Optimize Your Production Mix… Optimize Your Optimizers

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1. Introduction

Like most companies, you've invested millions in machine center optimizers throughout your mill. But does that mean your operations are truly optimal? In most cases the answer is no. Machine center optimizers give you the power to control production mix, and also mill flow. But to do so, they must be configured with appropriate parameters - primarily "decision values" and processing "penalty costs". Determining the optimum parameters to "drive" these optimizer decisions is a very difficult problem, which must take into consideration many interrelated factors. In most cases these parameters are determined on a somewhat "ad hoc" basis, based on intuition. The result is that despite the investment in scanning and optimizing systems, most mills operate at a substantially sub-optimal level.

This paper begins with a discussion of some of the challenges of production planning and implementing the plan through mill optimizer parameter settings. Following this, the development of a new optimization technique called WSO™, which includes automated, iterative sawing simulation and linear programming optimization runs, will be discussed. Finally, results of the use of WSO™ in mill operation will be presented.

Production Planning: What is the Objective?

Maximize production? Maximize recovery? More "premium" products? How about… maximize profit?

Of course one would think it goes without saying that the primary objective of the operation is not to make lumber, but instead to make money (profit). However, it is interesting how often the focus on maximizing profit can get lost. One of the main reasons for this is that the lumber manufacturing process includes a number of seemingly independent steps:

- Log procurement
- Sawmill operation
- Finishing (drying, planing, etc.)
- Lumber sales

But of course these steps are not in fact independent, and to maximize profit they must be considered together when operating decisions are made.

There are a number of ways in which the focus on maximizing profit can get lost. First, the different departments above are usually measured (and perhaps incented) on something other than profit. For example:

- Log procurement: Minimize delivered log cost
- Sawmill operation: Maximize production, maximize recovery
- Finishing (drying, planing, etc.): Maximize production, minimize unit costs
- Lumber sales: Maximize sales average

While each of the above metrics at first glance may appear on their own to be appropriate, they certainly don't always equate to maximizing profit. For example, simply maximizing recovery in the mill, without consideration of mill flow (production rate) or lumber sales mix will certainly not maximize profit. Similarly, minimizing log cost without considering the impact on mill recovery and grade yield will also not maximize profit.

Even with the eye squarely on the "profit maximization" target, how can one know whether a given production plan – and corresponding mill optimizer setup – is truly optimal? Lumber manufacturing is a very complicated business with complex relationships between the above steps. These are not easily quantified through standard analysis techniques such as cost accounting (which can in fact often lead one badly astray) or simulation analysis of individual steps in the process. The focus of this paper is thus the development of a system to determine optimum production plans that consider all the interrelated steps in the lumber manufacturing process, and the machine center optimizer parameters to implement the plan.

2. Machine Center "Optimizers"

Local Optimization versus "Operations-Wide" Optimization

Modern machine center optimizers, with their sophisticated optical scanners and powerful computers, are truly amazing machines. It is important to recognize, however, that while the individual machine center optimizers are quite sophisticated in their ability to scan logs, cants, and flitches, and project solutions into them, on their own they are also quite "dumb". By this we mean that, generally speaking, the systems find only a "local optimum" solution that maximizes value for the given single piece, but do not consider how the solutions fit into the overall production context, including:

- Required production mix (sales constraints)
- Mill flow (bottlenecks)
- Downstream processing constraints and capabilities

It is interesting to note that Applied Theory Associates (ATA), the early pioneers of edger and trimmer optimizers back in the 1970's, did not call their systems "optimizers", but instead "Maximizers". We believe that it is quite likely that this was not an accident, but that those behind ATA knew the difference between local optimization and true operations optimization.

Given this innate "dumbness" of mill optimizers, it is imperative that they be configured in such a way that the optimization decisions are driven to reflect the overall production considerations of mill flow and production mix. The optimizers are dumb, and so you have to be smart!

Mill Optimizer Operation: Key Optimization Parameters and Principles

The operating principle of scanning and optimization systems is generally the same, regardless of machine center. The solution decision process is quite simple in principle:

1. Scan the piece optically to determine the geometric, and in some cases biological characteristics
2. Chug away, considering all "possible" solution options for the piece (of course, this "chugging" typically takes place in several hundred milliseconds!)
3. Select the solution of maximum "value" for the given piece

Some discussion of key optimization parameters follows:

1. Decision Values

The most important parameters which drive the optimization decisions are the "decision values", which are the product values specified for the different lumber products defined to the optimizer.

2. Wane Rules and Other Parameters

This is a subject for an entire seminar! We will, however, make the following brief points:

- Wane rules at each machine center should not be unrealistically loose or tight, but instead should be set to levels that realistically project piece yields considering the accuracy of the machine center. This typically means tightening wane rules slightly as you move upstream in the process.
- Other "solution-constraint" parameters such as minimum opening-face restrictions should be used only to ensure a sufficient face for feeding through downstream equipment, ***not*** to directly influence the product mix or mill flow.

3. Machine penalty costs

Penalty costs, such as edging penalties, are key to relieving sawmill flow bottlenecks. Correct use of these penalty costs allows you to maximize profit by resolving the trade-off between throughput and value. The concept of penalty costs is discussed more fully below.

3. Bottlenecks and Machine Penalty Costs

Wikipedia defines bottleneck as "a phenomenon where the performance or capacity of an entire system is limited by a single or limited number of components or resources".

Every sawmill has one or more bottleneck. Sometimes the bottleneck is obvious: perhaps every time the front end of the mill runs well, the edger gets backed up and you have to stop processing logs until the edger catches up. This means of course that the edger is the bottleneck. Sometimes the bottleneck is less obvious. Often we'll hear "our mill doesn't really have a bottleneck". But that just means that downstream processing (the edger and trimmer) are not the bottleneck since they can take everything the primary breakdown sends their way. This, in turn, of course means that the primary breakdown itself (or perhaps the log preparation) is the bottleneck.

Sometimes the bottleneck can change depending on the operating condition. For example, perhaps when processing a large log diet the trimmer might be the bottleneck, while if you have a small log diet the primary breakdown might be the bottleneck.

Relieving Bottlenecks

Relieving bottlenecks can have a very significant impact on mill production, and overall profitability. There are two ways of doing this. The first way is through a change to the mill equipment itself, which may be something as minor as a change to PLC timing, or may involve a significant capital project such as installing a new, high-speed edger system. The second way is through controlling the mill's sawing patterns, to reduce the load on the bottlenecking machine.

It is important to note the differences between these two methods of relieving bottlenecks. First of all, changing the mill equipment may in some cases mean a substantial capital project, whereas it costs nothing to make correct sawing pattern decisions. Secondly, once you've done a capital project to relieve a bottleneck, that doesn't mean the mill no longer has a bottleneck; as stated above, every mill has a bottleneck. By relieving one bottleneck, you have likely just shifted the bottleneck to another machine center. And so ***there will always be a benefit by making correct sawing pattern decisions that recognize the mill bottleneck***.

For an enlightening, and rather entertaining, introduction to the theory of constraints and bottlenecks, we recommend reading "The Goal: A Process of Ongoing Improvement", by Goldratt.

Relieving Bottlenecks through Correct Sawing Pattern Decisions

Consider, for example, a mill where the back end (trimmer) is the bottleneck. In this case, every trimmer lug is a very valuable commodity! And so you must consider what you want to fill that lug with.

Do you want to fill that lug with a 1x4x8', or would you rather fill it with a more valuable product?

Or, let's consider a waney 2x6x20' piece being scanned at the trimmer, that could either be:

- trimmed to 2x6x14' at $4.10 ($293/Mbf)
- reman-edged to 2x4x20' at $4.15 ($ 311/Mbf)

But, reman edging would require the piece to be dropped out, then returned to the trimmer again after edging. If the bottleneck is the trimmer, do you really want to use that additional trimmer lug to increase the piece value by $0.05? Or, can that lug be put to more profitable use processing another piece, hence allowing the overall mill production rate to increase?

Thousands of decisions like the above are being made every shift, by both the primary breakdown optimizer and the downstream mill optimizers. Configuring these optimizers correctly, through use of the correct decision values and penalty costs, can have a very significant impact on the bottleneck machine loading, and hence the mill production.

Penalty Costs

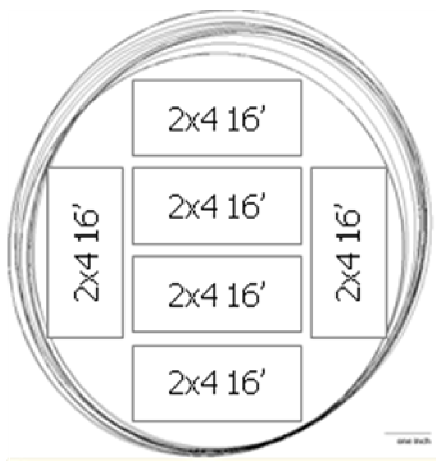
Penalty costs are a very simple, yet highly effective means to control optimizer sawing pattern decisions to recognize the mill bottleneck.

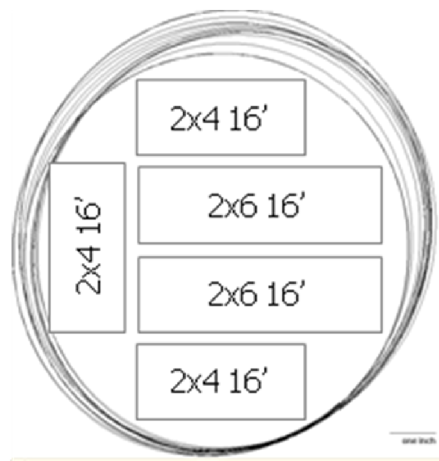
Let's consider the trim versus reman-edge decision described above. Most trimmer optimizers allow the user to specify a reman penalty to control the loading of the reman edger (and, indirectly, the loading on the trimmer itself since the reman piece will have to pass through the trimmer again). In the example above, if a reman penalty of $0.06 was defined to the trimmer optimizer, this "penalty cost" would be subtracted from the value of the re-edged piece, thus making the options considered:

- trimmed to 2x6x14' = $4.10
- reman-edged to 2x4x20' = $4.15 - $0.06 = $4.09

Therefore, with a reman penalty of $0.06/piece or higher, the trimmer would choose to trim the piece to 2x6x14' and send it straight to the sorter, rather than dropping it out to the reman edger.

The following example illustrates how penalty costs could be used to control mill flow to recognize bottlenecks at any machine center. Consider the following sawing patterns for an approximately 7.75" SED log, both of which produce the same volume of lumber. If solution values were equal, then which pattern is the most attractive will depend on the bottlenecks in the mill.





Bottleneck Machine		
Canter	✓	✓ (inconclusive)
Gang	✓	
Edger	✓	
Trimmer (if reman through trimmer once)		✓
Trimmer (if reman through trimmer twice)	✓	

Most primary breakdown optimizers allow the user to specify penalty costs for sideboard edging and cant board reman-edging, thus managing edger loading. Similarly, most trimmer optimizers allow the user to specify a reman penalty cost, hence controlling reman machine and trimmer loadings.

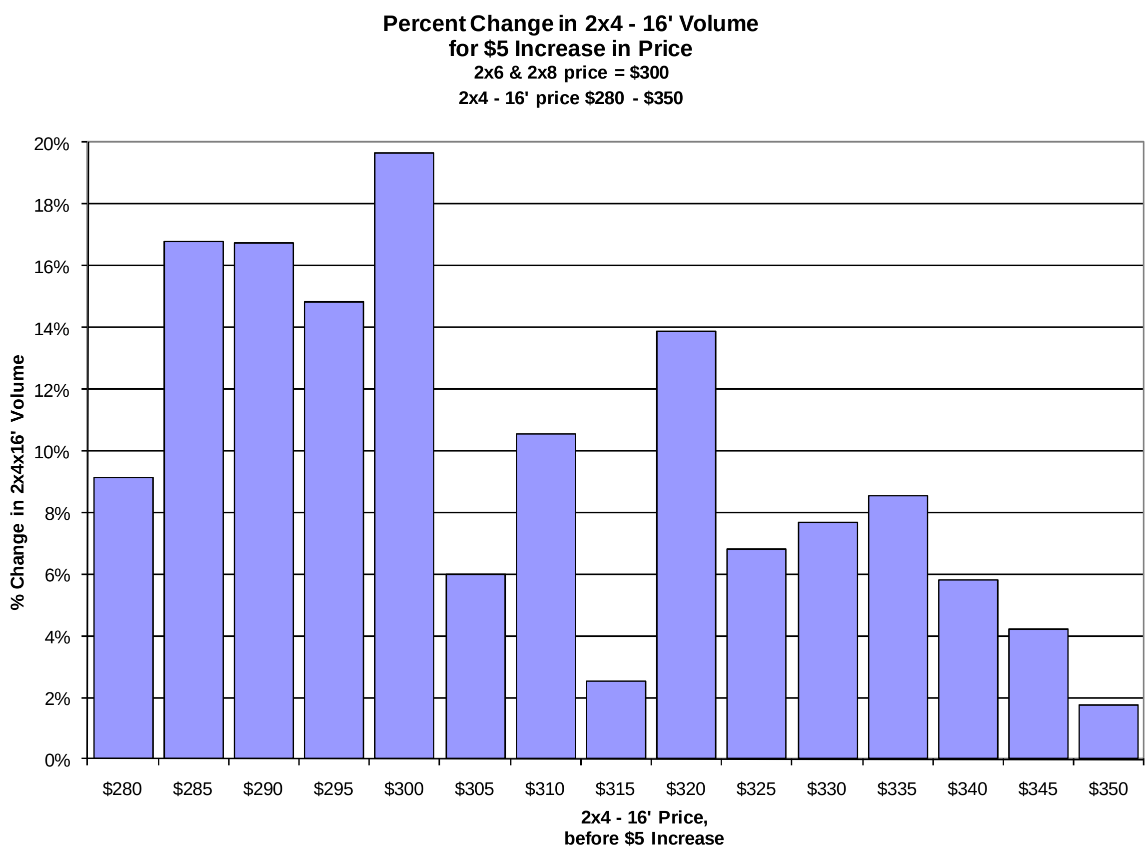
Surprisingly, we are aware of only one primary breakdown optimization vendor that allows a penalty cost to be defined for primary breakdown machine time (and even then, this feature is only included if specially requested by the mill). This means that most primary breakdown optimizers will choose a sawing pattern with saw cuts processed at, say, 225 fpm over a "chip-only" sawing pattern processed at 350 fpm, if the "with saw cut" pattern is valued at $0.01 more. This is an area where we feel the primary breakdown optimization vendors need to improve.

4. Common Production Planning Challenges

Non-Linearity

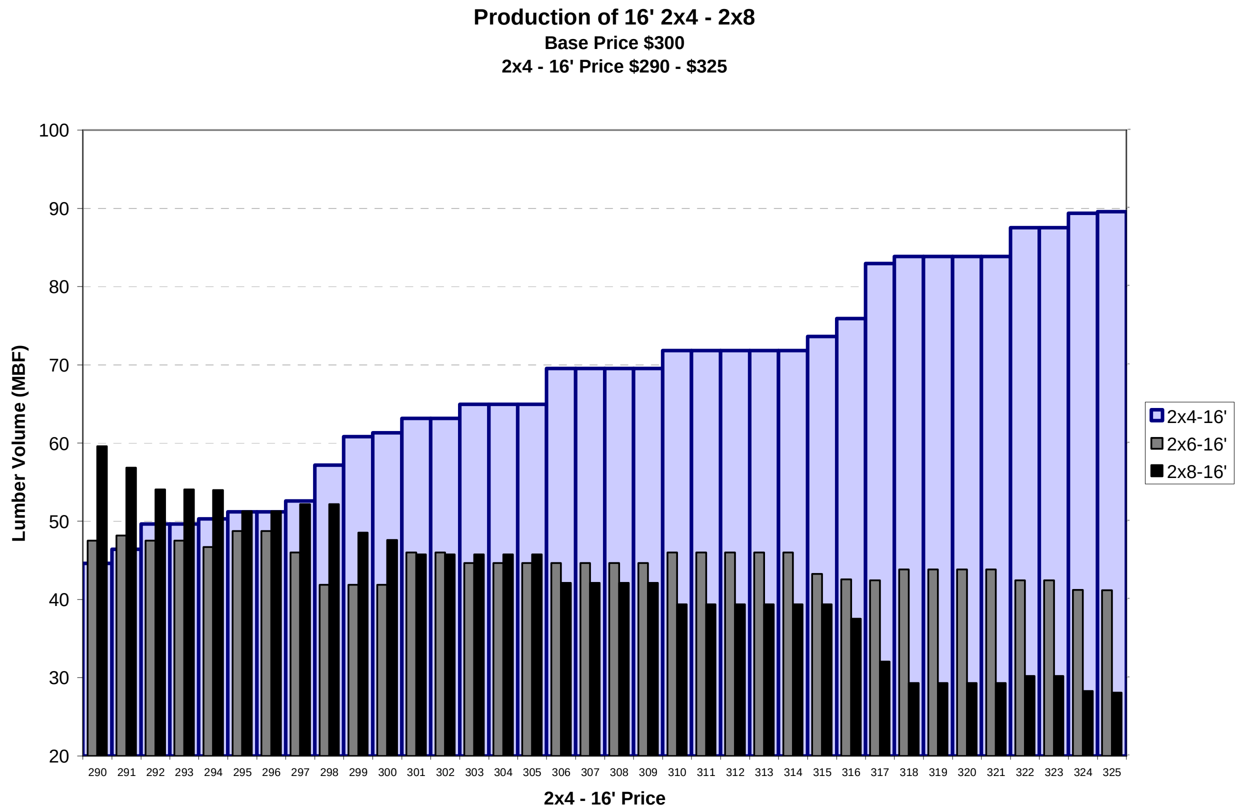
This is a problem that will be familiar to anyone charged with maintaining mill optimizers. You're told, for example, that you need to increase the volume of 2x4x16' to satisfy some orders. So, you increase the optimizer decision value by $3… nothing happens. You increase it another $5… it goes up a bit, but not what you need. You increase it $5 again and… you get way more than you wanted! Not only that, but the rest of the production mix has all of a sudden gone bad.

To illustrate this phenomenon, a series of SAWSIM® sawing simulation runs was executed. Starting with a baseline production scenario, the price of 2x4x16' was increased in $5 increments. The percent increase in 2x4x16' volume tallied for each $5 increment is shown in the following chart:



As can be seen, for any given $5 increase in 2x4x16' price, the increase in 2x4x16' volume ranged from a low of under 2% to a high of almost 20%.

An additional challenge is that as the volume of 2x4x16' increases, the production of the other products do not decrease proportionally, as shown in the following chart:



As shown in the chart, the increase in 2x4 volume has come mostly at the expense of 2x8x16, with the 2x6x16 volume remaining relatively stable. So, not only is what will happen to the volume of a given product as you change its decision value unknown, what's also unknown is what effect it will have on the volume of every other product you produce. In the end, managing production mix by changing optimizer decision values truly is like juggling fish!

This non-linearity (or "jumpiness") of the change in product volumes to a change in optimizer decision value complicates mill optimizer setup considerably. Traditionally, this has meant either ongoing "trial and error" changes in actual mill operation (costly in terms of sub-optimal mill operation) or the requirement for many simulation runs on the mill's primary breakdown optimizer simulator, which are costly in terms of personnel time. ***And both of these methods still result in a production plan that is inherently sub-optimal***.

Lumber Length Mixes, and Home Center Production

While mill optimizers make sawing solution decisions on the basis of individual product (size x length) values, the reality at many mills is that most lumber is sold in lumber length mixes. This situation is made further challenging when commitments for home center ("big box") production are added.

Home center production typically adds two challenges to the mill production planning:

1. The requirement for low wane (or wane-free) lumber
2. The length mix required for the home center products, which is typically different than the length mix required for "traditional" structural lumber markets

The requirement for wane-free lumber can be addressed in a couple of different ways:

1. Just pull wane-free lumber in the planermill, without changing the sawmill optimizer wane parameters to push wane-free production. This may be the correct approach if the home center products represent only a very small percentage of total sales.
2. Add a "home center" (low wane) product to the sawmill optimizers, to drive decisions to produce more wane-free products. This is the preferred approach if a significant volume of home center production is required. Note that in this method an additional home center (low wane) product is added to the optimizer setup, in addition to the standard wane product. In almost no cases should you simply tighten the wane allowance on your standard wane product, effectively considering only low-wane products.

The length mix issue is a very tricky one. What if your home center customers want primarily shorts (10' and 12'), while your traditional framing markets want 16's & 20's? Rather difficult, when the products are coming from the same logs! Similar length-mix challenges can exist between #1/Select Structural and #2/Standard.

Generally speaking, these length mix issues cannot be addressed with optimizer decision values alone. Instead, they typically must be addressed with a comprehensive plan considering:

- log bucking;
- optimizer decision values; and
- finished-product operations such as cut-in-2 or package sawing.

Development of these comprehensive plans was a primary focus of this project.

The "Optimization Guru"

At many mills, production planning and optimizer setup is under the control of one "optimization guru". Having all this knowledge inside one person's head is a significant problem, as it leaves the mill very much exposed should they lose that one person.

One of our objectives in developing this system was to develop a systematic method for determining optimum production plans and the mill optimizer parameters to implement the plans. By having a systematic method, it is much easier to transfer this knowledge within organizations.

5. Objective of the WSO™ Model Development

The objective of the WSO™ project was to develop a systematic method to determine the operating strategy (production plan) and the set of optimizer decision values and machine penalty costs, to maximize the sawmill's income, considering:

- Log costs and availability

- Machine rates
- Time available per machine centre
- Downstream processing options, costs, and constraints
- Lumber prices and market demands
- Byproduct prices

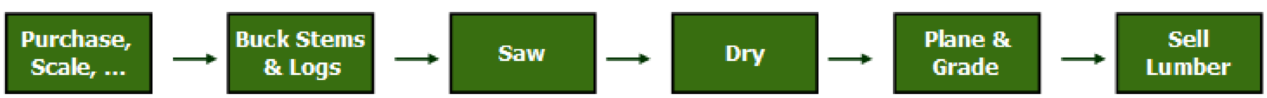
Because the above conditions are constantly changing, so will the optimum operating strategy. Consequently, it was important that the system allow calculation of a new production plan in an efficient, systematic way.

6. System Description

Description of a Typical Supply Chain

The fiber flow that transforms logs into lumber and byproducts will have, in the majority of cases, six instances where decisions can be influenced:

1. Log purchasing
2. Stem- and log-bucking
3. Sawing
4. Drying
5. Finishing and grading
6. Selling



Making an operating plan that optimizes this supply chain involves making a set of coordinated decisions throughout these six influence-points. All these decision points, with the exception of sawing, have the commonality of having a finite, and thus countable, set of solutions. For example, in the case of drying, the options are to dry or to leave green. In finishing and grading, one can decide to pull an appearance product, or leave these in to increase the potential value of the #2&Btr tally. Even in the case of bucking the solutions, although often many, can be counted (though a comprehensive bucking simulation program is required to tally them). The significance of being able to count the solutions is that one could develop well-defined equations to represent the fiber transformation. For example, we could write the expected volume of 2x4, 16’, Economy as:

FinishedVolume[2x4-16’-Economy] = 0.05 DryVolume[2x4-16’]

Meaning that we expect 5% of the overall volume of 2x4 16’ to grade as Economy.

The ability to write a set of simultaneous equations to represent the entire fiber flow means that existing mathematical techniques could be used to solve these equations to determine the solution that maximizes profit. One such technique is ***Linear Programming***.

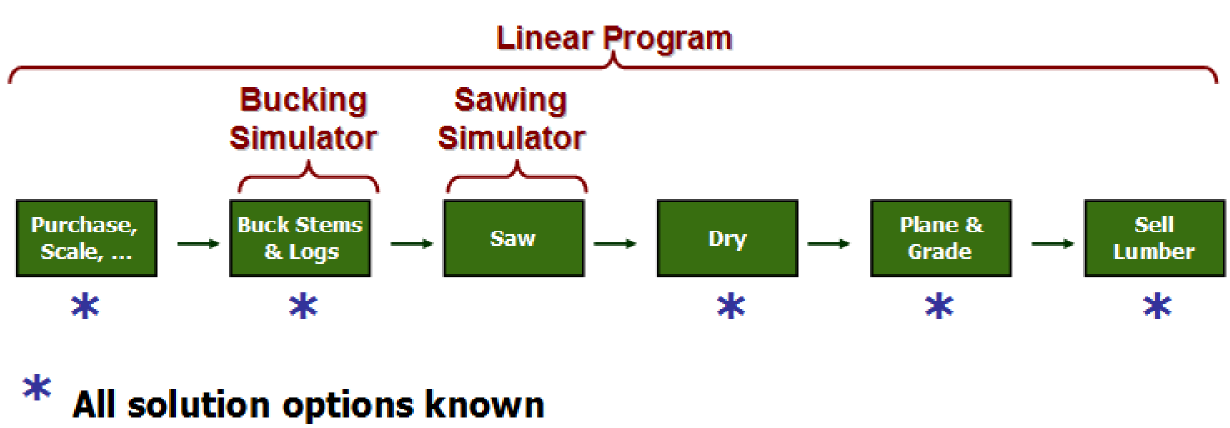
Linear programming is a widely-used method to determine optimum allocation of raw materials and production methods to optimize the overall profitability of manufacturing processes. It is attractive for applications such as this because it is simple, robust, and can handle large, complex problems.

This is all very good, until we try to include sawing as part of the model. The main issue is that one cannot develop equations that would predict the expected volume of each lumber item as a function of lumber values, machine penalties and other parameters. For starters, because of the continuous nature of lumber values, there are an infinite number of lumber-value and machine penalty combinations. Second, the nonlinearity described above makes it impossible to write an equation that could actually be solved using standard mathematical tools. So, how do we include sawing as part of the model?

The WSO™ Solution: Linear Programming and Simulation

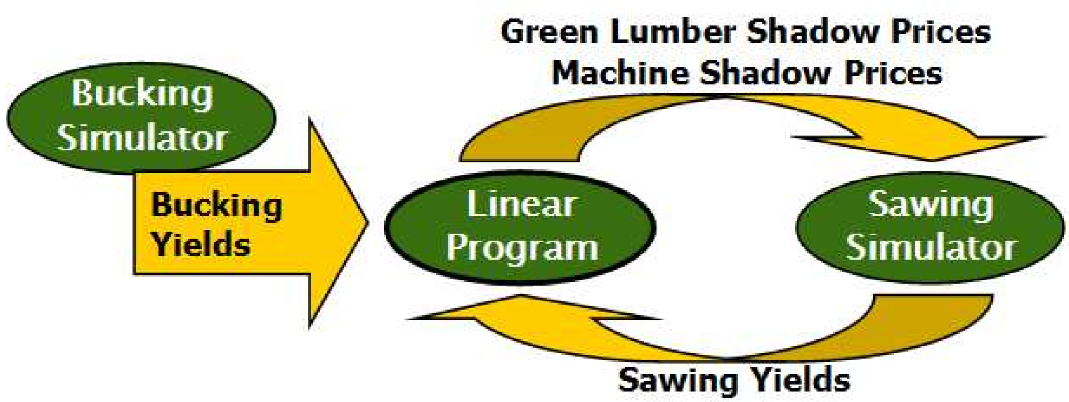
When one needs to predict the outcome of a system with the non-lineal nature of a sawmill, simulation is often the best alternative. The simulator needs to be capable of predicting not only what products will be recovered when using the same set of parameters as the mill, but also the machine loadings. For this, the simulator should be capable of calculating accurately the machine speeds, expected gaps, and hence processing times at all machine centers as they would occur in the sawmill.

Having simulated a set of lumber values, machine penalties and other relevant parameters, the simulation solution is included in the model to be solved by linear programming. Apart from all the different decisions described above, and the expected sawing results, the model should include data on the availability of resources (logs, time in the sawmill, kilns and planer, etc) as well as lumber demands, either by tally or by single product. The linear program will then solve by choosing the best set of bucking, drying, finishing and selling decisions for the given set of sawing results that was included in the model.



After solving, apart from the optimal solution described by the best alternatives, the linear program produces what are called marginal values, or shadow prices. These values indicate, for those resources that are limiting (constraining the solution), what the value of additional units of each such resource would be. For example, a resource might be the time at a bottlenecking machine center in the sawmill, say the edger; the marginal value of the edger would indicate the expected lift in profit if more time was available at this machine center. In the case of a mill that sells its lumber as tallies, each of the components of the tally is a resource. Often there will be one, or a few, items that are in shortage thus preventing more of other lengths being sold in a tally. In this case the marginal value of the products in short volume can be extremely high, as any increase in the volume of that product can also allow other lengths to be included in the tally.

What WSO™ does after the linear programming solution is an automated analysis of the solution, looking at what resources are limiting and their marginal values, and establishes the parameters for a new sawing simulation. Where a machine was limiting, WSO™ will suggest a higher penalty cost. Where a lumber item was scarce, WSO™ will suggest a higher decision value. This new sawing simulation solution is then used for a new model run, which is solved and re-analyzed to produce yet another sawing simulation. Each round of linear programming optimization and sawing simulation is called an iteration. Note that all iterations will have the same alternatives for all processes except sawing, but it is possible - and quite likely - that different solutions for the non-sawing processes will be selected by the linear programming solution in each iteration.



The objective of these iterations is to converge to an optimal solution. Such a solution will combine the optimum set of optimizer values with optimum decisions for all other processes. However, moving through the iterations needs to be done in a 'smart' manner. Being too aggressive in the change of lumber values and machine penalties will mean overshooting targets. This often results in cycling, for example having successive iterations alternating between bottlenecking at the edger, then the trimmer, but never quite balancing both optimally. Or it can result in iterations that do not converge to an optimum. Conversely, moving too slowly through the iterations will often mean not reaching the optimum in a timely manner. A significant part of the effort of developing WSO™ went into finding the optimum algorithms to yield a converging solution in a timely manner.

7. Results

In practice, WSO™ results have proven to quite accurately predict the sawmill's outcome. Of course, the basis for this is a carefully calibrated sawing simulation model.

WSO™ will drive production to satisfy the defined sales mix constraints while increasing throughput. Both these metrics are simply consequences of the main driver: profit maximization. A better production mix – achieved from accurate decision values – will translate into higher sales averages. A higher production rate – achieved from accurate penalty costs – will translate into increased production. Of course, higher sales averages and production will translate into higher profits.

Satisfying Product Mix Constraints

Product mix constraints are usually defined as min/max sales mix limits by length for a given lumber size. Also, min/max proportions by size as a function of total production is often a requirement. Controlling the length distribution is best done by applying a set of bucking rules, or log target mixes, that will produce a log mix in the right diameters and lengths that will produce the desired length distribution for each size. Controlling the size distribution is done by applying a set of lumber decision values that will drive the samwill's optimizers towards the desired production.

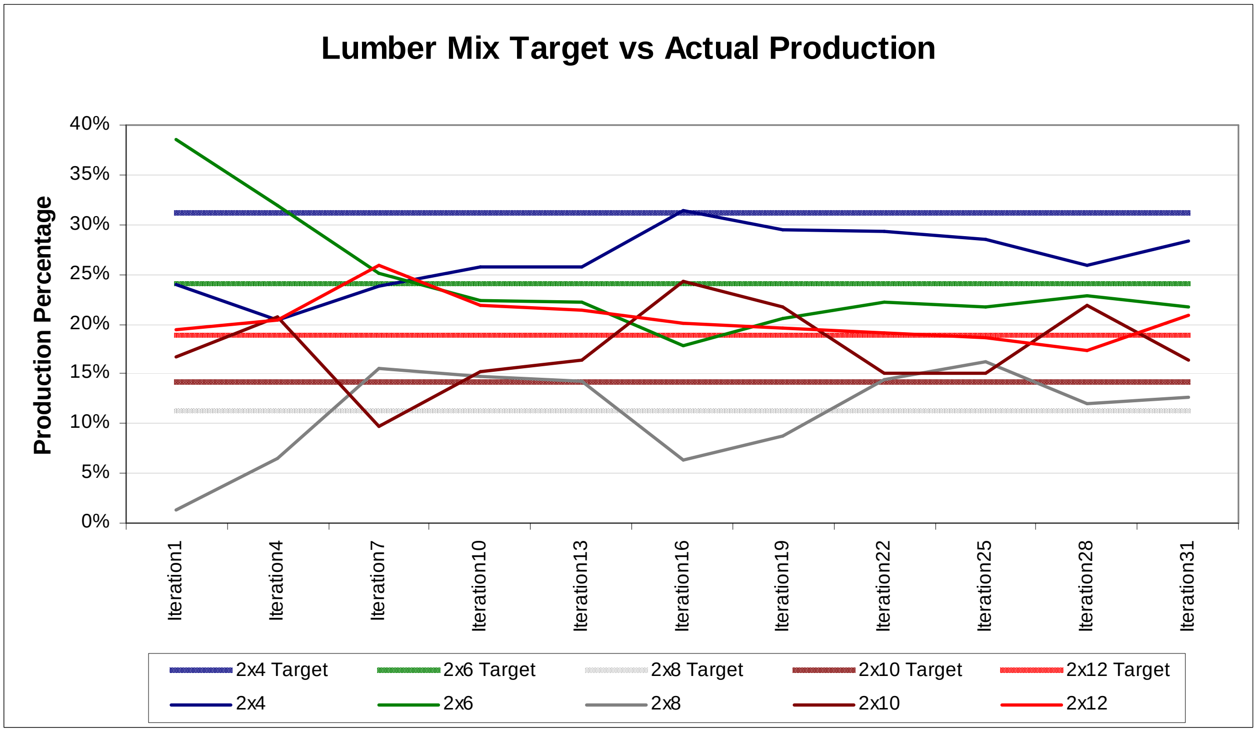
Usually, the more sizes included in the desired mix, the more iterations it might take to converge to a set of decision values that will produce such a mix. The following example shows a case where 5 sizes – 2x4 to 2x12 – were required in the following proportions:

	2x4	2x6	2x8	2x10	2x12
Target	**31%**	**24%**	**11%**	**14%**	**19%**

To simplify the view of the results, only results for every third iteration will be shown. Here is a table and chart showing the convergence of each size to the target:

	2x4	2x6	2x8	2x10	2x12
Target	**31%**	**24%**	**11%**	**14%**	**19%**
Iteration1	24%	39%	1%	17%	19%
Iteration4	20%	32%	6%	21%	20%
Iteration7	24%	25%	16%	10%	26%
Iteration10	26%	22%	15%	15%	22%
Iteration13	26%	22%	14%	16%	21%
Iteration16	31%	18%	6%	24%	20%
Iteration19	29%	21%	9%	22%	20%
Iteration22	29%	22%	14%	15%	19%
Iteration25	29%	22%	16%	15%	19%
Iteration28	26%	23%	12%	22%	17%
Iteration31	28%	22%	13%	16%	21%

By Iteration 31, all products are within 3% of target.



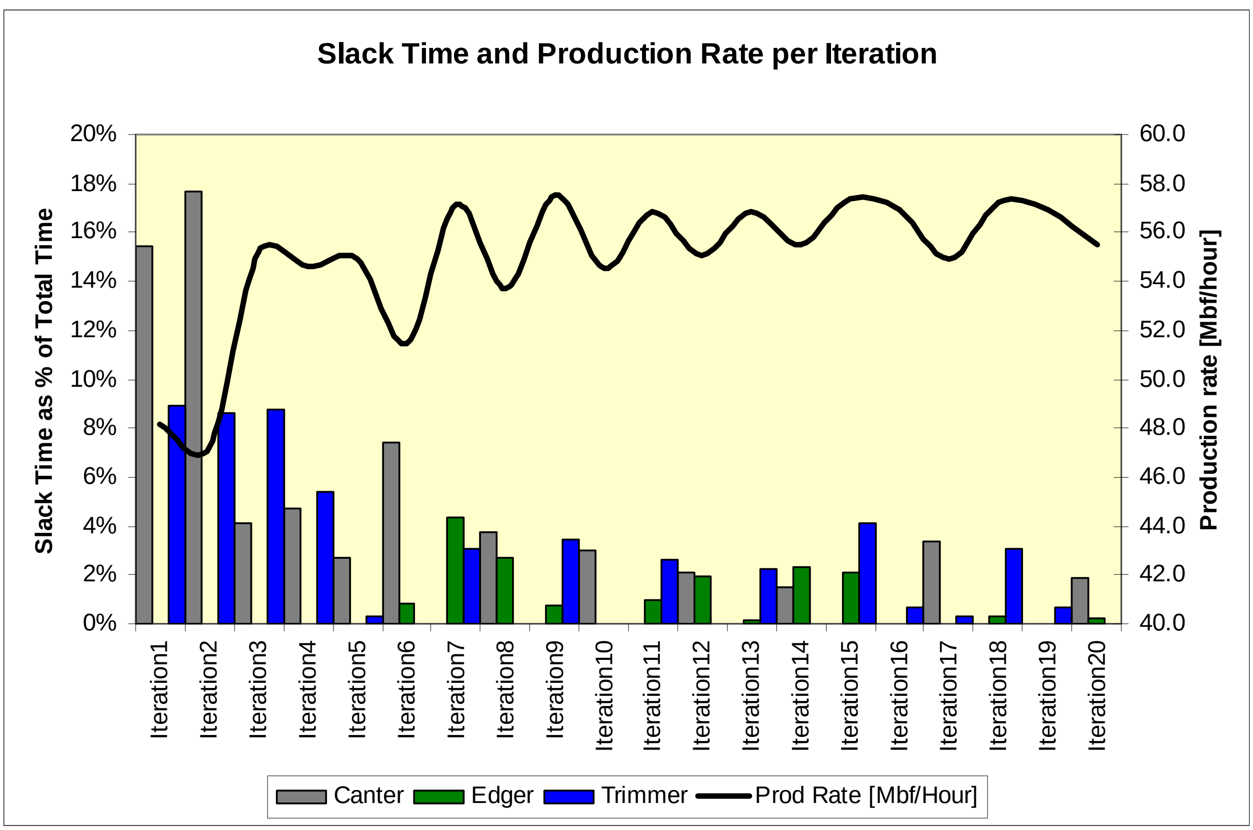
Increase in Throughput

The following example illustrates how effective use of machine penalties resulted in throughput increases. The mill in question operates a canter twin, followed by a gang, a horizontal resaw, an edger and a trimmer. The gang and the horizontal will never limit production, so the penalty costs were applied to the canter, the edger and the trimmer.

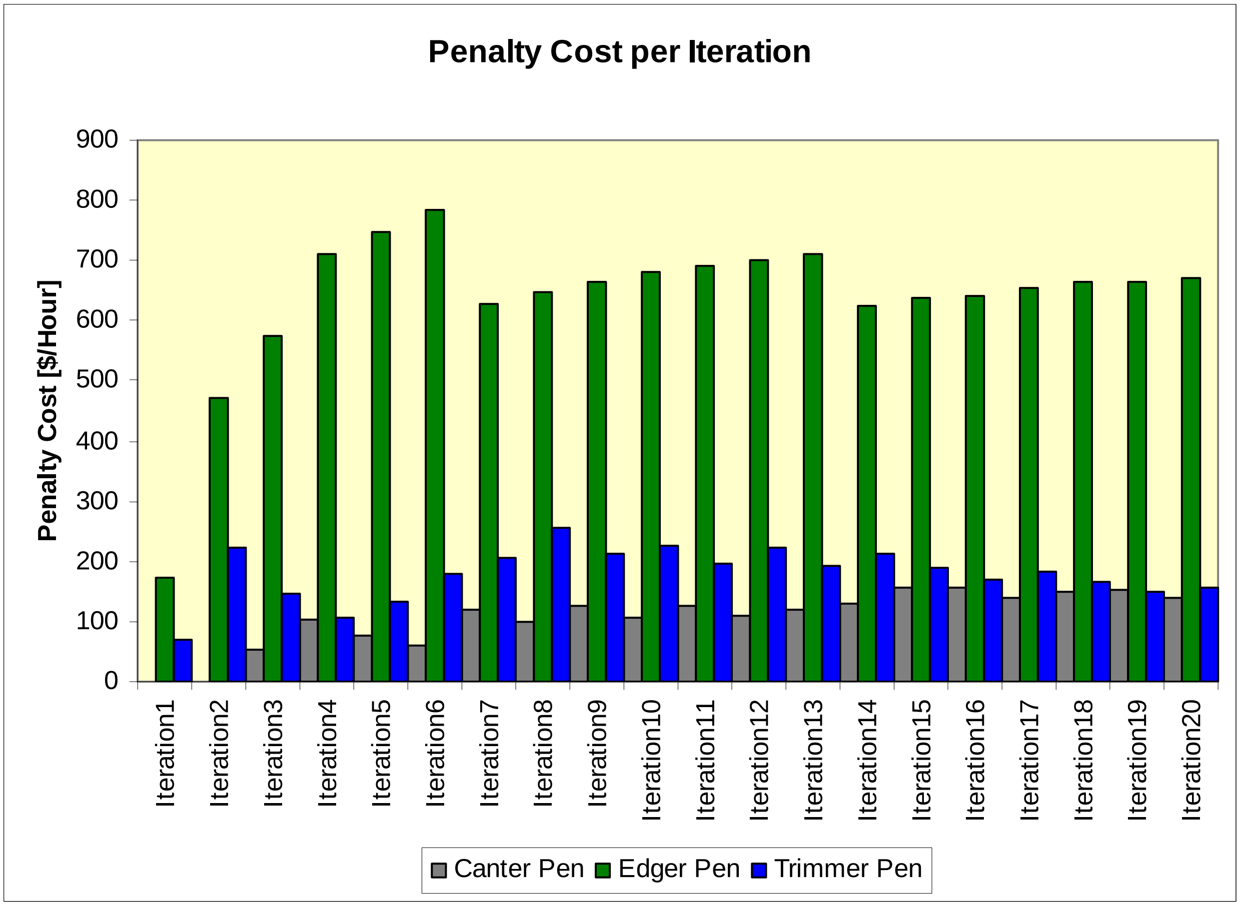
The following table shows the percentage of time available per machine for each iteration. Where a machine shows a 0%, it means that it is a limiting, bottleneck machine.

	Slack% Canter	Edger	Trimmer	Prod Rate [Mbf/Hour]
Iteration1	15%	0%	9%	48.2
Iteration2	18%	0%	9%	47.2
Iteration3	4%	0%	9%	55.2
Iteration4	5%	0%	5%	54.6
Iteration5	3%	0%	0%	54.9
Iteration6	7%	1%	0%	51.5
Iteration7	0%	4%	3%	57.2
Iteration8	4%	3%	0%	53.7
Iteration9	0%	1%	3%	57.6
Iteration10	3%	0%	0%	54.6
Iteration11	0%	1%	3%	56.8
Iteration12	2%	2%	0%	55.1
Iteration13	0%	0%	2%	56.8
Iteration14	2%	2%	0%	55.5
Iteration15	0%	2%	4%	57.4
Iteration16	0%	0%	1%	56.9
Iteration17	3%	0%	0%	54.9
Iteration18	0%	0%	3%	57.3
Iteration19	0%	0%	1%	56.9
Iteration20	2%	0%	0%	55.5

At first, the edger limited the production (bottlenecked), and both the canter and trimmer had significant slack times. At this point the production rate did not reach 50 Mbf per hour. By the 9th iteration, the three potentially limiting machines had been brought to balance, resulting in production rates of over 57 Mbf/hour.



The following chart shows the progression of the penalty costs per iteration:



Note that the edger's penalty increases until it no longer limits production, at that point it is lowered resulting in the edger limiting again. Its penalty is then increased again at a lower rate through the iterations, until it no longer limits (in iteration 14). At that point the penalty is lowered again and then increased at an even slower rate. The canter and trimmer penalties follow the same trends.

8. Conclusions

Ultimately, WSO™ does what many mills already do when planning a production run: it simulates a set of values to foresee what will happen in the mill. However, it takes this practice to the next level by including penalty costs (which very few mills use), alternatives for other processes, and by establishing an automated mechanism to repeat the process many times using an algorithm to arrive at an optimal decision set. It also uses a sawing simulator that was designed for such purpose, as opposed to online optimizers that – although excellent at the computational efficiency required for an online application – lack the accuracy to predict production mixes and machine loadings to the level of detail that is required for this application.

WSO™ also provides a tool that can be used by anyone in the organization, removing the need for gurus. It also provides common ground for log purchasers, lumber sellers and process people to discuss and establish practices that are fully coordinated throughout the supply chain, yielding significant increases in profit.

Implementation of a tool like WSO™ will often result in increases in average sales values and increases in throughput. It could also result in lower log prices by clearly establishing which logs are best suited for a given mill, thus not overpaying for logs that will not yield enough benefits. It is possible that recovery will decrease slightly, especially since sawmills have become quite efficient at improving this metric. However, any slight decrease in recovery will be easily offset by the benefits of a more valuable lumber mix and increased throughput.

In the end, the benefits will be significant. Assuming conservative lumber prices and log costs, even with modest increases in throughput (2%), and sales value (1.5%), and reduction in recovery (-0.5%), a mill producing 150MMbf per year can expect benefits exceeding one million dollars per year. Add to this the benefits of having a robust methodology at the core of your enterprise planning, and it is clear that such a tool is the obvious next step for mills looking to best exploit the potential power of their 'locally-optimized' supply chain.