Optimising the Manufacturing Process...
from Log Procurement through to Timber Sales

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1. Introduction

At this conference many topics will be discussed covering systems and technologies that can be used to improve efficiency within the various links in the wood supply chain, from log merchandising and transport through to finished product sales and shipping. While optimising within these various steps is important, overall process optimisation requires that the supply chain links are not considered independently. The subject of my session is how to achieve optimum returns by optimising through, rather than within, sections of the wood supply chain

This paper begins with a discussion of the objective and challenges of operations planning. Following this, the optimisation technique of linear programming will be introduced within the context of the wood products supply chain, and the benefits of linear programming optimisation will be discussed. Finally, an example application of linear programming to a real-world operations planning application will be presented. While the examples used in the discussion are related to the production of sawn timber, the concepts apply to the production of other wood products such as plywood and other engineered wood products.

Operations Planning: What is the Objective?

Minimize log cost? Maximize mill recovery (yield)? Maximize production? Maximize timber sales average? All good. But, how about… *maximize profit*!

Of course one would think it goes without saying that the primary objective of the operation is not to make timber, 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 timber manufacturing process includes a number of seemingly independent steps:

- Log procurement
- Greenmill operation
- Finishing (drying, planing, treating, etc.)
- Timber 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

- Timber 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, minimizing log cost without considering the impact on mill recovery and grade yield will certainly not maximize profit. Similarly, simply maximizing recovery in the mill, without consideration of mill flow (production rate) or timber sales mix will also not maximize profit.

Even with the eye squarely on the "profit maximization" target, how can one know whether a given operating plan is truly optimal? Timber 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.

Without a means to quantify the impact of a change in one link of the supply chain on the overall production efficiency, traditional planning systems have focused on developing a "local optima" within each link. This effectively results in production planning made at the individual steps on a heuristic, ad-hoc basis, and the overall process operating at a substantially sub-optimal level.

The focus of this paper is thus the development of systems to determine optimal operating plans that consider all the interrelated steps in the manufacturing process.

The Nature of Wood Products Manufacturing Processes

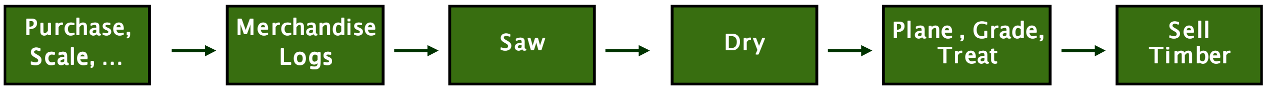
Before considering the possible application of different "supply chain optimisation" techniques and systems to wood products manufacturing processes, it is important to recognize a particular characteristic of wood products manufacturing. Most industrial manufacturing operations are ***assembly*** operations; various parts are manufactured or purchased, and then assembled to produce the finished product. In contrast, most wood products manufacturing operations are "***disassembly***" processes, in which logs are broken down from a whole (logs) to pieces (e.g. sawn timber). This fact needs to be recognized when considering the possible implementation of supply chain optimisation technologies, as some technologies that were developed for assembly operations may not be appropriate for wood products manufacturing processes.

2. The Wood Supply Chain and Linear Programming

Description of a Typical Wood Products Manufacturing "Supply Chain"

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

1. Log purchasing
2. Log merchandising (cross-cutting)
3. Sawing
4. Drying
5. Finishing, grading, and treating
6. Selling



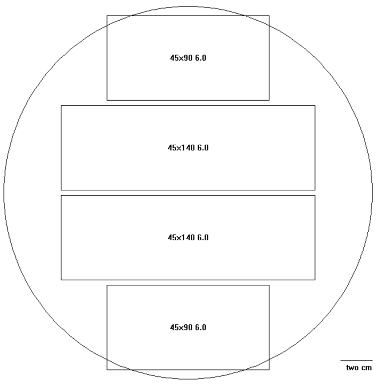
Developing an operating plan that optimises this supply chain involves making a set of coordinated decisions throughout these six influence-points. All these decision points, with the possible exception of sawing, have the commonality of having a finite, and thus countable, set of solutions. For example, in the case of drying, the options are to dry or to leave green. In finishing and grading, one can decide to pull a high-strength M12 product, or leave these in to increase the potential value of the M10&Btr sort. Even in the case of log merchandising and sawing the solutions, although often many, can be enumerated and yields tallied (though comprehensive log merchandising and sawing simulation programs are required to tally them). The significance of being able to count the solutions is that one can develop well-defined equations to represent the fibre transformation. For example, we could write the expected volume of finished, graded 90x35, 4.8m, Non Structural as:

FinishedVolume[90x35-4.8m-NonStr] = 0.12 DryVolume[90x35-4.8m],

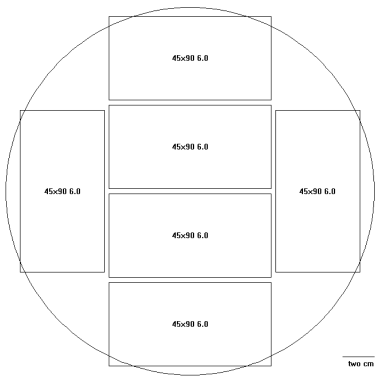
meaning that we expect 12% of the overall volume of 90x35 4.8m to grade out as Non Structural.

Within the sawmill, equations can be used to describe the expected yield of rough-sawn timber products of different sizes and lengths by applying pre-defined sawing patterns (profiles) to particular log sorts. Consider a simple example of a sawmill processing only one log sort, and with only two possible sawing patterns:

Product	Profile A	Profile B
90x45	2	6
140x45	2	0



Profile A



Profile B

For this example, we could write equations defining the greenmill production as a function of the number of logs sawn with each pattern, as follows:

2 * #SawlogsA + 6 * #SawlogsB = Pcs 90x45 produced

2* #SawlogsA = Pcs 140x45 produced

Similar equations can be developed to define things like processing times required at each stage in the process, production of byproducts, and so on.

The entire fibre transformation process, from trees to logs, logs to green rough-sawn timber, green to dry, and dry rough-sawn to finished products can thus be written as a series of simultaneous equations. This series of equations will be very large; in a typical application there may be as many as several hundred thousand such equations. Of course these equations are not generated manually; instead they're generated by appropriate process simulation systems and "matrix generation" software.

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

Linear Programming (LP) Optimisation

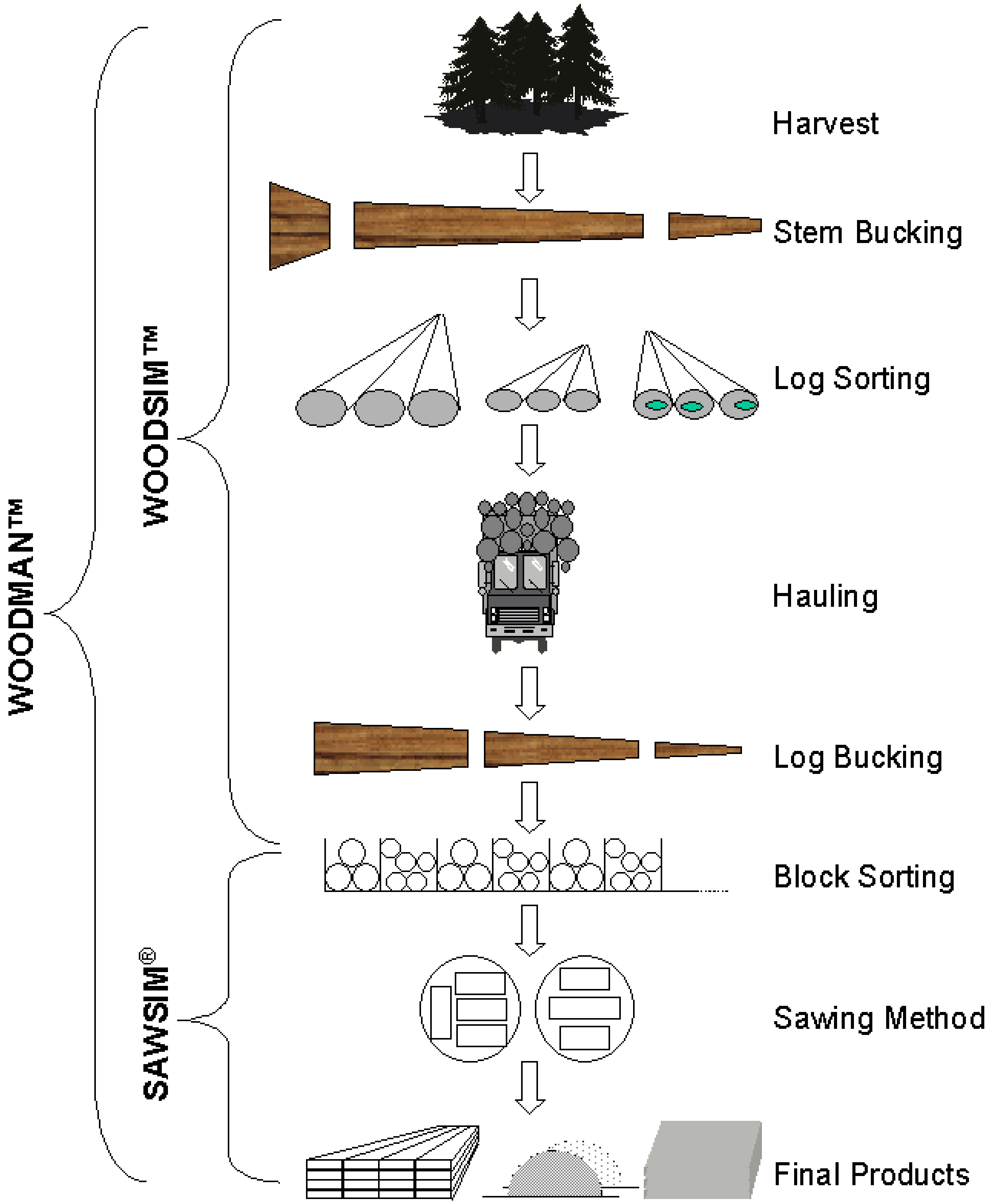
Linear programming is a widely-used method to determine optimum allocation of raw materials and production methods to optimise the overall profitability of manufacturing processes. It is attractive for applications such as this because it is simple, robust, and can handle large, complex problems.

As noted above, the entire fibre transformation process can be represented by a series of algebraic equations. In simple high school algebra, we were taught that there needs to be an equal number of equations as there are variables (unknowns), and that there is only one solution that satisfies the equations. In the real world, however, there are always many more variables than there are equations. The consequence of this is that there will be an infinite number of solutions (which makes sense, as of course there is an infinite number of ways to run a wood products manufacturing facility). However, with respect to a given "objective" (in our case, maximizing profit), there will be only one solution that maximizes the objective, and linear programming is a technique to determine that optimal, maximum-profit, solution.

While linear programming has been employed most heavily in industries other than wood products, most notably in the petrochemical industry, it is interesting to note that the industry in which it was first applied was in fact the wood products industry. Leonid Kantorovich, a Russian mathematician, was given the task of optimising production in the Russian plywood industry and in the course of this work effectively invented what we today call linear programming. For this he was awarded the Nobel Prize (quite likely the only Soviet-era Russian to win an award in economics!).

3. Components of a Linear Programming Optimisation Model

The components of an optimisation model covering the entire wood products supply chain are illustrated in the figure below. Where a given model begins and ends in the process will be a function of the decision points that can be controlled in the particular operation. For example, for an operation that buys logs, but has no control over the woods cross-cutting operation, the starting point will be delivered logs in various diameter, length, and "quality" sorts.



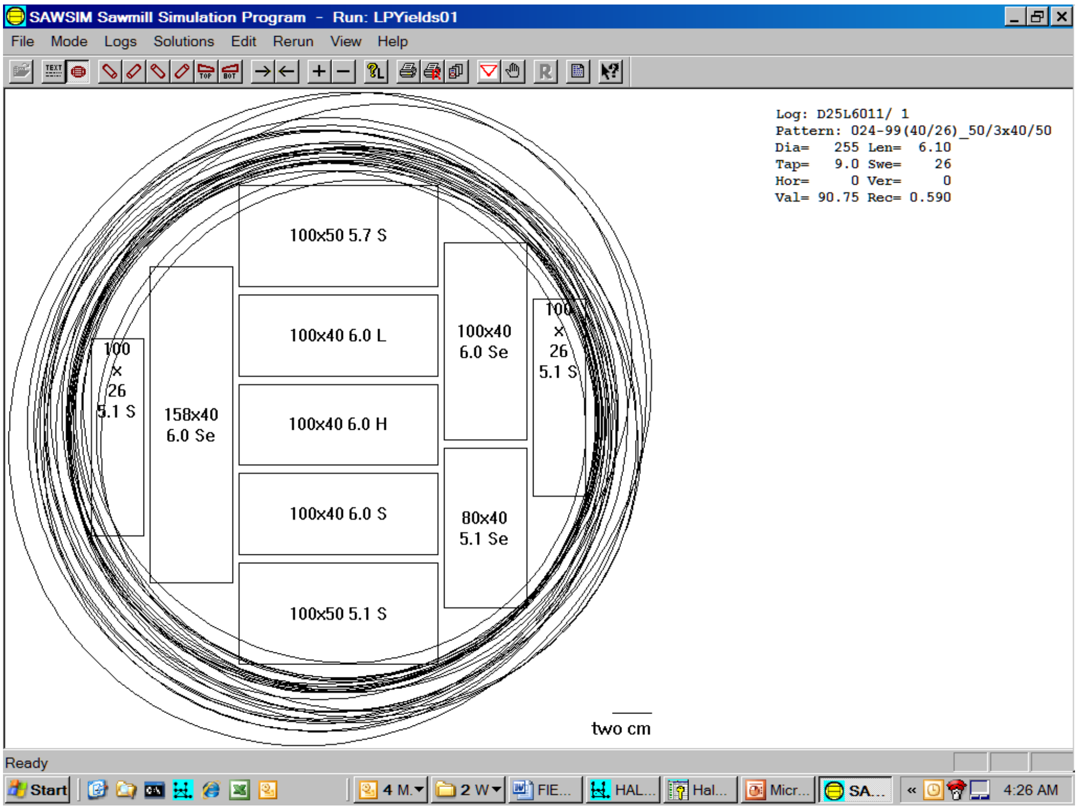
The primary optimisation model components are:

1. **Process Simulation Models**. Process simulation models are required to generate "yield" data, defining:

   - The yields of cross-cut logs in various diameter, length, and "quality" classes, from all possible harvest areas processed with all possible harvesting and log merchandising options.

- The yields of rough-sawn lumber of all sizes, lengths, and rough-grades generated from all possible sawing patterns, along with the processing times required at each mill machine centre.

A requirement of these process models is that they incorporate sufficient detail and flexibility to model the actual process. For example, the harvesting and cross-cutting model must include sufficient detail to represent real-world cross-cutting and log sorting practices; a system that tallies only 4.8m log yields will not suffice. In the case of the sawing model, realistic log form (not "perfect" computer logs) and allowances for imperfect log alignment and other process inefficiencies must be considered. A sawing simulation plot for a real-world application would thus look something like:



2. **Linear Programming Matrix Generation and Solver.** In addition to the process yield data described above, additional data must be defined for such things as:
   - Available log supply volumes and costs
   - Mill operating times and costs
   - Machine processing rates
   - Required production (sales) mix
   - Timber and byproduct values
   - Drymill splitting options
   - etc. etc.

The "matrix generator" generates the many thousands of simultaneous equations defining the entire fibre flow options. Included in the matrix is the "objective function" equation. In most cases the objective function equation defines all the revenues less expenses, and hence the operating income.

The matrix is then solved with an off-the-shelf linear programming solving system, which determines the solution which maximizes the objective function, i.e. the solution that maximizes profit. An output database is generated with all the solution details.

3. Database and Reporting Tools

A successful LP optimisation application requires efficient, user-friendly systems for data editing and report generation.

4. Optimisation Model Applications in the Wood Supply Chain

Following are just a few examples of the types of questions that can be answered with an optimisation model:

1) **Log Sorting and Pattern Decisions**

In a typical Australia/New Zealand sawmill, logs are sorted in the yard to many diameter/length sorts. Mill operations personnel are then given the task of satisfying sales commitments. The question then becomes: what sawing pattern (or patterns) should be used for each log sort, to produce the required production mix in the most efficient way?

This has proven to be a very successful application of LP optimisation modeling, as the nature of the problem fits very well the linear programming methodology. A good sawing simulator can easily generate accurate yields from sawing each log sort with each possible sawing pattern, and alternative finishing options (such as drymill splitting) can be defined. But while developing the data is quite easy, the sheer scale of the problem (the number of alternative solutions) makes solving it with traditional methods such as spreadsheet analysis absolutely impossible. An LP model, on the other hand, can solve this problem very effectively.

2) **Timber Sales**

An LP optimisation model is a very effective tool to evaluate common timber sales questions, like:
We've found a buyer for an additional 3,000 m3 of 120x35:

- Can we satisfy this order?
- Can we do it without sacrificing our existing customer's orders?
- What will be the impact on our recovery, productivity and - most importantly - on our bottom line?

Evaluating a question like this is straightforward: all you do is relax the previous sales constraint on the volume of 120x35, and re-run the model to determine a new solution.

In addition to answering specific questions like this, an LP model can help you by identifying for which products the greatest profit increase would ***most-likely*** occur by relaxing a current sales constraint. As we will see, when an LP solution is generated which satisfies given sales mix constraints, a "marginal value" is also generated, which is the change in the objective function (profit) that would result by relaxing a constraint by one unit - for example by allowing one m3 more of a product that is attractive to the operation.

3) **Log Procurement**

As with timber sales, an LP optimisation model can be used to evaluate log purchase options, such as: how much could we afford to pay for more of those 300-350 mm logs? Again, the LP solution marginal values will indicate which log classes are desirable, and undesirable.

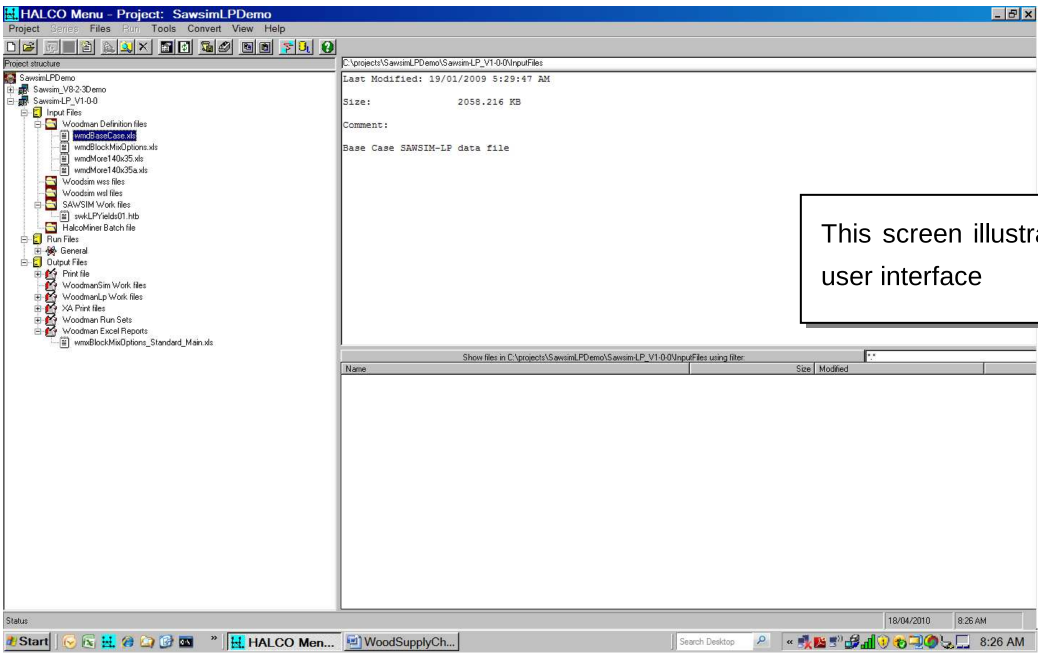
One thing to note about all the questions above is that the implications of the question cross the links in the supply chain. For example, a change in the timber sales mix will change the timber sales average ($/m3), but also of course impact sawmill and finishing operation and, ultimately, the optimal log supply options. So as can be seen, true operations optimisation must consider relationships between, not just within, links of the supply chain.

Once developed, an optimisation model that encompasses the entire operation, from raw material procurement through finished product sales, is an extremely valuable asset. An optimisation model is typically developed with a particular focus (type of question) in mind. In most cases, however, once the ability of the model to answer questions across the entire operation is recognized, there is usually no end to the types of questions raised for the model, such as mill capital project evaluations and mill purchase / rationalization decisions.

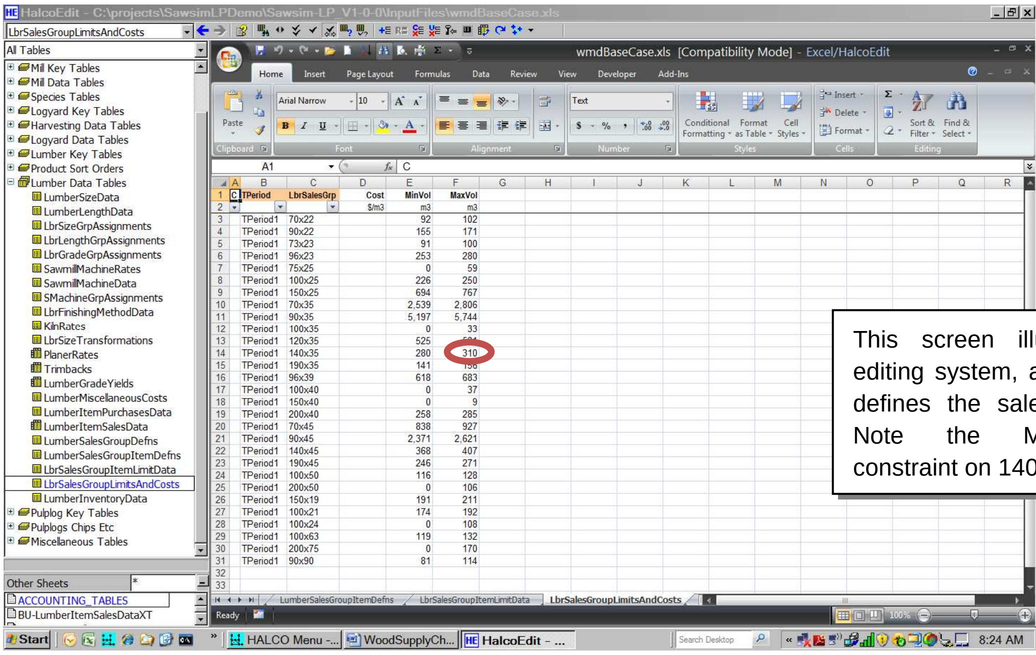
In addition, use of a model often results in a "cultural change" within the company; improved communication across the supply chain links often occurs, and people no longer will accept ad hoc operating decisions.

5. Optimisation Model Example

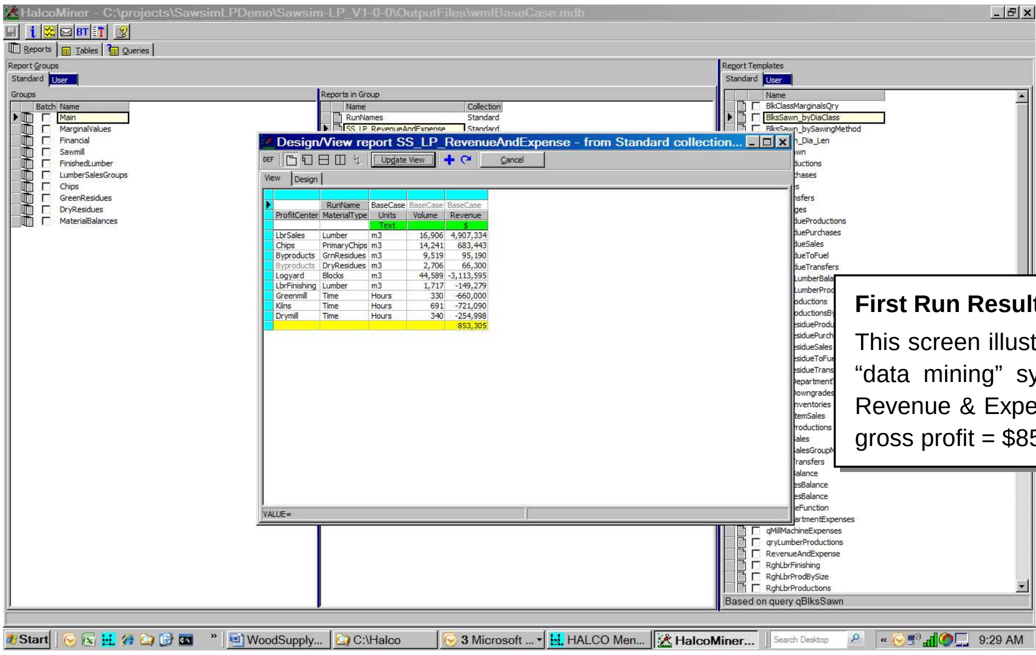
The following images illustrate an example optimisation model, and demonstrate a timber sales optimisation application.



This screen illustrates the model user interface

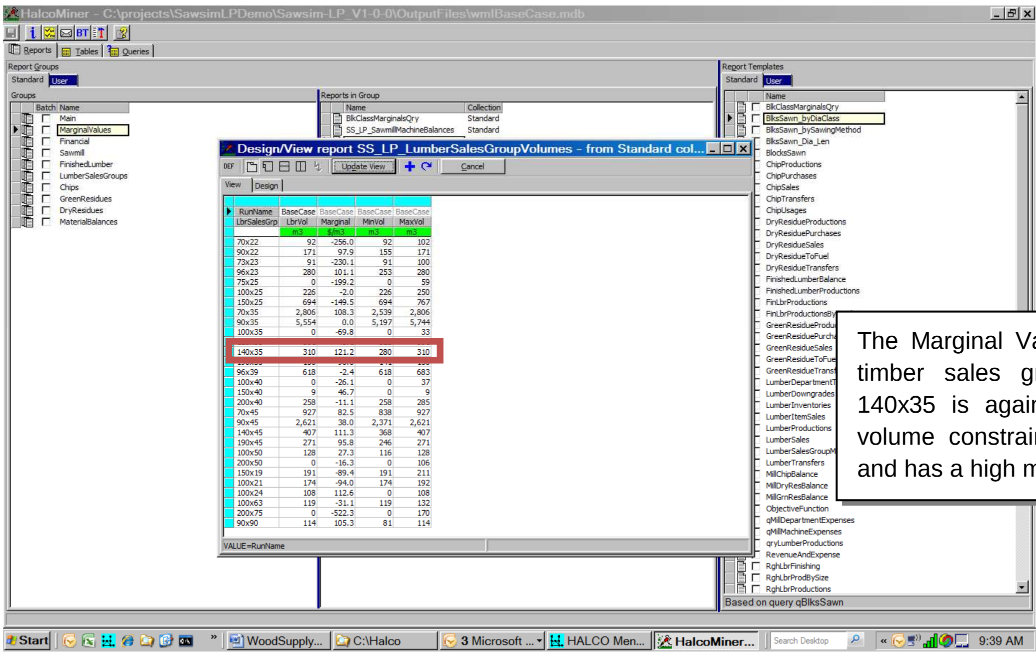


This screen illustrates the data editing system, and the table which defines the sales mix constraints. Note the Maximum volume constraint on 140x35.

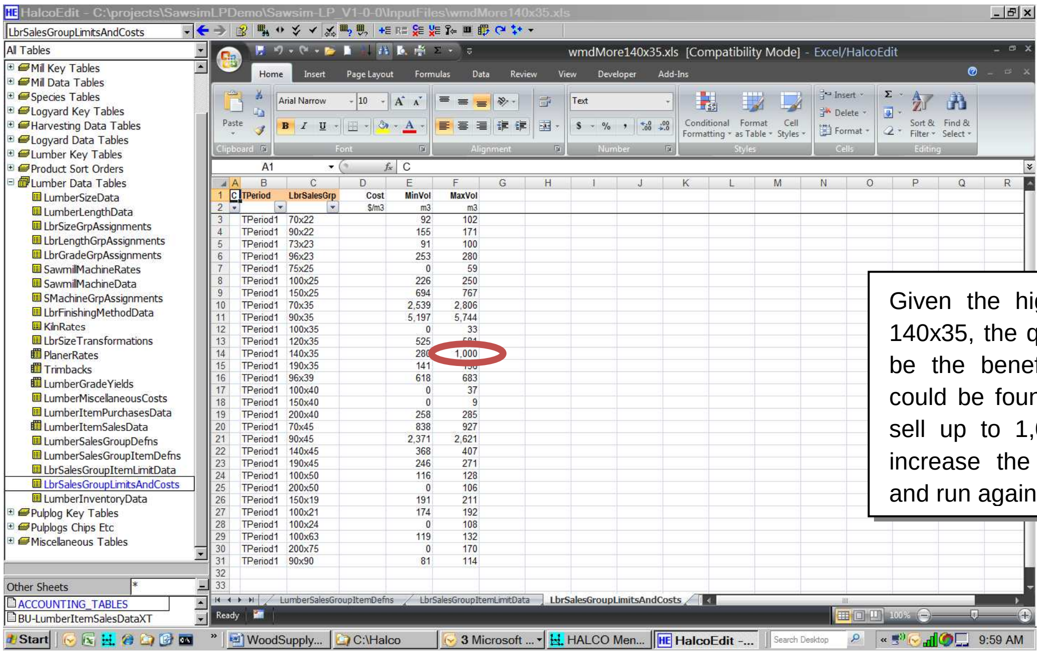


First Run Results:

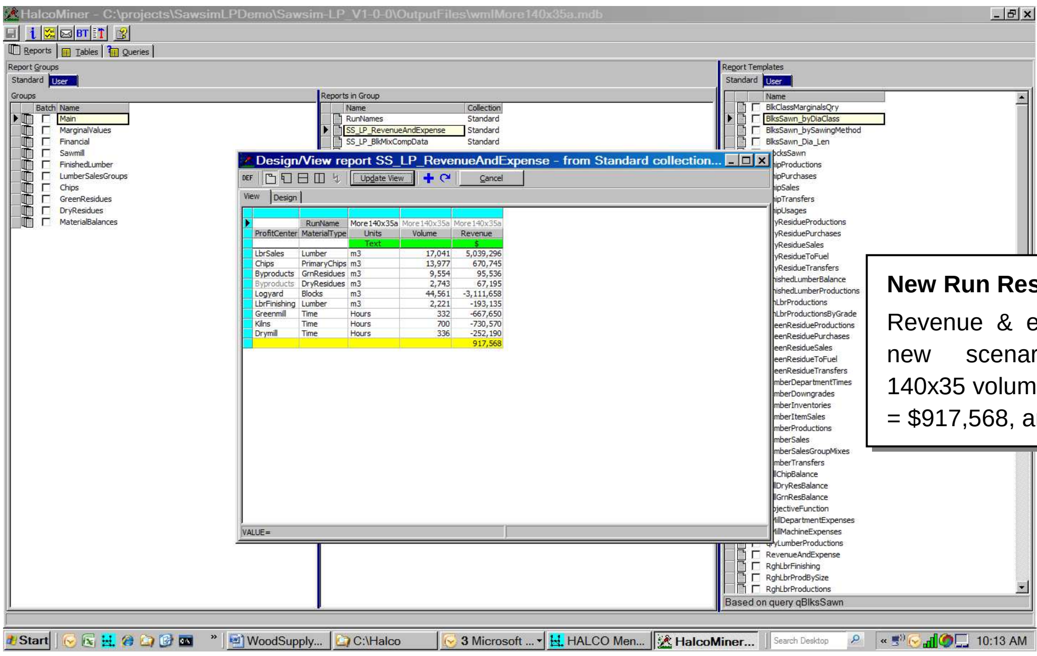
This screen illustrates the reporting / "data mining" system, and a quick Revenue & Expense report (monthly gross profit = $853,305)



The Marginal Values report for the timber sales groups. Note that 140x35 is against its upper sales volume constraint (310 m3/month), and has a high marginal value.

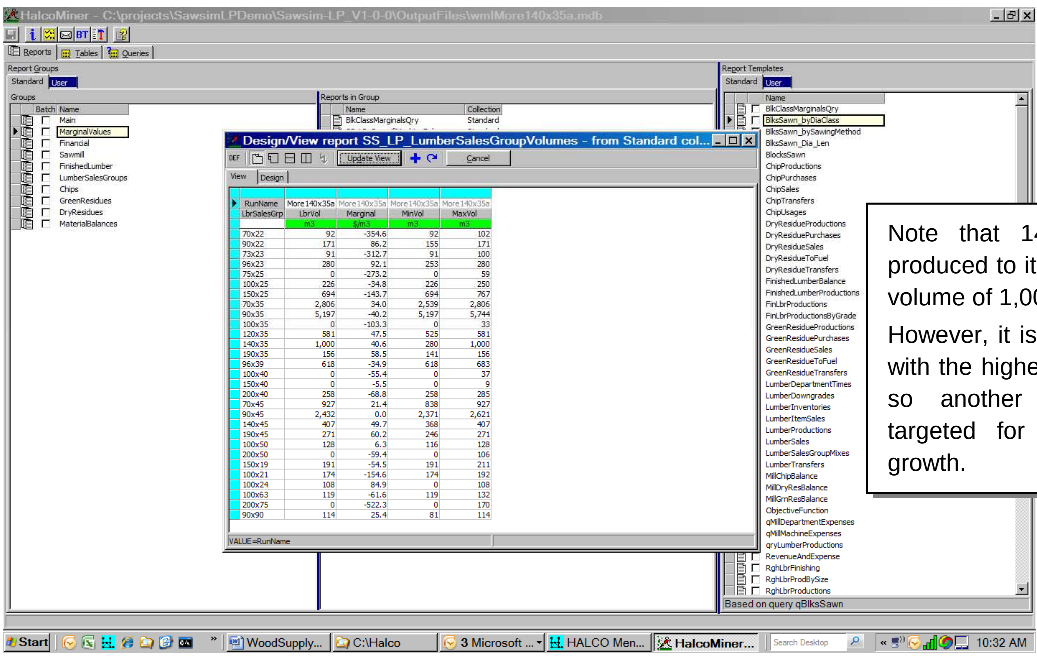


Given the high marginal value for 140x35, the question is “what would be the benefit if a new customer could be found, such that we could sell up to 1,000 m3/month?” We increase the sales mix constraint, and run again.



New Run Results:

Revenue & expense report for the new scenario, with increased 140x35 volume. Monthly gross profit = $917,568, an increase of 7.5%.



Note that 140x35 is now being produced to its new upper constraint volume of 1,000 m3/month.

However, it is no longer the product with the highest marginal value, and so another product should be targeted for future sales volume growth.

6. What We've Learned: Criteria for Success

HALCO Software Systems has produced commercial linear programming optimisation models for many years, including one model that has been in continuous use by a large North American wood products company for over 25 years, which is perhaps a record in the world of optimisation modeling! Along the way, we have learned a few things about what makes for a successful LP application.

1. Good Process Models are a Must

As previously noted, process models are required to generate yield data; yields of logs from trees for different merchandising options, and yields of sawn timber (and byproducts) from logs for different log sorts and sawing patterns. As an alternative to a sawing model, one could attempt to use mill tests to generate the yield data. For a working model, however, mill tests will absolutely not do. Mill tests are costly, and produce notoriously unreliable data. In addition, mill tests can't provide data for sawing patterns not yet used in mill operation, and mill test data will become invalid once mill operating parameters (e.g. target sawn sizes or saw kerfs) are changed.

As an alternative to mill tests a good sawing simulation program, with sufficient flexibility to provide realistic real-world product yields and machine time calculations should be used. The simulation program must be calibrated against actual mill operating results.

2. The System Must be "Slick" and User-Friendly

The amount of data processed in one of these applications, both input data to the model and output data produced by the model, is very large. By "slick" we mean that the model cannot require a lot of manual steps such as copying data from one part of the application to another. Manual operations are problematic both in terms of the time required and the opportunity for error, and a system that requires these manual steps ultimately just won't be used. A good system must be designed to be as "seamless" as possible, from input data specification, through run execution, to reporting.

Good user-friendly data entry (complete with error checking) and reporting systems are also important.

3. Sufficient Detail for Credibility

An optimisation model can often present results that are initially non-intuitive – in fact, these solutions are of course often the ones which are most valuable! However, for these non-intuitive solutions to be accepted, the model must include sufficient detail; without that, the results will not be credible and people will not act upon them with confidence.

One of the skills of a good model developer is the ability to recognize the detail that must be included to recognize the important factors of an operation, without the model becoming bogged down in excessive detail. This can sometimes be a fine line to walk.

4. Client Commitment

Development and implementation of these models is not a simple task. Development may require some fairly substantial data collection tasks. And, the first results presented will almost certainly not be correct. To be successful, the client must be willing to support the development, work through the initial solution checking and implementation, and apply sufficient personnel resources to continue the model use over time. In the end, the return on investment from this commitment will typically be very great.

7. Benefits from Optimisation Modeling

1. Increased Profit

Of course this is the primary objective of the exercise. Numbers typically quoted for the benefits of optimisation modeling such as this are several percent of total operations sales. Given the scale of a typical wood products processing operation, this can of course be very significant.

2. Improved Communication between Departments

Implementation of an operations-wide optimisation model invariably results in a cultural change within the organization. Realistic, fully-detailed plans are developed, which all departments have contributed to and can thus relate to. Through use of the model, changes that benefit the overall operation, but which may hurt the metrics in a given link in the chain, are better understood. When departments work together, much is achieved.

3. Uncovering Problems with the Current Process

Developing and validating the optimisation model requires that the existing operation be looked at in fine detail. The component process models (log merchandising and sawing simulation) are configured to model the operations as they are understood to operate. These models are sufficiently detailed, with all important operating variables taken into account, and so the departures from the models that occur in practice should be quite small. Sometimes, however, these departures are not small, and the validation process reveals operating situations, such as inappropriate machine settings, that can be easily corrected. In many cases these things learned "along the way" to developing the model can alone pay for the model development.

4. Acting with Confidence

Once confidence is built in the model, it becomes possible to make changes in the operation with confidence.

In a plywood mill application in British Columbia, an optimisation model showed that the "fishtail" veneer should no longer be dried and consumed internally, but instead sold green. Doing so relieved a significant constraint at the veneer dryers, hence allowing production to increase without purchasing outside veneer. The impact on profit was substantial. When the model operator presented these results to management, some of them said "Well, I knew that!" Well, if they knew that why hadn't the practice been implemented? It was because the belief wasn't universal, and the model was able to ***quantify*** the impact of the change. They subsequently made the change, which as predicted had a significant impact on operations and profitability.

Another benefit of acting with confidence is that less time is spent second-guessing. These models are very accurate in their ability to predict changes in mill recovery. Therefore, should the model show that a change in sales mix increases profit, but at the expense of a 1% loss in recovery, there will be no panic, or a tendency to back off the change, when the mill recovery actually does fall by 1%.

5. No More "Gurus"

In many operations, greenmill production planning is under the control of one "production planning 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 benefits of optimisation modeling is that it is a ***systematic method*** for determining optimum production plans. By having a systematic method, it is much easier to transfer this knowledge within organizations.

8. Conclusions

In conclusion, log procurement and merchandising, mill operations, and finished product sales are not independent operations, and to maximize profit they must be considered when operating decisions are made. Linear programming optimisation is an effective and well-proven method to optimise across all links of the wood supply chain.