tr>
<td>64-Dry</td>
<td>185</td>
<td>130</td>
<td>2.4</td>
</tr>
</tbody>
</table>

First, I must establish the relationship between kiln time and redry. Ordinarily, the procedure would be to go into the kilns at various hours and estimate the percent redry if at that moment the charge were conditioned 7 hours, then pulled. In this example, however, I used a sample of past data normally recorded in our kilns. The moisture content of about 50 to 60 boards per charge is measured with a "T" handle resistance meter. I allowed a 1% change in moisture content during the conditioning and calculated the percentage of the boards that would be painted at our dry chain moisture meter for being above our maximum 19% moisture content. The scatter diagram looked like Figure 1 with each point representing the percentage of boards that would be redried from a particular charge.

The question now is how to interpret the diagram. A common method is to average observations within selected time intervals. The two dotted graphs show the results of grouping by different 5-hour intervals and demonstrate a smooth curve is not likely from this technique and there are many possible graphs.

A second method, and the first O. R. concept, is a mathematical system of plotting a smooth curve through

* Published in Wood and Wood Products, August 1967.
these points. "Regression" is a technique that locates the curve such that the total distance from all points to the line is a minimum. This agrees with our common-sense idea of best fit. (Actually it minimizes the sum of the distances squared.) Besides yielding a smooth curve, regression has the additional advantages of yielding only one curve and of evaluating how well the points agree with the curve. However, this technique only works over constant EMC because the redry curve is not smooth where EMC changes.

Another O.R. concept is the objective must be clarified and the relationship expressed in a mathematical equation. The production order to increase drying time actually means to minimize the average kiln time per thousand board feet of white fir dimension. In this example it is assumed that:
1. There is sufficient redry from several charges to make a full charge of redry.
2. There will be an average of 4 hours lost kiln time in loading kiln and reheating redry.
3. Once the redry is reheated to the EMC prevailing when the charge was first conditioned, the redry will dry completely in a total of 125 hours (from the curve at 0% in Figure 1). The total time redry occupied the kiln is 125 hours plus 7 hours of first conditioning plus 4 hours to load and reheat -- a total of 136 hours.

Under the above assumptions, the objective is to minimize the expression:

\[
\text{Average time} = \frac{(\text{vol. dry early} \times \text{kiln time at 1st pull}) + (\text{redry vol.} \times \text{total kiln time})}{\text{total volume in 1st charge}}
\]

or

\[
\frac{(100\% - \% \text{ redry}) \times (\text{hrs}) + (\% \text{ redry}) \times (125 + 7 + 4)}{100\%}
\]

The equation may look complex to some of you, but it is theoretically what you would have used in some fashion or other in making your calculations on the back of an envelope. Often the effort to express even routine objectives in this manner is justified because it clarifies the interrelationships between alternatives.

The percent redry at selected hours can be found by reading the curve in Figure 1. The results are shown in columns (a) and (b) in Table 2. By performing the simple math in the above formula, it is found that the amount of redry that minimizes average kiln time column (c) is about 33% -- much higher than most of us accept now. Yet it reduces kiln time by as much as 20% depending on your present practice.

Table 2. Average Drying Time vs. % Redry.

\[
\begin{array}{|c|c|c|c|c|}
\hline
\text{% Redry} & \text{Hrs/MBM} & \text{100\%} & \text{Avg. Time} \\
\hline
0 & 0 & 1 & .25 & .25 \\
5 & 112 & 1.07 & .07 & 1.14 \\
10 & 100 & .90 & .14 & 1.04 \\
15 & 91 & .77 & .20 & .97 \\
20 & 83 & .66 & .27 & .93 \\
25 & 77 & .58 & .34 & .92 \\
30 & 72 & .50 & .41 & .91 \\
35 & 67 & .44 & .47 & .91 \\
40 & 64 & .38 & .54 & .92 \\
45 & 60 & .33 & .61 & .94 \\
\hline
\end{array}
\]

Saves 28% over dry 20% 10% redry

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Should the objective be to minimize total cost per kiln charge of white fir, a verbal expression of the objective is shown in Table 3. Since redry from any one charge is only occupying a portion of the kiln, only a portion of the cost is prorated to that particular redry. This explains the factor of (additional time x kiln cost x % redry).

Table 3. The Cost Objective.

Minimize Total Cost =

\[ \text{Hrs. 1st run x kiln cost x full charge} + \text{[Full charge x handling cost]} + \text{[additional hours x kiln cost x % redry]} + \text{[% redry x handling cost] or, stated mathematically --}
\]

\[ (100\% x \$7/hr. x \text{Hrs.}) + (100\% x \$130/charge) + (136 \text{ hr. - Hrs.}) x \$7/hr. x \% \text{redry}) + (\% \text{redry} \times \$130/charge)] \]

Before actual costs can be substituted in the expression, I must explain that O.R. recognizes many kinds of costs. The concept of direct costing separates costs by how they change according to the production decision being considered. Fixed costs include taxes, depreciation, insurance, etc. -- costs that do not vary with kiln production. These costs are not included here because they must be paid even if the kiln is empty. Variable costs are those that vary directly with production, such as power and overtime. These must be included in our calculations as we only pay them if we use the stacker and kilns. Fixed-variable costs are those in the "twilight zone;" they vary by jumps with production -- i.e. once a 3rd shift is started, the wage cost is fixed, but the cost did change with production. These costs were not considered since additional stacking and unstacking will be done on overtime (a variable cost), and the kiln is already on 3 shifts. If this is confusing to you, you are not alone, for there is a field in itself in O.R. of just sorting out costs. In this case most handling costs were variable while most kiln costs were fixed, since all facilities had to be operating to maintain pine schedules in our other kilns.

Included in the calculations is another cost that does not show up in your departmental cost review. How often have you commented, "It is not just the additional cost of recycling redry or redress, but we also lose the other production we could be running." In O.R. this cost is called an opportunity cost. The profit from the best alternative is added to the actual cash cost of using the kiln space to dry white fir. This sum is the total profit that is sacrificed to dry white fir. The opportunity cost concept is simply organized common sense, but the cost is very difficult to measure. For a sophisticated and speedy analysis a computer is used to examine the many relationships between decisions to insure the "best alternative" is used as a standard. However, a careful "seat of the pants" estimate by all departments working together will come close enough for many decisions.

A simplified calculation of the opportunity cost of using our kiln capacity to dry white fir is shown in Table 4. Using April prices, it is shown that we lose about $16/MBF in sales realization on 2x4 Douglas fir because we cannot dry the lumber and ship to eastern markets. However, the company does avoid a handling cost of $2/MBF by not stacking and drying Douglas fir. There is no charge for the dry kiln since the costs in this area are fixed and do not vary with production. Thus, there is a cost in lost profit of $14/MBF every time green 2x4 Douglas fir is sold. As shown, this means a loss of $7 for every hour the kiln is not available for Douglas fir, which is our best alternative to drying white fir. Seven dollars an hour is a very high kiln cost, but it is a reasonable measure of the real cost of a slow schedule for white fir.

To find the amount of redry that minimizes the total cost per charge of white fir dimension, the cost factors are substituted in the verbal expression as in Table 3. Again, in Table 5 the % redry at selected hours can be read from the smoothed curve in Figure 1. The optimum redry is about 25% and saves over $150 compared to waiting until the redry is minimal as many of us do now (column g). Remember that not all of this cost savings would show up in your cost review -- most of it would show up as increased sales realization on the Douglas fir that is dried.

For the few skeptics who are reluctant to recognize the concepts of direct costing and opportunity costs, I include the results of a calculation with a budget cost of $2/hour which is commonly used for a kiln. As shown in column (h), Table 5, there is a smaller savings ($25), but the optimum redry percentage still indicates our industry may be shooting for too little redry at present.
FIGURE 1. Redrying as a function of total hours initial charge is in kiln

- Individual observation
- Relationship estimated by averaging observations within each 5 hr. interval
- Smooth estimation from regression \( \%R = 7.26 - 0.145(H) + \frac{172,000}{(H)^2} \)
Table 4. Costs.

**HANDLING COST PER CHARGE:**
- Stacker cost, variable overtime: $60
- Unstacker cost, variable overtime: $70
- Kiln unloading cost: $0

Applicable handling costs: $130

**KILN COST PER MBM**
- Possible Eastern sales DRY: $94
- Present L.A. sales GREEN: $78

Lost sales income w/o kiln capacity: $16

Less handling costs avoided handling green Douglas fir: $2

Less fixed kiln costs avoided handling green Douglas fir: $0

Total profit lost when 2x4 Douglas fir cannot be dried: $14

Loss per hour, assuming 100 hr. to dry 2x4 Douglas fir is equal to volume that could be in kiln times loss per MBM all divided by 100 hours, or:

\[(50 \text{ MBM} \times $14/\text{MBM}) / 100 \text{ hr.}\]

Kiln opportunity cost = $7/hr.

Table 5. Minimum Cost vs. % Redry.

<table>
<thead>
<tr>
<th>% Redry</th>
<th>(b)</th>
<th>(c)</th>
<th>(d)</th>
<th>(e)</th>
<th>(f)</th>
<th>(g)</th>
<th>(h)</th>
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<tbody>
<tr>
<td>0</td>
<td>125</td>
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<td>130</td>
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<td>130</td>
<td></td>
<td>239</td>
<td>+</td>
<td>58</td>
</tr>
</tbody>
</table>

Total cost equals \((100\% \times \$7 \times \text{Hr.}) + (100\% \times \$130) + (136 - \text{Hr.}) \times \$7 \times (\% \text{Redry}) + (\% \text{Redry} \times \$130)\).

Note that shooting for 25% redry in col. (g) reduces cost (increases profit) by over $150 per charge. Shooting for 20% redry in column (h) reduces budget costs by over $25 per charge.

Note the careful use of the term "may", for as emphasized at the start -- the results of Operations Research are only a guide to production decisions. The effect of degrade, storage space and other factors that might influence the decision were not built into these calculations. You, as supervisors, would have to modify the O.R. solution by the effect you feel these factors would have within your operations.

Although this final intuitive modification is always a key factor in O.R., many of the "other factors" can be considered in a large analysis if a computer is used. But most of the concepts are just common sense mathematically defined, and a computer is an efficient and up-to-date substitute for "figuring on the back of an envelope."