ADCHEM 2006

International Symposium on Advanced Control of Chemical Processes
Gramado, Brazil – April 2-5, 2006

OPPORTUNITY FOR REAL-TIME OPTIMIZATION IN A NEWSPRINT MILL: A SIMULATION CASE STUDY

Antoine Berton, Michel Perrier and Paul Stuart

NSERC Chair in Environmental Design Engineering
Chemical Engineering Department
École Polytechnique, Montréal, Canada
email: paul.stuart@polymtl.ca

Abstract: Real-time optimization (RTO) is applied for the broke recirculation in the stock approach system of an integrated newsprint mill simulation. New optimal broke ratio profiles are set for the paper machine recipes each time the process is confronted with an important disturbance. The variability in the four paper machine headboxes is minimized while the inventory management is handled. The proposed approach is compared to the actual mill operation, making use of a detailed plant simulation. While maintaining broke tank level within an acceptable range, RTO brings the pulp variability down about an order of magnitude. It is expected that it could significantly reduce the sheet break occurrence in a real plant and therefore enhance its economical efficiency. *Copyright ©2006 IFAC.*

Keywords: Real time optimization, newsprint mill, sheet break, paper machine.

1. INTRODUCTION

A typical state-of-the-art integrated newsprint mill involves the production of pulp by mechanical pulping and deink pulping, which are combined with broke pulp and delivered to a high-speed newsprint paper machine, typically running at speeds over 1 000 m/min. The broke pulp consists of recycled dry paper and wet pulp coming from the paper machine. The machine uptime is mainly limited by breaking of the paper sheet, causing stops several times per day, for periods of up to one and a half hour. In addition to the loss of production, these stops have drawbacks on the process by creating new instability resulting in future breaks on the sheet of paper. In fact, sheet breaks (or rupture) are major perturbations for the paper making process and accounts for a net loss of 10 to 15% of production (Bonissone *et al.*, 2002) resulting in revenue loss of billions every year for the global pulp and paper industry.

Paper breaks generally occur due to local weaknesses in the mechanical resistance of the sheet or when the sheet is subjected to sudden load increase. A number of studies have been carried out on characterizing breaks (Khanbaghi *et al.*, 1997; Akrour *et al.*, 2006) and in the identification of its causes (Linstrom *et al.*, 1994).

During a break, the paper machine is in continuous operation while action is taken to restore the continuity of the paper sheet. Until this is achieved, pulp is still fed to the paper machine but is directly collected in pits located below the machine and subsequently diluted and reutilized as it contains valuable raw materials (broke pulp). The broke pulp and fresh pulp have different properties and must be mixed in appropriate proportions depending on the type of paper produced. Recirculation of broke pulp is a major disturbance that increases the variability of the pulp feeding the paper machine affecting its performance. The variability is shown to increase the sheet break occurrence, bringing the process into a vicious circle, as a high variability in the headbox is a source of paper sheet breaks. Various studies on broke recirculation and its management have been published (Bonhivers *et al.*, 2002; Croteau and Roche, 1987; Orccotoma *et al.*, 1997; Ogawa *et* *al.*, 2004).

The present work is part of a vast research project on simulation, control and optimization of newsprint mills. The final objective is to design new control and optimization strategies on a plant-wide scale.

In the present paper, a Real-time optimization (RTO) strategy (Forbes and Marlin, 1996) is tested considering a key area of the plant: the stock approach system, the broke system and the four paper machines. Very few RTO applications exist in the pulp and paper industry (Flisberg and Rönnqvist, 2002).

First, the process is presented in detail and the actual control strategy for broke recirculation is shown. Then, the metric used for comparing operating strategies performance with regards to the headbox variability is presented. Using mill databases, an informal validation of this metric is established, showing a clear link between sheet break occurrence and headbox variability. In section 4, the proposed RTO control strategy is presented. Section 5 finally presents the results comparing the RTO control strategy to the usual plant operation. Through the use of simulation, the control approaches are compared considering the headbox variability and the behavior of the broke tank level. This is illustrated for a typical scenario of one day of operation.

2. PROCESS DESCRIPTION AND ACTUAL PRACTICES

This study has been performed in collaboration with an existing newsprint mill in Canada. However, the proposed approach is not specific to that mill and can be applied to other newsprint mills.

2.1 Mill description

The mill considered in this study produces newsprint at a rate of approximately 1000 t/d. It has four different paper machines that are fed with thermomechanical pulp (TMP) and deinked pulp (DIP). In addition, broke pulp, is also recycled to the headbox, at a rate appropriate to maintain reasonable inventory level in the broke storage tank. The broke and white water system is shared by the four machines. Figure 1 shows a simplified view of the process with the three principal storage tanks and the four paper machines. For the sake of simplicity, the white water system, as well as many intermediate storage tanks considered in the study are not illustrated. The mixed pulp composition is adjusted several times a day depending on pulp inventory, type of paper produced, presence of breaks on a paper sheet, etc. Since the three different sources of pulp are characterized by different properties, a change in the recipe introduces variability in the properties of the mixed pulp feeding the headbox. Table 1 shows how five pulp properties considered in this study vary depending on the type of pulp (Dabros *et al.*, 2004). The problem consists of adjusting the different pulp ratio of the mixed pulp, taking into consideration the inventory levels for the different break scenarios. When a break occurs, broke pulp is feeding the broke tank at a higher rate creating a disturbance in the control of its level. In the present study, only the management of the broke pulp is considered, having a constant DIP feed. The remainder of the pulp is TMP.

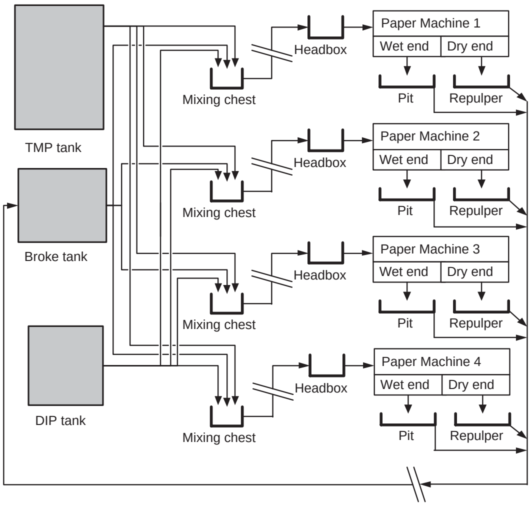

Fig. 1. Simplified flowsheet of the mill stock approach system and paper machines.

Table 1. Typical characteristic values of TMP, DIP and broke pulp at the mill.

Property	TMP	DIP	Broke
Consistency (%)	3.4	4.0	3.2
Temperature (°C)	65	52	58
Fibre content (%)	79	79	49
Fine content (%)	21	21	51
Dissolved solids (%)	0.4	0.4	0.08

2.2 Mill operating strategy

The current method for adjusting the broke ratio in the mill is manual. Operators supervise the inventory level of the broke tank and when it reaches too high a level or when a break occurs, they increase the broke ratio usually by increments of 5 %. This method for adjusting the broke ratio causes sudden changes in the mixed pulp properties, highly affecting the headbox stability.

2.3 Process simulation

A dynamic simulation of the papermaking section of the mill was developed using the WinGEMS 5.3 sequential simulation software, which is commonly used for simulation of pulp and paper processes (PacSim, 2005). The model includes the four different paper machines, the white water and the broke systems. An informal validation of the simulation was performed using mill data (Dabros *et al.*, 2004). The dynamic input variables include, for each paper machine, the mixed pulp flowrate, the proportion of TMP, DIP and broke pulp as well as the break status (if there is currently a break on the paper machines). The simulator then provides the tank levels, the flowrates and all the properties listed in Table 1.

3. HEADBOX VARIABILITY

In this study, the headbox variability, referring to the variability of several physical properties of the pulp at the headbox is used for two objectives. First, it is included in the optimization objective function and then, it is used in order to compare operating strategies.

3.1 Definition of headbox variability

In previous work (Bonissone *et al.*, 2002), five pulp properties were selected for characterizing the headbox pulp variability (HV): consistency (%), temperature (°C), flowrate (l/min), fines content (%) and dissolved solids (%). The metric that will be used to compare the performance of different operating policies is a summation of the squared normalized incremental changes of those five properties:

$$HV(t) = \sum_{k=1}^{5} \left(c_k \left(P_k(t) - P_k(t-1)\right)\right)^2 \qquad (1)$$

where P_k denotes a specific property. Normalizing coefficients (c_k) are included as weighting factors for the five properties. The c_k coefficient are chosen to be the inverse of the average incremental change over a standard day of operation. In that way, each property should contribute equally to the headbox variability metric (HV). The simulation sampling time is one minute, making a new metric evaluation available every minute.

3.2 Informal validation of the objective function

Recently, extensive statistical studies of mill data have been carried out that proved that there is a clear correlation between the headbox variability and sheet break occurrence (Akrour *et al.*, 2006). Figure 2 offers a qualitative relation between the probability of break and the properties involved in the HV as defined in Equation 1. Note that the actual values of HV cannot be determined since there is no available information due to lack of sensors in the plant to measure all the properties in Equation 1. In Figure 2 a surrogate of HV is composed with two of the measurements of Equation 1 (consistency, flowrate) and with a surrogate of the other variables (white water temperature, broke ratio). The broke ratio has been included as its change is strongly correlated with changes in dissolved solids and fines content. Figure 2 is made from data over a 10 months period. For the right half of the histogram, very few observations were available making the corresponding probabilities inaccurate. For some classes, there was even no observation (for instance, between 90 and 115 in the y axis). The actual value of HV (x axis) has no physical meaning but it is clear that the probability of break occurrence is enhanced when its value is higher. By keeping the HV function below a value of around 10, the break occurrence should be significantly minimized. Even if it is not exactly the same metric, the clear tendency observed in the break probability validates the hypothesis that high headbox variability increases break occurrence and is therefore a suitable metric to evaluate the performance of different operating strategies.

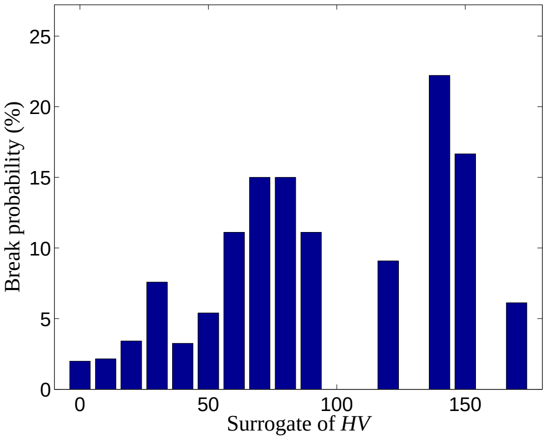

Fig. 2. Observed sheet break probability in the mill with respect to a surrogate of HV.

4. PROPOSED APPROACH FOR BROKE MANAGEMENT

The proposed strategy for broke management is basically inspired by mill operator's methods, but in an automated and smoother way. In the mill, the operators adjust the broke ratio so that the broke inventory remains within an acceptable range. The proposed strategy is simultaneously adjusting the four broke ratios, taking into consideration the broke tank level.

The time to perform RTO could be set periodically or when the process is facing a significant disturbance. In the present study, RTO occurs every time the break status changes. It means that every time a break occurs or ceases, a new optimization is performed. In addition, when the break status is not changing for a long time, a new optimization is performed for safety.

4.1 Process models

The RTO strategy uses a WinGEMS dynamic model which is similar to the simulation model that is to be used as a test mill. The WinGEMS model used for RTO purposes is simpler in order to enable the fast simulation which is critical for practical implementation. The main simplification is that no convergence of the steady state simulation is obtained, signifying that the starting point of the optimization model does not agree strictly to material conservation.

4.2 Optimization window

Each time RTO is performed, a snapshot of the current states of the plant (in this study the plant simulator) is taken. This snapshot includes all variables necessary to initiate a new simulation. It also includes the current break status, i.e. which machine is affected by breaks. From that point, the broke ratio profiles must be optimized for a certain time window in the future. This time window was set to 30 minutes, thus 30 sampling period. For this chosen time window, the break status is assumed to be constant.

4.3 Optimization parameters

Ideally, the optimization parameters would be the four broke ratios at each sampling periods. However, it would make the optimization problem too big and practically impossible to implement.

Choosing a fixed value for the broke ratios in the optimization window would bring the number of parameters to only four. In that way, the broke ratio profiles would be a succession of steps of different amplitude. These sudden changes would significantly increase the probability of breaks.

In a recent study, Dabros et al. (2004) show that the best way to minimize headbox variability when performing a modification of the pulp proportions was to implement gradual changes spread over time. The same idea is used here by setting each broke ratio profile to be gradually increasing or decreasing. In that way, the headbox variability is minimized and the optimization problem remains simple, having only four optimization parameters. Those parameters are the incremental rates of change, constant at each sampling period.

4.4 Objective function

In order to satisfy the dual objective of minimizing HV over the optimization window and keeping the broke tank level within an acceptable range, the broke tank level ($L(t)$) is included in the objective function. Also, the actual break status is included as it has a direct impact on the broke tank level. When a break occurs, the pulp is recycled and thus requires more of the storage space in the broke tank. For a given optimization window, the objective function corresponds to the sum over time of the headbox variability function ($HV(t)$) for the four paper machines added to a squared sum of the broke tank level deviation from its setpoint:

$$J = \sum_{4}\sum_{t} HV(t) + \sum_{t} \left(\kappa\,(1+n_b)\,(L(t) - L_{sp})\right)^2 + \lambda \sum_{4} \left(poslin\,(BR_{max} - BR_{lim})\right)^2 \qquad (2)$$

The inclusion of the number of breaks (n_b) in the objective function allows automatically more emphasis on the tank level control when there is break(s). The broke tank level setpoint (L_{sp}) was set to 30%. The objective function also includes a term limiting the range of the broke ratio. The third term of Equation 2 is the squared difference of the broke ratio's maximum value over the optimization window (BR_{max}) and its soft limit (BR_{lim}). The term *poslin* denotes a transfer function equal to one when the inner term is positive and 0 when it is negative. The coefficients κ and λ are normalizing parameters in order to put a similar weight on the three terms of J in Equation 2. The broke ratio limit (BR_{lim}) can be different on each machine depending on the type of paper produced. In the present study, it was set to 35% for the four machines. Although none were used, the actual architecture also allows implemention of hard constraints which might be necessary for some operating conditions.

The RTO strategy is depicted in Figure 3. For each block of the flowchart, the box format indicates if the operation is made in Excel, Matlab (Mathworks, 2005) or WinGEMS. The three softwares are necessary as no communication protocol is available between Matlab and WinGEMS. A first guess is made for the incremental changes and is sent along with simulation parameters to the simplified 30 minutes dynamic simulation. After it is completed, the objective function J is evaluated. The Optimization toolbox from Matlab is used to solve the optimization problem. Once the algorithm has converged, the recommended incremental changes are sent to the WinGEMS mill simulation. This dynamic model simulates the mill from the present time until the next change in the break status, at t_{newD} (for *new disturbance*). From that point, a snapshot of the mill is taken and sent back for a new optimization. For the

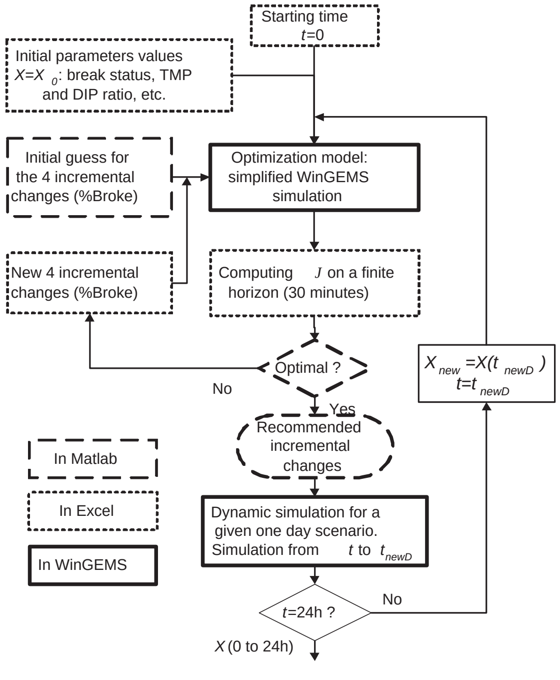

Fig. 3. Flowsheet of the RTO algorithm.

purpose of the study, this routine is repeated until the one day scenario is completed.

5. CASE STUDY AND RESULTS

The proposed strategy for broke management is compared with the actual mill operation in the simulated newsprint mill for a typical one day scenario. Breaks occurrence and length correspond to a real day of operation in May 2003. For that day, a total of 24 breaks occurred among the four machines. Figure 4 illustrates the occurrence and the length of the breaks. The scenario chosen is not a particularly good day for the mill as the uptime of the four machines was low (88 %). This is therefore a good candidate to test if the proposed procedure can handle difficult situations. For that day, the broke ratio set by the operator was also recorded and applied to the newsprint mill simulation to be compared to the proposed RTO strategy.

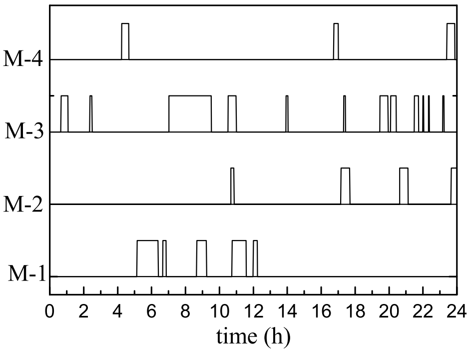

Fig. 4. Occurrence and length of breaks during the one-day scenario of study for the four paper machines (M-1 to M-4).

5.1 *Impact on the headbox variability*

As defined earlier, the headbox variability (HV) is used as a comparison metric to evaluate the operating strategies. Figure 5 shows the broke ratio profiles for the whole day of operation as performed by mill operators (left axes). On the right axes, the headbox variability function is shown on the bottom part of the graphs. When the operators change the broke ratio in the plant, it increases dramatically the variability of the headbox pulp properties, resulting in very high values of HV.

The peaks are observed for two main reasons: change in broke ratio and sheet break. Referring to Figure 2, the high peaks after a broke ratio change can highly increase the probability of breaks. This can be seen in Figure 5 where for machine 1, breaks occurred just after the first and second changes of the broke ratio. This observation agrees with the results observed over a 10 months period shown in Figure 2.

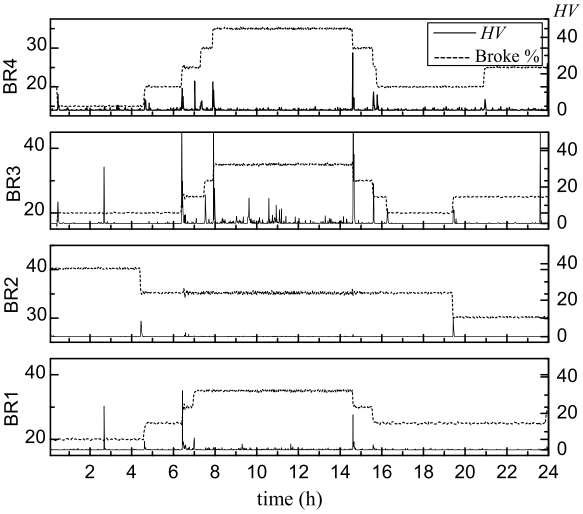

Fig. 5. Broke ratio and headbox variability profiles of the four paper machines.

By implementing the broke ratio changes more gradually while considering the safety aspects of broke tank level and broke ratio limitations, the RTO strategy (illustrated in Figure 6) gives better results than the operator's strategy. From the results of Figure 6, the improvement on the variability is obvious, the peaks for HV being decreased by about an order of magnitude compared to Figure 5. The broke ratio is adjusted more smoothly in the proposed approach, resulting in a higher stability of the headbox pulp properties.

For the mill operating strategy, peaks in HV are the results of both breaks (disturbance) and radical changes in the broke ratio. For RTO, the remaining peaks, while being attenuated, are almost only due to breaks (see Figure 4 for the break occurrence). The operator disturbance, which is indeed the most important one, is eliminated. The proposed approach shows the advantage of minimizing one type of disturbances while not creating others.

Referring to historical databases, this improvement can be translated into a decrease of more

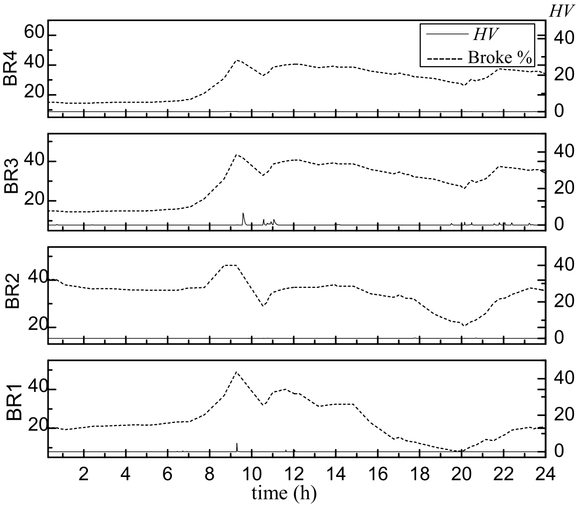

Fig. 6. Broke ratio and headbox variability profiles with RTO.

than 40% of breaks potentially caused by headbox instability. According to data available in Akrour et al. (2005), this improvement could result in a decrease of around 20% of the total mill loss due to breaks.

5.2 Impact on the broke tank level

A major concern of the plant personnel when a smoother broke ratio management approach is proposed is that during breaks, the effect on the broke tank level is too important to be able to slow down the broke ratio changes. This is an incorrect belief as the tank is able to absorb a large number of breaks. Figure 7 shows the broke tank level behavior for the two operating strategies. The total number of breaks is also shown in order to identify the most demanding periods for broke inventory.

Although RTO could seem very different than regular mill operation, the broke tank levels remain in a similar range. Therefore, the RTO strategy brings the headbox variability down without having any negative effect on inventory. Furthermore, RTO even brings the broke tank level lower by 20% at the end of the day, which represents an improvement.

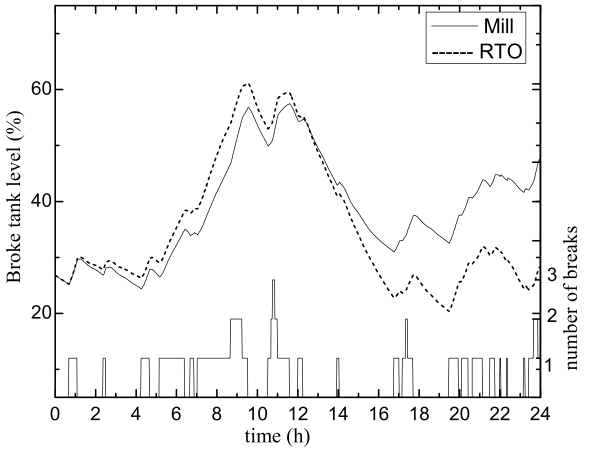

Fig. 7. Broke tank profile for manual and RTO strategies along with the number of breaks.

6. CONCLUSION

The proposed RTO strategy shows promising results for the control of stock approach systems in newsprint mills. The approach, based on the online optimization of a WinGEMS mill simulation, can bring tangible improvement in the mill performance. By keeping the headbox variability down, the probability of break occurrence of the mill operation can be lowered significantly, having a direct impact on its profitability. In future work, it is planned to refine and develop the RTO strategy to take into account the whole mill including the DIP and TMP plants.

ACKNOWLEDGEMENTS

Support for this project was provided by *NSERC* and *FQRNT*. We also thank Madhukar Gundappa, Michel Ruel (TopControl), Sylvain Gendron (Paprican) as well as Martin Fairbank and Pascal Hébert (Abitibi Consolidated).

REFERENCES

Akrour, F., A. Berton, M. Fairbank, M. Perrier and P.R. Stuart (2006). Probabilistic Index for Paper Machine Web Break Prediction due to Headbox Instabilities. *submitted to TAPPI journal.*

Bonhivers, J. C., Michel Perrier and Jean Paris (2002). Pulp properties: management of broke recirculation in an integrated paper mill. *Pulp and Paper Canada* **103**(2), 44–49.

Bonissone, P., K. Goebel and Y. Chen (2002). When will it break? A Hybrid Soft Computing Model to Predict Time-to-break Margins in Paper Machines. In: *Proceedings of SPIE 47th Annual Meeting.*

Croteau, A. P. and A. Roche (1987). Study of broke handling and white water management using a dynamic simulation. *Pulp and Paper Canada* **88**(11), 420–423.

Dabros, M., M. Perrier, F. Forbes, M. Fairbank and P.R. Stuart (2004). Improving the broke recirculation strategy in a newsprint mill. *Pulp and Paper Canada* **105**(11), 45–48.

Flisberg, P. and M. Rönnqvist (2002). Optimized control of the bleaching process at pulp mills. In: *Preprints of Control Systems.* pp. 210–214.

Forbes, J.F. and T.E. Marlin (1996). Design cost: a systematic approach to technology selection for model-based real-time optimization systems. *Computers & Chemical Engineering* **20**, 717–734.

Khanbaghi, M., R. Malhame, M. Perrier and A. Roche (1997). A statistical model of paper breaks in an integrated TMP-newsprint mill. *Journal of Pulp and Paper Science* **23**(6), 282–288.

Linstrom, R., W. H. Manfield, A. F. Tracz and J. Mardon (1994). Coping with an avalanche of breaks. *Appita Journal* **47**(2), 163–172.

Mathworks (2005). *Matlab 6.5: Optimization toolbox.*

Ogawa, S., B. Allison, G. Dumont and M. Davies (2004). Automatic control of broke storage tanks. In: *Preprints of Control Systems.* pp. 203–206.

Orccotoma, J. A., J. Paris, M. Perrier and A. Roche (1997). Dynamics of whitewater networks during web breaks. *Tappi Journal* **80**(12), 101–110.

PacSim (2005). *WinGEMS 5.3: Pulp and paper simulation software.*