Smart Scheduling of Pulp Mills & Chemical Recoveries

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ABSTRACT

In capital-intensive industries such as pulp and paper, maximum utilisation of assets is essential. The design capacities of production units in a pulp mill/recovery complex are often matched such that under steady state conditions, the whole mill can run at maximum. However, because of the dynamic nature of breakdowns, restrictions and varying demands, the steady state scenario is rarely achieved.

Breakdowns of equipment, or constraints in other interdependent areas, often reduce the utilisation of key production units. When there is a breakdown, and a plant area shuts down, domino effects follow as other plant areas, upstream and downstream are forced to shut. Smart selection of targets for stock levels, tank levels and unit production rates can maximise the utilisation of key assets despite unplanned breakdowns and restrictions.

Constraints or bottlenecks determine the maximum throughput of the mill, but short-term variations in each production area are required to achieve the optimal storage levels. The demand for each grade of pulp depends on paper machine making plans, market pulp demands and desired stock levels.

Competition for finite resources, such as white liquor supply, black liquor processing capacity and steam availability, requires that priorities for pulp users be set and adhered to.

Some of the principles involved in planning to maximise production are discussed, along with description of the systems available to assist mills to achieve this goal. Issues including the scheduling of downtime for maintenance and cleaning (eg. Evaporator boil-outs), washer dilution factor optimisation and methods for dealing with constraints are discussed.

Simulations highlighting the improvements resulting from following the recommended strategies demonstrate the importance of having a system in place to assist planning and scheduling of pulp mills.

"THE MORNING MEETING"

A typical "Morning Meeting" in a pulp and paper mill covers all that's gone wrong in the previous 24 hours, and what can be done to satisfy the demands of the next 24 hours.

The most common incidents of the previous period we hear of are:

- unplanned shutdowns due to equipment failure,
- unplanned shutdowns due to equipment failure in other areas,
- deviations from paper machine plans due to:
  - change of grade,
  - non-standard stock proportions,
  - non-standard machine speed.
- pulp production limited due to not enough white liquor,
- pulp production limited due to high black liquor storage levels,
- planned shutdowns not adequately prepared for,
- boiler restrictions due to environmental limitations,
- unplanned boiler outages.

In some cases, the root causes of these outcomes are sought, but often they are just accepted as uncontrollable events.

Then comes the planning for the next period. All the competing demands from various departments must be considered, including:

- the desire to make budget in individual departments (which is sometimes not what's best for the overall mill),
- the need to satisfy customer "promises".

These desires need to be tempered by consideration of the bottlenecks and other constraints in the various pulp and recovery processes. For example:

- impaired throughput (such as fouled evaporators),
- maintenance down-time,
- black liquor processing bottlenecks,
- white liquor strength and supply,
- steam limitations,
- environmental limits.

A rough plan is concocted, usually based on:

- normal paper machine demands,
- the nominal maximum rate through a bottleneck,
- the desires of the most influential departmental head, and
- whatever's comfortable.

The plan often does not consider all that can go wrong in the next 24 hours. There is little attempt to set up to minimise the effect of possible events.

THE THEORY OF CONSTRAINTS

In planning the operating strategy for a pulp mill (or any other manufacturing site), the Theory of Constraints should be employed. The Theory of Constraints (TOC) is a set of management principles that help to identify impediments to your goals and effect the changes necessary to remove them. These principles are outlined in "The Goal" by Dr. Eli Goldratt (1).

Where manufacturing is concerned, TOC postulates that the goal is to make more money (2). It describes three avenues to this goal:

1. Maximising Throughput
2. Minimising Inventory
3. Minimising Operating Expenses

As Dr. Goldratt notes: "The opportunities to make more money through reductions in Inventory and Operating Expense are limited by zero. The opportunities to make more money by increasing Throughput, on the other hand, are unlimited".

In "The Goal", Throughput is defined as the rate at which a system generates money through sales. It is critical that we distinguish sales from production: While manufacturing operations traditionally measured production at each stage of the process, the only Throughput that counts is that which comes off the end of the line to be sold.

TOC recognises that the output of any system that consists of multiple steps, where the output of one step depends on the output of one or more previous steps, will be limited (or constrained) by the least productive steps. In other words, a bottleneck in one mill area can control the output of the entire mill.

Therefore, TOC requires that we maximise the throughput of bottlenecks.

THE LOST OPPORTUNITIES

Obviously, if evaporators or recovery boilers, for example, were the bottlenecks in a mill, we would strive to maximise throughput there. However, the rest of the mill must also be coordinated with precise planning to ensure that we facilitate maximum production through the bottlenecks, minimise costs and be best prepared to deal with unplanned events.

Unplanned breakdowns, restrictions and variations in demand disrupt production in various mill areas. Tanks empty or fill, and the mill becomes out of balance.

The design capacities of production units in a pulp mill/recovery complex are often matched such that under steady state conditions, the whole mill can run at maximum. However, this limits the ability for out of balance areas to "catch up" and restore the balance. Thus, the steady state scenario is rarely achieved.

Constraints or bottlenecks determine the maximum throughput of the mill, but short-term variations in each production area are required to achieve the "optimal" intermediate storage levels.

Lack of precise planning results in a loss of opportunity to maximise production.

In a supply chain where manufacturing output exceeds sales, sales is the bottleneck. But, generally, the bottleneck(s) will occur in the mill processes.

The demand for each grade of pulp depends on paper machine making plans, market pulp demands and desired stock levels. The initial "pull" of material must be generated from this demand. Where there are constraints, production planning must "pull" throughput from upstream of the bottlenecks, and "push" throughput downstream of the bottlenecks.

Intra-Mill Competition

Pulp throughput may not be the bottleneck. The production limiting constraint may vary in location and magnitude from day to day and from grade to grade. It may be an environmental limit (eg. TRS limit on a recovery boiler), or in mills with more than one pulp line, it may be competition for finite resources, such as white liquor supply, black liquor processing capacity or steam availability. Where there is competition for finite resources, these resources must be shared according to priorities calculated based on the relative economic contributions to the overall mill result.

"Business Rules" should be established to resolve these situations of intra-mill competition, such that the limited resources can be allocated to the best benefit of the total mill.

Evaporator Performance

Since the output of the whole plant may hinge on the productivity of a bottleneck, the production rate there must be maximised. If the bottleneck is the evaporators, it is essential that evaporators are kept as clean as possible to achieve this goal. Scheduling of downtime for maintenance and cleaning (eg. Evaporator boil-outs) must also be optimised.

Algorithms exist to determine the best time to take an evaporator off-line to do a boil-out.

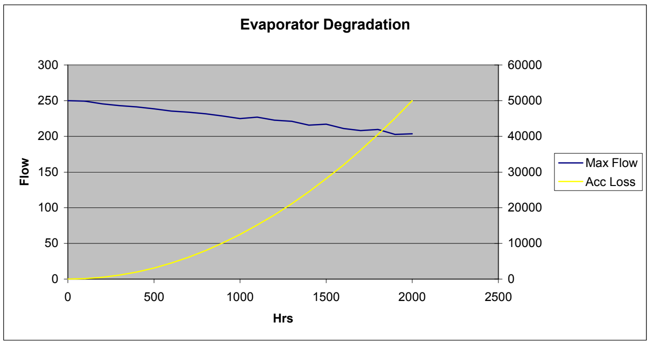

Fig. 1

Evaporator performance should be monitored - and if the evaporator set has degraded to the optimal level for a wash, and the liquor system has capacity for an evaporator wash, then a wash should be scheduled. The aim is to maximise evaporator performance over the longer term. The variables to be monitored depend on the particular situation.

Degrading evaporator performance may be indicated by:

- liquor throughput,
- steam valve position,
- % solids out,
- evaporator economy or
- delta T.

In mills where the evaporators are a bottleneck, the maximum throughput is the dominant factor. In other mills, evaporator economy may be the main issue.

Therefore a system is needed that will:

- monitor mill production and the planned product mix
- determine where the bottlenecks are for the planned pulp demands over the next 24 hours (or more)
- resolve the allocation of limited resources to different pulp lines
- precisely plan the production strategy considering the demands, grade changes, constraints, priorities and any special needs such as evaporator washes, etc.

Lack of precise planning results in a loss of opportunity to minimise inventory.

In an ideal mill, throughput in each area would be matched, and there would be no need for any intermediate inventory. However, unexpected breakdowns or other events require that these upsets be insulated from the rest of the mill by intermediate production storages.

When there is a breakdown, and a plant area shuts down, domino effects are triggered as other plant areas, upstream and downstream are forced to shut. The only things inhibiting this consequence are the buffer storages between processes. The larger the available capacity in these storages, the more time available to restart the processes that have stopped, before shutting down more plant areas.

Larger storage tanks will provide a greater buffer which will slow the domino effect, but size is usually limited during mill design due to pressures on capital cost and the increased operating cost of carrying larger inventory. But, the utilisation of these storages can be managed to best prepare for unplanned events.

When a shutdown does occur, it would be advantageous to maximise the capacity available in storages to cushion the domino effect. However, the disruption may be upstream or downstream of the storage, so the likelihood of shutdowns upstream and downstream must be considered. If there is an unreliable plant upstream, the storage should be kept fairly full, and if there is an unreliable plant downstream, the storage should be kept fairly empty.

The reliability of the plants immediately adjacent to a tank can be used to calculate the optimal level. However, the reliability of plant areas further afield must also be considered if the intermediate storage volumes are small and a breakdown is likely to cascade beyond them. As the calculated time to fill or empty the intermediate storage decreases, the probability that an unplanned shutdown will propagate beyond it increases.

Therefore, optimal storage levels can be calculated using the probabilities of shutdowns upstream and downstream of each storage. Maintaining these optimal levels will make better use of the available capacity to avoid shutting down or reducing production rates.

During normal operation, the historical reliability statistics are used to calculate optimal levels. However, if a known shutdown is approaching, the optimal levels should be adjusted to best prepare for the shutdown.

Thus, over time, if the distribution of breakdowns follows the same pattern, the shutdowns of other plant areas will be minimised. Quality will be more consistent by avoiding shutting down or reducing production rates in other plant areas.

At times there may be a need to build stocks for grades where demand out-strips pulp mill output. This requires looking ahead a week or more and calculating the additional tonnes of inventory required.

Therefore a system is needed that will:

- use probabilities of shutdown upstream and downstream of each storage to calculate the "optimal" storage levels
- modify the optimal storage levels to cater for excessive demand, and/or planned shutdowns
- precisely plan the production strategy to restore all storages to their "optimal" storage levels.

Lack of precise planning results in a loss of opportunity to minimise costs.

The "optimal" Dilution Factor is often calculated to minimise costs for a particular pulp line. This usually considers cost functions of bleach chemical consumption, soda loss and evaporator steam versus Dilution Factor. This is fine, except for the case where evaporators may be a bottleneck, and what is the "optimum" for one pulp line may result in excessive weak black liquor that will inhibit the production of other pulp lines. Therefore the cost of lost production must also be considered in calculating the "optimal" Dilution Factor for each pulp line.

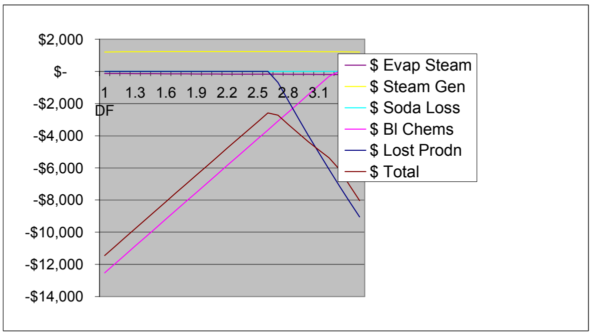

Fig. 2

Where black liquor evaporation is a bottleneck, the optimisation of washer Dilution Factors and evaporator performance become important.

Hence, a system is needed to determine:

- the "optimal" Washer Dilution Factors for each pulp line, and
- whether they need to be changed to maximise production (defined as $ of sales) for the total mill.

SUITABLE SYSTEMS

Several software packages are available for modelling and simulation of mill processes. However, these systems are difficult to set up and are generally not suitable for use by shift coordinators to solve immediate operational situations.

The Pro-Plan Pulp Mill and Recovery Optimisation System is an optimisation system that uses simulation and in-built decision making rules to determine the best operating strategy for any given situation. It is demand driven, and will maximise production consistent with any constraints in force at the time. It takes a global view of the mill to ensure that the recommended strategy is the best overall result for the mill as whole, as opposed to maximising benefit for any one area. The result is better coordination of the whole mill.

The system recommends the production rates of digesters, washers, bleach plant, evaporators, recovery boilers, causticizers, lime kiln, and, pulp stock to/from off-line storages. These recommended rates would deliver the required amount of pulp to end users, and drive the intermediate storages to their optimal levels. Controlling these levels ensures that production units will not be constrained by high or low tank levels.

Pro-Plan also handles other constraints such as:

- equipment shutdowns,
- steam limitations.

Pro-Plan will recommend the optimal Dilution Factor for each pulp line. The recommended DF is limited by minimum and maximum values where there are operational constraints (eg. maximum upflow in a continuous digester).

The system can also be used for shutdown planning, and evaluation of options when designing new plant.

MILL STUDIES

Three mill studies have been conducted which use actual mill data as inputs to the Pro-Plan Pulp Mill & Recovery Optimisation System. The studies were started with the system's storage levels set at the actual mill levels, and the system run at 12 hour intervals over a two week period using the actual mill pulp demands. Simulations highlighting the improvements resulting from following the recommended strategies demonstrate the importance of having a system in place to assist planning and scheduling of pulp mills.

Mill Study 1

Analysis of mill operation over a 10-day period showed a potential increase in output that could be achieved by better coordination of the mill:

Pulp Line A output	+ 5%
Pulp Line B output	+ 2%
Bleach Plant output	+ 5%

Pulp Line C output	- 29%
(Due to high stocks).	

Although the major bottlenecks in the mill were known and operators instructed to maximise production through them, several times during the study period, major bottlenecks such as evaporators, recovery boilers and causticizers were restricted due to high or low storage levels upstream or downstream.

Mill Study 2

If system recommendations had been followed over the 10-day study period, it is estimated that the following benefits would have been achieved:

Pulp Line A output	+ 3%
Pulp Line B output	+ 3%
Bleach Plant output	+ 5%
Pulp Line C output	- 28%
(Due to high stocks).	

The economic value of this increased output is most easily quantified by the increased production displacing the need for expensive imported fibre.

During the 10-day period, some observations from using the model were:

Pulp Line A

Because several machines use this pulp, the probability of all users failing is relatively low, so the optimal level of the Pulp Silos is quite high. Digester production recommended by the system was higher and more stable than actual. Initially production was run at the maximum production rate to build silo levels to the optimal level, but eventually wound back to match demand.

Pulp Line B / Bleach Plant

The most significant gain was due to the increased output of bleached fibre. The economics are such that the system tries to maximise the bleached production at all times.

Pulp Line C

The Pulp Line C off-line stocks were high at the beginning of the 10-day period. The system controlled the off-line storage level to a lower target; consequently production was reduced, which resulted in:

1. Building the silo to the optimal level of 90% and holding it there.
2. Reducing the stocks to target and holding them there.
3. Reducing the amount of Weak Black Liquor sent to Recovery, thus allowing other mills to operate at higher rates.

Recovery

Shift Coordinator Logs showed how often rates in the recovery circuit are constrained due to high or low storages. Despite evaporators, recovery boilers and causticizers all being bottlenecks at various times, the simulation provided by Pro-Plan showed that the circuit could be managed to increase throughput.

Mill Study 3

Analysis of mill operation over a 2-week period demonstrated a potential increase in output that could be achieved by using Pro-Plan on a daily basis. The overall results of the study indicated a potential increase in pulp production over the period of 5%.

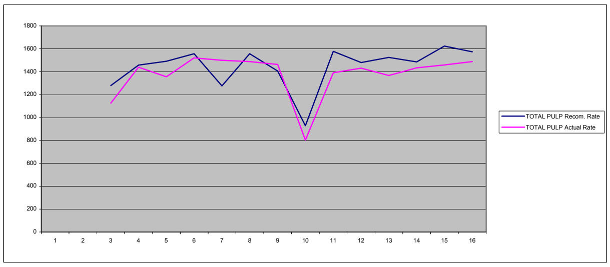

Fig. 3

Another important benefit was the improved stability of operations in that production rate and storage level changes are minimised.

During the study period where there was no dominant constraint. The increased output was the result of running pulp mills and recovery areas at faster rates in a coordinated manner.

Other issues included:

- Recovery boilers often restricted by opacity and TRS limits.
- Shortage of white liquor restricted actual pulp production on a few occasions.
- The mill is recovery limited in summer, and this was apparent with the shortage of white liquor, and evaporator limited in winter.

OTHER BENEFITS

In addition to the economic value of increased output, there are other operational and quantity benefits that would result from more stable operation. Less variability in pulp quality should result from fewer and smaller production rate changes. This will stabilise continuous digesters, washers and bleach plant operation. The gains here could be substantial - both on reduced equipment wear and more consistent pulp quality.

Better planning and prediction will allow lower pulp inventories. For example, lowering the level of pulp in off-line storages will reduce the amount of double handling and energy required pressing pulp, and later reclaiming it.

CONCLUSION

In summary, the main business drivers for implementing a production scheduling system for pulp mills are:

Business Drivers for Paper Machine

- Better availability of pulp when required.
- Less need to shutdown or slow down.
- Less variability in pulp quality would improve runnability and product quality.

Business Drivers for Pulp Dryers

- Better availability of pulp when required.
- Less need to shutdown or slow down.
- Increased output.

Business Drivers for Pulp Mills

- Better knowledge of forecast pulp demand allowing stock to be built in preparation.
- Business rules/strategies agreed by all departments.
- Increased output.
- Optimisation of washer dilution factors.
- Less variability in pulp quality for washing and bleaching.
- Lower inventories required.

Business Drivers for Steam/Recovery

- Maximising throughput by better management of bottlenecks as they change from day to day.
- More stable operation of evaporators and recovery boilers.
- More stable clarifier levels leading to more stable white liquor quality.
- Better scheduling of evaporator washes.
- Business rules/strategies agreed by all.
- Better knowledge of forecast steam demand.
- Better allocation of boiler loading.

Business Drivers for Mill

- Better coordination leading to optimal economic result for total mill, instead of individual departments maximising their own production to the detriment of others.
- Better planning of shutdowns knowing the consequences for all areas.

A production scheduling system to optimise pulp mill and recovery production in the short to medium term is a desirable element of the pulp and paper "supply chain". It deals with the "real time" scenario and all its unplanned situations, with the aim of increasing output and mill profits.

REFERENCES:

1. Goldratt, Eliahu, & Cox, Jeff, The Goal: A Process of Ongoing Improvement revised edition, North River Press, Croton-on-Hudson, NY 1987.
2. Smith, Jeffry J., Theory of Constraints and MRPII: From Theory to Results.