Optimizing Pulpwood Inventories At Roadsides, Millyards And Concentration Yards: A Case Study

by
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Abstract

A case study is presented to illustrate how pulpwood inventory profiles and inventory costs at the mill, at the roadside, and at a concentration yard can be analysed and optimized by way of computer simulation. A model, pertinent to the operational environment of the forest products company examined, was developed to account for various inventory holding costs and shortage costs, and allowed for a realistic week-by-week simulation of the Company's wood procurement and wood consumption activities.

Résumé

A partir d'une étude de cas, on illustre la simulation possible par ordinateur pour analyser et optimiser les états et les coûts des inventaires de bois à pâte au moulin, en bordure de route et dans le parc à bois. Un modèle pertinent au secteur opérationnel de l'industrie forestière fut développé pour calculer les coûts des diverses quantités de bois gardées en inventaire et les coûts des pénuries; il fut alors appliqué à la simulation d'un programme réaliste d'achat et de consommation hebdomadaire de bois.

Introduction

The enormous investments required for building, maintaining, and operating a modern pulpmill make it almost mandatory that the mill should always work at or near productive capacity and should never run out of wood. Adequate wood procurement, however, is no mean feat in view of various uncertainty factors afflicting the daily, weekly, monthly, seasonal, and annual rates at which the available pulpwood on the stump can be logged, transported, and converted for consumptive use. To buffer against possible wood shortages, especially during spring-thaw, and to allow the logging, transportation, and conversion operations (Fig. 1) to be carried out as independent of one another as possible, it is desirable to pile up wood inventories at the roadsides, at the millyard, and — if economical — at strategically located concentration points. The need for such wood piles is therefore obvious, but their optimal size and distributions are not.

The literature contains several papers on how to determine optimal inventory profiles throughout the year, with Hewson (1960), Beckett (1966), and Hølemo (1971) taking the lead in conceptualizing the problem. Sellers (1971) and Tyre and Screpetis (1978) also wrote on this subject, and were mainly concerned with pulpwood inventory monitoring.

The systems analysis approach was taken up by Newnham (1973, 1975) who developed LOGPLAN, which appears to be a complete pulpwood inventory model useful for planning inventory process controls and logging operations by way of computer calculations. Galbraith (1977), using computer simulation, focussed attention on a realistic cost assessment of pulpwood inventory problems at the millyard.

In this paper we wish to illustrate how cost-effective inventory levels at the roadsides, millyards, and readily accessible concentration yards can be determined, using pulpwood inventory data (Erdle, 1979) derived from the 1978 pulpwood inventory of an Eastern Canadian forest products company.

As will be seen, much of the pulpwood inventory problem of the Company is seasonal due to the extent of trafficability of logging roads and the duration of imposed weight restrictions on primary and secondary public highways during spring break-up when the road supporting soils become wet and soft.

Background

The Company

The Company owns a pulpwood conversion plant which is centrally located between its two adjacent wood producing land bases totalling 1.52×10^6 ha of which 36% represent leased Crown Lands while 64% belong to private ownership. The Company has about 2 000 employees and maintains two product lines: sulphite pulp and newsprint, each manufactured at an average annual rate of 160 000 tonnes and 145 000 tonnes, respectively. Capacity mill requirements approximate $1\ 200\ 000\ m^3$ of wood per annum. The Company, at the point of enquiry, had been unable to carry out a detailed study of its wood inventory situation and was interested in the results of such an analysis.

Logging Operations

Contract loggers are employed by the Company to harvest wood on freehold and on leased Crown Lands and, in some instances, are hired to carry out harvesting operations for private woodlot owners. These contractors perform the majority (59%) of all harvesting activities, with the balance done by private woodlot owners on their own holdings (26%), and Company loggers on freehold and Crown Lands (15%).

The forests from which the Company draws its wood are characterized by small diameter trees (*Abies balsamea* [L.] Mill., and *Picea* spp.) of relatively small volume. This has led to logging operations employing either manual felling with off-road forwarding or fully mechanized systems (Koehring Shortwood Harvester, or feller buncher/processor combinations). Each type of logging delivers shortwood to the roadside. In cases where felling and off-road transport are performed by different complements of men and machines, inventories may also accrue at the stump area. In this study, such inventories (Fig. 1) are considered part of the roadside inventory.

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Fig. 1 Pulpwood inventories and the chain of wood procurement activities required for the continuous running of a typical pulpmill.

Millyard Operations

The wood delivered at the millyard is scaled by weight and is unloaded and piled (by Pettibone Cary-Lifts) onto the "permanent" woodpile and from there onto the life-deck which could receive wood at a maximal rate of 22 603 m³/week.

On-road Transportation

The on-road transportation from the roadside to the millyard is done by private contractors. The trucking fleet consists of 33 10-wheelers and 93 semi-trailers with an average load size per truck of 16 m³ and 28 m³, respectively. To capitalize on maximum hauling efficiencies, 10-wheelers are scheduled for hauling runs of less than 64 km; semi-trailer vehicles generally operate over longer hauling distances.

The company's potential capacity for hauling pulpwood on logging roads and highways is at least twice as large as the life-deck capacity of the mill at all times. The actual rate of pulpwood volume transported, however, is predominantly dependent on weather conditions, especially during the spring break-up season.

Analysis

Rate of Pulpwood Consumption

Wood procurement and conversion activities (Fig. 1) ultimately depend on the sales volume (and price) of the end product. Ideally, therefore, the analysis of the Company's wood inventory system should commence with an economic sales forecast to predict wood consumption levels for the future (Beckett *et al.*, 1966). Since sales forecasting, however, is beyond the scope of this paper, past mill average weekly consumption volumes and their standard deviations (Table 1) are used as the basis for analysis. The weekly data basis suggested by Hewson (1960) and Galbraith (1977) are chosen because a daily basis greatly increases computation time, while a monthly basis is deemed

too long to yield sufficiently accurate results.

Table 1. Weekly wood consumption (Erdle, 1979)

Week Number	Month	Average consumption (m ³ /week)	Standard deviation (m ³ /week)
1 ^b	January	17 748	a
2-14	January-April	22 603	1 860
15-16 ^c	April	7 630	2 100
17-25	May-June	22 603	1 860
26 ^b	July	8 772	a
27-35	July-August	22 603	1 860
36 ^b	September	11 832	a
37-40	September-October	22 603	1 860
41-42 ^c	October	7 630	2 100
43-50	November-December	22 603	1 860
51 ^b	December	13 668	a
52 ^b	December	13 668	a

Total annual consumption — 1 068 137 m³

^aInsufficient Company data; assumed to be zero.

^bHoliday weeks.

^cMill maintenance weeks.

The Roadside Inventory

The inventory volumes at the roadside and millyard fluctuate markedly over time and are functions of the initial inventory volumes and of the rates at which wood quantities are added to or removed from roadside storage. By knowing the volumes harvested (Table 2) and transported (Table 3) the changes in the roadside inventory level can be calculated for each period (week of year) of consideration. The resultant period-end inventory volumes become the initial volumes for the next time interval (week) and are then adjusted by adding the harvest/transport differences. Reiteration in this manner will yield the annual roadside inventory profile as a function of time.

Mathematically this can be expressed as:

$$RI_n = RI_{n-1} + VH_n - VT_n \quad [1]$$

where RI_n is the roadside inventory at the end of the n 'th week ($n = 1, 2, \dots$), VH_n is the weekly wood volume harvested and transported to roadside, and VT_n is the weekly wood volume transported away from the roadside.

Table 2. Wood harvesting data (Erdle, 1979)

Month	Harvesting rate (m ³ /week)	Standard deviation (m ³ /week)
January	13 874	1 387
February	17 308	1 731
March	15 118	1 512
April	9 925	992
May	19 327	1 933
June	26 283	2 628
July	24 780	2 478
August	27 458	2 746
September	27 758	2 776
October	26 901	2 690
November	21 275	2 128
December	15 790	1 579

Total annual harvest — 1 068 137 m³

Table 3. Weekly wood delivery (Erdle, 1979)

Season	Week	Average delivery rate (m ³ /week)	Standard deviation (m ³ /week)
Holiday	1	14 266	c
1	2-5	18 311	2 425
2	6-10	21 481	1 650
3 ^a	11-17 ^b	6 018	3 025
4	18-25	26 098	4 950
Holiday	26	21 302	c
4	27-35	26 098	4 950
Holiday	36	25 894	c
4	37-43	26 098	4 950
5	44-50	20 890	3 290
Holiday	51	9 755	c
Holiday	52	1 563	c

Total annual delivery — 1 068 137 m³

^aSpring break-up season.

^bAverage road weight restriction period; for actual durations see Figure 3.

^cInsufficient Company data; assumed to be zero.

The Millyard Inventory

The wood inventory at the millyard is regulated by the volumes of wood delivered and removed from millyard storage. The calculations for the millyard inventory level are, therefore, identical to those outlined for the roadside except that the harvesting/transport differences are replaced by the transport/consumption differences. Hence

$$MI_n = MI_{n-1} + VT_n - VC_n \quad [2]$$

where MI_n is the millyard inventory at the end of the time period n , and VC_n is the corresponding wood volume consumed.

There are two other important inventory constraints to be considered:

(1) The millyard has a limited pulpwood storage capacity of 255 000 m³. When this capacity is reached, the managers suspend the transport operations and retain all deliveries at the roadside, where for all practical purposes no storage limits exist. This constraint is incorporated in the model, by setting $VT_n = 0$ whenever $MI_n > 255\,000\text{ m}^3$.

(2) It is possible that a negative value may be calculated for the millyard inventory level. Such a value indicates that shortages have occurred, which, to a certain extent, can be remedied by hauling more wood from the roadside. To incorporate this activity into the model below, a negative millyard inventory value is set to zero, while the roadside inventory is reduced by an amount equal to that of the millyard shortage.

Wood shortages at the roadside can be eliminated by accelerating the harvesting activities or by purchasing wood

from other sources. The model handles this contingency by setting negative roadside inventory values to zero and by maintaining delivery of needed wood to the mill, while any additional costs incurred by so doing will be accounted for.

Pulpwood Inventory Cost Assessment

There are two types of inventory costs to be considered: holding costs (defined below), and shortage costs relevant when millyard and/or roadside inventories have been exhausted.

(a) Holding Costs

Unit holding costs consist of (i) interest rates foregone by freezing capital, (ii) fibre deterioration losses, and (iii) insurance premiums of wood stores against fire and other losses (Galbraith, 1977). Realistic values for these costs — as percent of the total unit value of the wood stored — are given in Table 4.

Table 4. Inventory unit holding costs

Interest rate	Fibre deterioration rate	Insurance rate
12.00 (%/yr)	0.86 (%/mo) ^a	0.79 (%/yr)
0.23 (%/wk)	0.20 (%/wk)	0.0152 (%/wk)

^aEstimated by Galbraith (1977).

(b) Shortage Costs

The Company management provided approximate premium rates which would be incurred if transportation and harvesting activities were to be accelerated to remedy possible wood shortages at the mill and at the roadside. From these premium rates it was possible to estimate that the delivery of extra wood to the mill (above the mean seasonal value) would cost (conservatively) \$5.00 per m³, while the acceleration of harvesting and off-road transportation of extra shortwood to the roadside would cost (conservatively) \$10.00 per m³.

These values, however, cannot be applied to any volume of extra wood required, since there are limits to which the increased wood producing activities can provide the needed wood at these unit costs. Wood requirements beyond these limits would necessarily be accompanied by even higher unit costs, and may lead to "non-recoverable" wood shortages, i.e. loss of sales, the cost of which must be reflected in the overall pulpwood inventory cost assessment.

To accommodate any wood shortage costs including those from loss of sales it was decided that:

(1) any weekly mill wood shortage up to 2 000 m³ could be filled at a cost of \$5.00 per m³, while shortages above this level would be charged at a maximal cost of \$90.00 per m³;

(2) any weekly roadside wood shortages less than 3 000 m³ could be remedied at a cost of \$10.00 per m³, with shortages above that limit costing \$90.00 per m³ (maximum).

(c) Other Costs

The taxes incurred on storage site land were difficult to isolate, but were estimated to represent a minor portion of the total property tax levied on the Company and where thus considered negligible. The handling expense associated with transferring the delivered wood from the millyard store to the live-deck of the pulp mill was estimated to be \$0.80 per m³, but this expense was omitted, because the total annual millyard wood handling cost was assumed to be fixed

as it would depend on the total annual rate of pulpwood consumption. This cost, therefore, is part of the fixed operating cost of the mill. Costs due to prospective sales losses incurred by a temporary but non-correctable pulpwood shortage at the mill are difficult to estimate, and are not considered.

(d) The Total Cost Equation

Each of the various costs considered must be applied to the monetary value and/or to the volume of the pulpwood inventory at any time and place. To do so it was decided to fix the price for shortwood delivered and piled at the roadside to a value of $RC = \$11.27$ per m^3 , whereas at the millyard the value of the received and piled pulpwood was set to $MC = \$17.23$ per m^3 .

Applying the unit holding costs against the pulpwood unit values, and considering any possible shortage costs one obtains the following equation for the total weekly pulpwood inventory cost T_n :

$$T_n = CRI_n + CMI_n, \quad [3]$$

where

$$= CRI_n = (RI_n \cdot RC)(i + d + p), \text{ when } RI_n \geq 0,$$

$$= \$10.00 RI_n, \quad \text{when } -3\,000 \leq RI_n \leq 0,$$

$$= \$90.00 (RI_n - 3\,000) + \$30\,000.00, \text{ when } RI_n < -3\,000,$$

and

$$CMI_n = (MI_n \cdot MC)(i + d + p), \text{ when } MI_n \geq 0,$$

$$= \$5.00 MI_n, \quad \text{when } -2\,000 \leq MI_n \leq 0,$$

$$= \$90.00 (MI_n - 2\,000) + \$10\,000.00, \text{ when } MI_n < -2\,000,$$

and i is the interest rate per week, d is the cost of fibre deterioration per week, and p is the insurance rate per week.

The annual total inventory cost T will then be given by

$$T = \sum_{n=1}^{52} T_n \cdot [4]$$

The year-after-year average total annual inventory cost $\bar{T}$ referred to below is the average of T obtained for each year of the various 100-year inventory simulation runs.

The Model

An iterative FORTRAN IV simulation model² based on Equations [1], [2] and [3] was developed to calculate the Company's average roadside and millyard inventory profiles and costs throughout the year. The flow chart of this model is given in Fig. 2. For the purpose of validation the model was run in its simplest form by using the average rates of harvesting, transportation, and consumption. To simulate the real-life situation, however, the uncertainty associated with these activities (Tables 1, 2, 3) had to be taken into account. This was done by way of Monte Carlo calculations, using computer generated random numbers, the frequency distributions of which were adjusted to match those of VH_n , VC_n , and VT_n precisely. In this way actual and realistic values for RI_n and MI_n were obtained for each week in each 100-year simulation. From each such simulation the average long term inventory profiles and costs could then be determined, and the probabilities and extent of possible wood shortages at the mill and at roadside could be assessed at the same time.

In the model we assume that VH_n , VC_n , and VT_n are not correlated with one another, to enable the Company to carry out its logging, transportation, and conversion operations as independently of one another as possible to reduce

²A copy of the computer program listings for the model can be obtained from C.H. Meng.

Fig. 2 Flowchart of the pulpwood inventory cost assessment model described in the text.

the frequency of costly, inefficient, and generally disruptive inventory control actions. Undoubtedly, this requirement will increase the size of the optimal pulpwood inventory levels, but the added size of such levels should provide a good insurance against frequently recurring inventory problems, predominantly in the form of shortages.

We wish to point out that these calculations included the simulation of the variable and uncertain onset and duration of the crucial spring break-up season, again using random numbers the frequency distributions of which matched those of the road weight restriction commencement and duration dates for the last 20 years (Fig. 3).

Fig. 3 Onset (upper) and duration (lower) histograms of the spring break-up season as observed during the last 25 years by the Company's pulpmill management.

Results

The Least Cost Inventory Base Volumes

Since the harvest, delivery and consumption activities each follow an annually recurring pattern it is reasonable to expect that the optimum inventory volumes to be established for any period (week) of the year will establish the optimum inventory profile for each and every year (Galbraith, 1977).

The beginning period of the simulated inventory year was the week associated with July 1st (termed the base week). The millyard and roadside inventory volumes present at this time of year are defined to be the base volumes.

Any week of the year could have been used for the base week, but the first week in July was selected because it falls shortly after the onset of favorable weather conditions when Company operations would be least restricted by weather, in case inventory adjustment at the roadside and at the millyard would have to be made by accelerated harvesting and/or delivery activities.

The optimal inventory profiles were determined by setting the roadside and millyard base volumes to any particular levels under study. For instance, the first simulation trial was made using the then current average inventory base volumes of the Company which at the mill and at the roadside were $MI_0 = 124\,440\text{ m}^3$ and $RI_0 = 120\,360\text{ m}^3$, respectively. Using these as input data and simulating the inventory profile for 100 years with the model above yielded an average total annual inventory cost of $\bar{T} = \$956\,000$. No wood shortages arose at roadside, while insufficient millyard inventories occurred at a rate of one week in every 50 years, always starting near the end of the spring break-up season.

Since there are two pulpwood inventories (millyard and roadside), it was necessary to hold one base volume constant while testing the effects of varying the other. Different millyard base volumes were tested first, with the base roadside volume maintained at $RI_0 = 120\,360\text{ m}^3$. Starting with a millyard inventory of $MI_0 = 20\,000\text{ m}^3$, eight 100-year simulations were made, incrementing the base volume by $20\,000\text{ m}^3$ for each consecutive run. The results are presented in Figure 4, and in Figure 5 (upper curve).

Fig. 4 Average total annual inventory costs versus the base (July 1st) millyard inventory volume when the base roadside inventory volume is set at $120\,360\text{ m}^3$. Also shown are the inventory shortage, interest, fibre loss, and insurance costs, as indicated.

The cost curves in Figure 4 reveal how total inventory cost is affected by the magnitude of storage costs and holding costs. The steeply sloping portion of the total cost curve, corresponding to low inventory base volumes, stems from the frequent occurrence of millyard wood shortages and from the high unit cost ($\$90/\text{m}^3$) assigned to such shortages. The right-hand-segment of the curve slopes less

sharply as shortages occur less frequently. In fact, for base volumes greater than $MI_0 = 125\ 000\ m^3$, no millyard shortages will occur, and the shortage costs drop to zero. Beyond this point, the total cost curve takes on a constant slope equal to the sum of the interest, fibre deterioration and insurance costs.

Figure 5 reveals that the average total annual inventory costs are minimized when the millyard base volume lies between $80\ 000$ and $120\ 000\ m^3$. To identify the least cost volume more accurately, a second simulation trial was made, setting the millyard base volume to $80\ 000\ m^3$, and making six successive tests at $5000\ m^3$ increments.

The results of these simulations are displayed in Table 5, and indicate that carrying a millyard inventory of $MI_0 = 95\ 000\ m^3$ should yield the lowest yearly inventory cost of $\bar{T} = \$905\ 000$ according to the present Company wood procurement patterns. To arrive at the overall least-cost base volumes, a second simulation series was run in which the millyard base volume was held at the least cost level of $MI_0 = 95\ 000\ m^3$, while the roadside base volume was varied. Altogether nine simulation trials were made using roadside base volumes ranging from $RI_0 = 40\ 000\ m^3$ to $120\ 000\ m^3$, by $10\ 000\ m^3$ increments.

Fig. 5 Average total annual inventory costs versus base (July 1st) inventory volumes when the base roadside inventory volume is set at $120\ 360\ m^3$ (upper curve, A) and when the millyard inventory volume is set at $95\ 000\ m^3$ (lower curve, B).

The results of these simulation runs are presented by the lower cost curve of Figure 5, which reveals that carrying a July 1st roadside inventory of $RI_0 = 90\ 000\ m^3$ yields the lowest average total annual cost of $\bar{T} = \$843\ 000$.

Table 5. Total annual inventory costs as affected by millyard base inventory volumes. The roadside base inventory is $120\ 360\ m^3$.

Millyard base inventory (000's m^3 @ July 1st)	80	85	90	100	105
Average total inventory Cost (000's dollars/year)	952	928	909	908	912

Consequently it would appear that the Company can reduce its average total annual inventory cost by approximately $\$113\ 000$ provided that the inventory base (= July 1) volumes are adjusted from their present levels to $95\ 000$ and $90\ 000\ m^3$ at the mill and at the roadsides, respectively. A further reduction in $\bar{T}$, perhaps, can be obtained by varying the base levels at the roadsides and the millyard simultaneously.

Sensitivity Analysis

The placement of a dollar value on the potential savings and specification of the least-cost inventory volumes assumes that all the unit cost factors of the model are valid. This, however, may rarely be the case. Galbraith (1977) contended that the least-cost volume was not affected by changes in holding costs. Thus, having determined the average inventory profile through simulation, it is a minor task to calculate the components of the mean annual holding costs when unit costs for insurance, fibre loss and interest need adjustment.

The effects of unit shortage cost changes on the total costs, however, could only be ascertained by further simulation runs. These runs were made by changing the unit shortage costs from $\$90$ to $\$60$ and $\$30$ per m^3 and by varying the millyard base volume while the roadside base volume was held constant at $90\ 000\ m^3$. The results are shown in Figure 6 and in Table 6. Notice that both the total annual inventory cost and the least-cost millyard base volumes are strongly affected by changing the unit shortage costs. Hence, it is important to specify accurate unit shortage costs, a task which may be difficult since sales losses and possible loss of consumer good-will are involved.

Table 6. Least-cost millyard base volumes and total annual inventory costs associated with varying unit shortage costs. The loose roadside inventory is $90\ 000\ m^3$.

Unit shortage cost (\$/ m^3)	Least cost millyard base inventory (m^3)	Total annual inventory cost (\$)
30.00	75 000	782 000
60.00	85 000	819 000
90.00	95 000	843 000

The Concentration Yard: Economic Feasibility Considered

A number of minor modifications and additions to the model above were made to evaluate the cost-effectiveness of an all-season accessible concentration yard centrally located on one of the two pulpwood land bases of the Company. The distance between the concentration yard and the mill was approximately $110\ km$. The average cost of wood delivered to the concentration yard was determined to be $\$14.87$ per m^3 . The concentration yard holding costs for interest, insurance, and fibre loss were assessed against this value which compares favourably with the value of $\$17.23$ per m^3 for the wood when piled at the mill.

Fig. 6 Average total annual inventory costs when the base (July 1st) inventory volume at the roadside is set at 90 000 m³, and the unit shortage costs (Equation [3]) are varied from \$90 (upper curve, A) to \$60 (middle curve, B) and to \$30 (lower curve, C).

Company managers felt that wood transported to the mill during the spring break-up season when the mill yard stores would be at their lowest could be delivered from the concentration yard directly to the live-deck. The extra handling cost arising from the concentration yard (\$1.18 m³) would then be partially offset by eliminating the intra-millyard transfer of wood costing \$0.80 per m³. Therefore, the net handling cost of directing the flow of wood from the concentration yard to the live-deck should be \$0.38 per m³.

The average single-trip cost between the roadsides and the mill was approximately \$4.77 per m³, while the double-leg hauling cost (roadside to concentration yard to mill) was about \$5.92 dollars per m³. Consequently, an extra transportation expense of \$1.15 per m³ was added to the \$0.38 handling cost yielding a total additional cost of \$1.53 for each unit of wood delivered to the mill from the concentration yard.

To answer the question: "Is the reduction in wood holding costs obtained by using a concentration yard sufficient to outweigh the extra handling and transportation expense?" a simulation trial was made using the following input data:

- (1) the base volumes were set to 95 000 m³ and 90 000 m³ at the millyard and roadside, respectively,
- (2) the cost parameters as outlined above were used, and
- (3) the concentration yard was to be filled to its capacity of 51 000 m³ during September and October, the "best weather" months for harvesting operations.

The results of the simulation revealed that the use of the concentration yard yielded an average total annual inventory cost of $T = \$907\ 000$. This was a \$64 000 increase over the annual cost incurred when the system was operated without this yard. Storing wood in the concentration yard represented an annual holding cost saving of \$14 000, but this benefit was outweighed by the extra transportation and holding expenses of \$78 000 per year.

Perhaps — as was suggested — substantial holding cost savings could be made by filling the concentration yard at an earlier date, thus further reducing the inventory volume at the millyard. In order to test this possibility, the model was run using July and August as fill-up period. It was found that in this manner only \$5 000 could be trimmed off the annual inventory cost, yielding an average total annual inventory cost of $T = \$902\ 000$.

Ignoring the advantages that might accrue from a reduction in the truck fleet, it is apparent that the concentration yard will produce extra inventory costs should the Company make it operational. The maintenance of concentration yard inventories, at least in this instance, does not appear to reduce inventory costs mainly because the millyard versus concentration yard unit cost differential is not large enough. Further simulation runs would show that the cost-effectiveness of the concentration yard may depend on the distance between this yard and the mill. Perhaps an optimal distance may be found for which the use of the concentration yard would become an economic feasibility. Such a possibility, however, should strongly depend on the transportation costs, which are likely to continue to increase much faster than any other inventory costs to be considered.

Conclusions

In general, the construction of a wood inventory system model is not a simple undertaking, nor is the formulation of a sound wood inventory policy. It is hoped, however, that the case study presented herein has served to elucidate the fundamental considerations required for pulpwood inventory management.

The use of a model cannot define the best inventory policy to follow, but can be helpful to analyze, interpret and predict the company's operational inventory environment and options as they may change from year to year. The value of such analytical work, however, is contingent upon the accuracy of the model and upon the flexibility, and convenience with which the model can be used.

In this study, the terms *average least-cost inventory* and *optimal inventory profiles* have been used synonymously. Optimality, within the context of a given inventory policy, however, is ultimately defined by the pulpwood shortage risk a company is willing to assume. For example, the pulpwood shortage risk at the mill drops to zero when the annual July 1st base volumes at the mill and at the roadside are set to 120 360 and 118 000 m³, respectively, every year. The additional inventory cost incurred by this "non-optimal" adjustment (equivalent to \$0.30 per m³) is an extra cost which most pulpmill managers perhaps are willing to pay to guarantee "zero shortage" year after year.

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