# INVESTMENT MODELLING IN RED PINE (*Pinus resinosa* Ait.) PLANTATIONS

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## ABSTRACT

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Key words: microcomputer-based planning model, individual investments, silvicultural treatment responses, alternative thinning regimes, stand-level growth model, physical and economic returns, preferred regimes, red pine (*Pinus resinosa* Ait.).

The objective of this study was to develop a microcomputer-based planning model for guiding individual investors in choosing between alternative forestry investments as well as other nonforestry investments in the Thunder Bay District. This model has a special focus on alternative thinning regimes in red pine plantations for these reflect stand response to changes in stand density. The model was built from stand-level growth, yield, and product models for southern Ontario. The planning model was constructed as an interactive computer program which allows inputs and thinning treatments to be entered at the terminal. The model inputs involve stand, site, and economic variables; while thinning treatments are mainly age of first thinning, thinning weight, thinning cycle, thinning intensity, thinning frequency, and rotation age. The outputs of the model are in the form of physical and economic returns as well as stand volume development over time. The model allows evaluation of 'what if' alternatives which enable physical and economic returns to be examined under varied market and environmental conditions. A lack of adequate data for model construction restricted this planning model to stands of ages 20 - 45 years, basal area of 10 $m^2$/ha and above, and site indices of 16 to 26 m. The model was tested with data from the Rockland plantation of southern Ontario and the Hogarth plantations of the Thunder Bay District. The tests for the Rockland plantation were based on mean ratios of simulated to observed total volume means and $r^2$ values. Such tests were not possible with the Hogarth plantations because there was not enough data for the tests. Instead, for the Hogarth plantations curves representing three points each for the simulated and observed basal area data were drawn for comparisons. The results with the Rockland plantation gave a mean ratio of 1.05 and $r^2$ value of 0.96. The tests with the Hogarth plantations also showed consistent results. The data used in both tests were very limited for any strong conclusion. Rigorous tests are necessary to confirm these preliminary results. The model was finally tested for physical and economic information based on alternative thinning treatments. The results of this test showed that returns from alternative thinning regimes depend on: age of first thinning; thinning weight; thinning cycle; thinning frequency; thinning intensity; and average stand diameter. Further studies on the influences of individual factors on physical and economic returns are suggested.

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# 1 INTRODUCTION

The growth of red pine (*Pinus resinosa* Ait.) natural stands and plantations has been widely studied for a wide range of site conditions and influences of silvicultural treatments in Ontario and the Lake States region of the United States (Mulloy 1943; Stiell 1953; Buckman 1962; Von Althen et al. 1978; Lundgren 1981; Beckwith et al. 1983; Berry 1984; Thrower 1986). These studies give considerable growth, yield, and site quality information. However, individuals wishing to invest in intensively managed red pine plantations do not yet have access to quantitative models for assessing such investments, in terms of patterns of wood volumes and financial criteria such as internal rates of return, net present value, and after-tax cash flow. Some research has been done in this area (Wambach and Lundgren 1965; Sutherland 1980; Beckwith et al. 1983; Lothner and Bradley 1984), but none relates periodic stand growth, as influenced by alternative silvicultural regimes, to physical volume output and financial indicators.

The basic problems facing private forestry investments in many parts of the world are a lack of clear criteria for economic evaluation (Johnson et al. 1967), and a lack of knowledge regarding the product and product-mix economics among the private investors (Fedkiw and Yoho 1960). Generally, private investors have a high time preference for the money invested in a business (Gourlay 1976); as such, they tend to avoid long-term investments by heavily discounting the invested capital (Petrini 1953). The long time periods for forestry investments and high discount rates chargeable by private investors may make forestry investments relatively unattractive to individuals. Forestry investment may be attractive to individual investors if solutions can be found to address these problems.

We know from basic silvicultural literature such as Smith (1962) that stand volume and value growth is responsive to treatments like weeding, fertilization, and thinning. The magnitude of the responses varies among treatments and depends on such factors as species, stand age, stand density, and site quality. A proper choice of site quality and the above treatments and factors can result in shorter rotations, especially if the management objective is maximum financial yield (Openshaw 1980). Shorter rotations, possible with the thinned stands on good sites, mean a shorter discounting time and perhaps a higher financial yield from the capital invested (Wambach and Lundgren 1965; Carmean 1975; Openshaw 1980).

We also know that modern wood-based industries utilize many wood sizes for production of various items (Gregory 1972). These wood sizes include for example, poles, pulpwood, sawlogs, and veneer logs. Thinnings may be used for poles and pulpwood, with the residual stems harvested later for sawlogs and veneer logs. Generally, the costs of producing the various wood products differ due to the differences in the time required to produce them and the influence of time on the value of money. For example, lower pole classes (e.g., fence poles) and pulpwood are generally low value but short rotation products; they incur less interest charges over the period of a rotation. In contrast, higher pole classes (e.g., telegraphic and power transmission poles), sawlogs, and veneer logs are high value but long rotations are needed, thus they are subject to greater interest charges. A knowledge of the economics of various wood products and the product-mix may be useful to individuals contemplating investment in intensively managed forest plantations. Such a knowledge would enable the investors to schedule their production strategies in a way that would enable them to achieve their targeted economic ends.

This study was aimed at developing a technique for identifying the existing silvicultural treatment regimes that can make forestry investments attractive to individual investors, with special reference to red pine plantations in the Thunder Bay area. Thinning treatments form the basis of this study because these can readily be reflected through changes in stand basal area, an important parameter in determining volume growth over time. Periodic basal area growth due to the various levels and timings of thinnings, for a given site quality, was chosen as a basis for the thinning study rather than height and total volume because periodic basal area is more responsive to changes in stand density (Lemmien and Rudolph 1959; Stiell 1964; Von Althen et al. 1978; Anon. 1983; Berry 1984).

The specific objectives of this study were:

(i) to develop a planning model which will guide individual investors in choosing between (a) forestry and alternative investments, and (b) among forestry investments, including silvicultural alternatives in managed red pine plantations; and

(ii) to demonstrate the usefulness of such a model through application to a specific, local plantation.

Data were collected from publications on red pine plantation management in Ontario. Where data were not available in publications, opinions were sought from experts involved in the intensive management of forest plantations.

The methodology of the study involved construction of an interactive computer-based system which evaluates any desired thinning regime in terms of management indicators such as patterns of wood volumes and costs over time, net present value (NPV), and internal rates of return (IRR). The approach followed the general technique for simulation studies. The basic data for model construction were the growth and yield models of red pine plantations (Beckwith et al. 1983), merchantable volume tables for red pine plantations (Berry 1984), and the product yield tables for alternative products: sawlog, pulpwood, and poles (Ontario Dept. of Lands and Forests 1961).

To demonstrate the usefulness of the model in a local plantation area, records of two stands of known silvicutural treatments were obtained from the Hogarth plantations in Thunder Bay ( F.R. Clarke 1986 - unpublished) . The development of these two stands up to the present were evaluated with the planning model, and five alternative management options were devised for each stand in terms of thinning regimes and consequences. Whether the chosen option will meet the predicted returns cannot be ascertained until results are obtained at clearfelling. It is at this time that the usefulness of the planning model in aiding decision-making can be corroborated. If the planning model proves feasible in the above test, then it will aid individual investors in designing and evaluating thinning regimes in red pine plantations in terms of wood volume, costs over time, NPV, and IRR.

# 2 LITERATURE REVIEW

## 2.1 PRIVATE FORESTRY INVESTMENT PROBLEMS IN ONTARIO

Private forestry investment has been encouraged by the provincial government of Ontario since the late part of the 19th century. For example, in 1883 the new Office of Clerk of Forestry was established with the primary intent of exposing and rectifying deteriorating farm and forest conditions and to demonstrate the needs and desirability of reforestation (Brodie 1967). In 1896, the Ontario Tree Planting Act provided financial incentives to improve private land by reimbursing farmers up to 25 cents for each shade tree planted along highways and property boundaries that survived for at least 3 years. In 1911, the Counties Reforestation Act, which later became the Tree Act, was passed (Stanley 1974). This Act enabled lands to be put under long-term agreement for development, protection, and management. In 1927, the Forest Act empowered the Minister of Lands and Forests to enter into agreement with other persons, firms, corporations, and municipalities on lands they held for the purpose of reforestation, developing and managing for forestry purposes. Other government efforts to promote private forestry in Ontario include the Woodland Improvement Act (WIA) of 1966, and the Managed Forest Tax Reduction Program (Sutherland 1980).

Despite these efforts, the provincial government of Ontario did not achieve what was desired. Many private forest owners showed little or no interest in tree planting partly because they believed there was no immediate financial gain in evidence (Germain 1981). This negative attitude towards forestry originated from the depression years in the 1930's and was quite pronounced in southern Ontario where the area of improved forestland was reported to have decreased at a rate of 25,000 ha/year during the two decades ending in 1961 (Love and Williams 1968).

The major problems with private land forestry in Ontario were outlined in the 1947 report of the Ontario Royal Commission on Forestry (Anon. 1948). These problems include: (1) owner's indifference and lack of knowledge; (2) high costs of fencing; (3) high land value assessment; (4) unfair drainage schemes; and (5) lack of marketing information.

Problems such as owner's indifference and lack of knowledge and marketing information have been observed elsewhere in the world (e.g., see Fedkiw and Yoho 1960; Johnson et al. 1967). As a solution, the 1947 Royal Commission made the following recommendations: (1) the province to pay 1/2 of the fencing and repair costs; (2) tax rates to be equalized; (3) tax on productive land to be decreased and tax on barren and scattered land to be increased; (4) a bonus to be paid on young forests until production stage is reached; and (5) a marketing division in the Department of Lands and Forests to be established to organize sales transactions and determine volume estimates.

## 2.2 PRIVATE WOODLAND OWNERSHIP IN ONTARIO

Surveys of private woodland ownership in Ontario (Anon. 1982) have shown that three kinds of private ownership exist. These include individual, corporate, and municipal ownership. The surveys have shown that individual owners differ in their objectives for managing the woodlands. For example, some individuals manage the woodland merely for the satisfaction of owning woodland. Perhaps the woodlands are beneficial to these owners in terms of aesthetics, woodfuel and modified local climate. These owners may have no interest at all in timber yields; such owners may have inherited their woodlands. Day (1980) observed that in southern Ontario, an increasing number of individuals purchase woodlands for recreational uses. These owners may be uninterested in the rate of tree growth on their woodland. Other owners may manage their woodlands for commercial timber production, and these owners may be interested in the average volume that the woodlands can produce on a unit area over the rotation. Alternatives which provide these owners with more volume output may be more preferred. These owners also are interested in financial yield of the investment. Therefore they may use the returns from the investment for comparison with alternative investments in decision making.

The foregoing discussion show that individual investors may be interested in financial yield, physical timber volume output, recreational values, prestige, or aesthetic values. Investors having the same investment criteria, such as financial yield, may differ in the amounts they consider satisfactory to them. This problem can further be complicated by the major factors that influence investment alternatives. Duerr et al. (1979) described these factors as: (1) magnitude of the cost-benefit flow; (2) relative timing of the costs and benefits; and (3) duration of the flow or life of the investment. People interested in physical timber volume output may differ in the amounts and timings of output they may consider desirable. These factors can influence the individuals' decision to invest in forestry.

## 2.3 THINNING IN RED PINE PLANTATIONS

### 2.3.1 The importance of thinning

Red pine occurs on a wide range of site qualities (Lundgren 1983); as such, the species is important for reforestation purposes and in increasing land productivity (Frederick and Coffman 1978).

Periodic thinning such as commercial thinnings provide an important means of regulating stand composition and development. Red pine stands according to Benzie (1977) should be thinned before they surpass the upper recommended limit of the stocking chart for the region (Figure 1). Benzie suggests leaving at least a minimum recommended stocking of quality trees after thinning; well and uniformly distributed. He cautions however that this condition is necessary but should not be attempted with a single thinning removing more than half of the basal area. This is necessary to anticipate natural catastrophies and changes in the morphological characteristics of the stand which may damage timber quality and lumber recovery (Maw 1909). According to Benzie, managing red pine stands near the minimum recommended stocking limit results in the fastest growth in diameter. However, this management option may be disadvantageous if a tree improvement program is one of the activities of forest management. This is because the smaller number of trees/ha which is possible with the minimum recommended stocking limits reduces selection possibilities for crop trees.

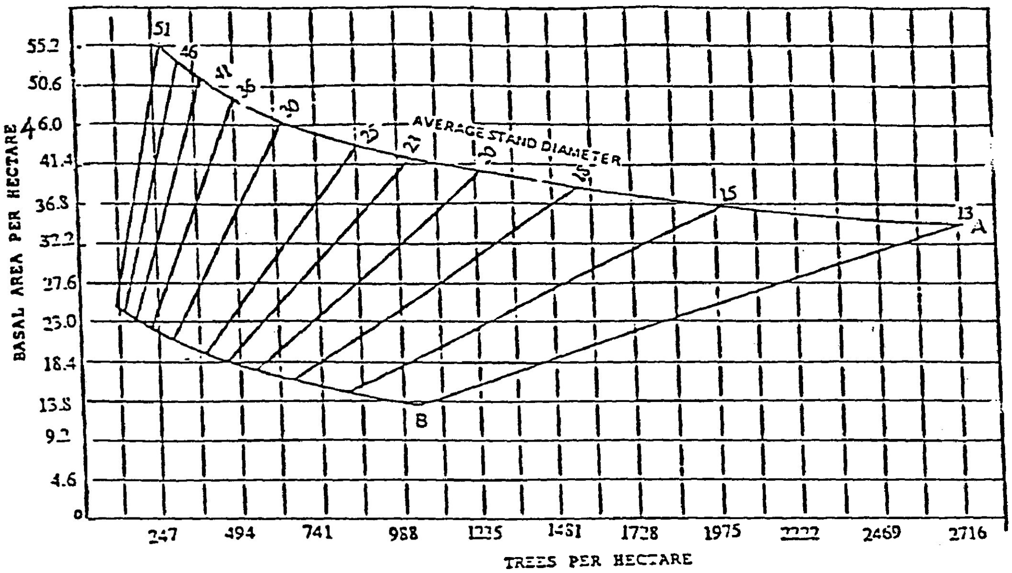


Figure 1. The stocking chart for managed red pine stands developed by Benzie (1977) from data collected by Brown and Gervorkiantz (1934), Woolsey and Chapman (1914) and Ek (1971).

Maw (1909) recommended that thinning operations be repeated every 5 to 10 years depending on the kind of crop and the density required, after the precommercial thinning. He also recommended that thinnings be conducted every 10 to 15 years in the later stage of the crop life when the main height growth has slowed. Maw stated that light-demanding and fast-growing species require more frequent thinning than shade-bearing and slow growing species. Thus red pine stands should be thinned more frequently than many other species since red pine is a fast-growing and light-demanding species. He argued that after the trees are 45 to 55 years old, thinning may not be necessary unless partial clearances are desired or natural regeneration cuttings are required.

Severe thinnings at early ages encourage the expansion of crown and growth of branches, to the detriment of the height growth, though the individual trees will increase their d.b.h. measurements to a greater extent than if the canopy is closed (Maw 1909; Benzie 1977). The authors observed that trees taper unduly if heavily thinned, especially during early ages. Maw observed that stands left unthinned too long could lose in basal area and even in height growth, for their vigour is reduced, and stands also would be liable to windthrow. Benzie suggested reducing basal area to 20.7 $m^2$/ha after thinning in a stand having an initial average d.b.h. of 12.7 - 22.8 cm and a basal area of 32.2 $m^2$/ha.

### 2.3.2 Thinning factors

Periodic thinnings can improve the quality and quantity of yield, thus can bring about considerable economic gains from forestry investments. Thinning can be a means to attract potential individual investors to forestry. Thinning treatments may be described or prescribed either qualitatively or quantitatively, although this task involves difficulties from ambiguity in forecasting stand growth response to thinning. This ambiguity stems from the fact that thinnings are characterized by a large number of factors which cannot be described adequately by the general measures favoured by foresters as indicators of growth and yield estimates. The time taken to prescribe a treatment and then to observe the treatment results, as well as the bulk of data required to analyse growth and yield due to various factors involved in thinning, have always been the major bottleneck to controlled thinning experiments (Johnson et al. 1967). This in turn has contributed to inadequate development of means by which forestry investments can be compared with alternative investments (Openshaw 1980). As such, forestry as a business has tended to remain a responsibility of governments, despite the fact that individuals could play a key role. The involvement of individual investors in forestry can supplement the government efforts in forestry undertakings. This would in turn relieve some of the government funds for other socio-economic development activities.

The individual factors in thinning treatments include: (1) type of thinning; (2) weight of thinning; (3) thinning cycle; (4) level of growing stock; and (5) thinning intensity (Smith 1962; Johnson et al. 1967). Type of thinning refers to the type of trees removed in thinning and can be determined by the size distribution of the trees relative to size of trees forming the growing stock. Thinnings which remove trees regardless of size can be described as being neutral. Random and systematic thinnings fall under neutral type of thinning. A thinning removing the smaller class of trees in preference to larger trees is termed low thinning, while a thinning which removes larger trees in preference to smaller trees is called high thinning.

This present study concerns neutral thinning, where removal of rows and or randomly selected trees is the thinning method considered. The ratio of average volume removed by thinning (v) to average volume of the growing stock before or after thinning (V) is normally employed as a measure of type of thinning. For example, a ratio of $v/V=1$ represents neutral thinning, while ratios $v/V>1$ and $v/V<1$ represent high and low thinnings, respectively (Johnson et al. 1967). In this study, type of thinning is defined by the ratios of v/V, where v=average volume/tree thinned and V=average volume/tree for the growing crop after thinning).

Weight of thinning refers to the volume removed in a single thinning. It can also refer to the severity of a series of thinnings if the weight of these series of thinnings is not the same as thinning intensity. Thinning weight can be measured in many ways but the most common methods involve volume removed in $m^3$/ha, or volume removed as a proportion of the growing stock volume before thinning (Smith 1962; Johnson et al. 1967).

Thinning cycle refers to the average interval between successive thinnings. The terms long and short cycle are normally used in quantitative descriptions of frequency of thinning, but with a particular rate of growth implied (Smith 1962; Johnson et al. 1967). The economics of forest plantations as associated with thinning cycles and related factors has not yet received much attention in the Great Lakes Forest region of Canada and the United States. The cycles are generally not adopted as the criteria of thinning in the region; instead, the criteria of thinnings are based on other factors such as level of stocking (Benzie 1977) and stand density ( Sutherland 1980; Lundgren 1981).

Level of growing stock refers to the number of trees, basal area, or volume per unit area. It is critical in thinning because a sufficient stocking level has to be maintained to occupy a site fully. A decision to do the first commercial thinning is, for example, determined by the level of the available growing stock, and by the expected economic returns. Knowledge of the stocking level at which a stand can be thinned is important because some levels can cause increases in periodic costs of managing the plantation. For example, if the stand receives a large thinning of 30 to 70 per cent of the growing stock (depending on the crop species), vegetative competition may increase making weeding indispensable before the canopy can close again. Another possible problem area is blowdown (Maw 1909; Johnson et al. 1967; Benzie 1977).

Thinning intensity refers to the average volume removed in thinning. Thinning intensity can be defined as the weight of thinning divided by the thinning cycle. Thinning intensity of a single thinning is the weight of the thinning divided by the number of years before another thinning or before the stand is clearcut. Thinning intensity is, therefore, a measure of the yield removed over a specified period of time and this period may include a series of individual thinnings the intensity of which is the total thinning yield divided by the number of years between the first and the end of the thinning cycle. Total thinning yield for a given rate of growth is inversely related to the level of the growing stock. As such, the level of remaining growing stock can be viewed as an index of cumulative thinning intensity. The level of growing stock therefore reflects the growth which the stand has made in response to thinning. This makes it a useful basis for thinning control, although it provides only an indirect basis for describing the thinning treatment itself (Johnson et al. 1967). Alternative thinning intensities enable study of the rates of growth, total volume production, and financial returns from a stand. Therefore thinning intensity can be used as an indicator for choosing the desired thinning regime. In the present study, thinning intensity is among several factors considered in establishing alternative thinning regimes.

The above factors form the basis of thinning regimes. For example, the thinning cycle together with the timing of the first thinning can be varied to result in many different regimes. If the thinning intensity (or thinning weight) is altered within the above regimes, a discernibly larger number of thinning regimes is obtained. Indeed, a large number of thinning regimes can be generated for a single stand at various ages. Realistically, the attractive investment opportunities in forestry are associated with only a small subset of these many possible regimes. Thus, to analyse exhaustively the physical and economic returns from most or all of the regimes would be desirable as a way of maximizing information. But this is a difficult task to undertake because of the general scarcity of forest stands, capital, and human resources. Growth models to analyse such varied thinning situation results can be quickly obtained using a modelling technique. Walker (1987) discussed the merits of modelling in forestry, where the major problems of management are characterized by large spatial and temporal dimensions. He argued that models allow the prediction of expected effects resulting from alternative silvicultural treatments to be readily observed. But Walker also cautioned that skill is needed to ensure that models achieve an adequate compromise among transparency, generality, accuracy, and precision. Walker concluded that if properly used, models can provide forest managers with improved silvicultural knowledge, important for controlling stand development over time.

2.3.3 Some thinning studies in the Great Lake States region of Canada and the United States

Studies related to the potential advantages of thinning in red pine plantations have been widely conducted in Ontario and the Lake States region of the United States. For example, thinning treatments in 24-year-old stands at Rockland, Ontario showed that there was a substantial increase in the current annual increment in thinned stands compared to unthinned stands (Mulloy, 1943). Current annual increments of about 4 $m^3.ha^{-1}$ were observed in thinned stands against only 2 $m^3.ha^{-1}$ in unthinned stands in the above study. This is a clear indication that thinning practices produce faster net growth of the residual crop, and that the practices can possibly be exploited to achieve higher economic returns to the private investor. Stiell (1953) observed that thinning can stimulate diameter growth and thereby shorten the time required to produce sawlogs. Among other observations that Stiell made are that thinning increased current annual volume growth, reduced volume losses from natural mortality, and that commercial thinnings realized early returns on initial investments, hence reducing the time effects of invested capital. Petrini (1953) and Fedkiw and Yoho (1960) advocated the use of early and frequent commercial thinning practices as a means of dealing with the problem of long time periods of forestry investments. They observed that intermediate financial returns can contribute substantially to the discounted cash flow making long-term projects such as forestry economically feasible to undertake.

Buckman (1962) constructed yield tables for natural red pine stands in Minnesota based on 10-year thinning schedules (cycles) in stands having permanent densities of 20.25, 27.0, and 33.75 $m^2.ha^{-1}$. He observed for stands ranging from 30 to 160 years that the maximum current annual basal area increment occurred at about 28.35 $m^2.ha^{-1}$ of basal area per hectare for site indices 14 to 18 m. This finding is supported by results obtained by Day and Rudolph (1972) with red pine plantations who found that thinning to residual basal areas of 21 to 28 $m^2.ha^{-1}$ achieved the highest yields. These results are of particular importance to private investors because equipped with the knowledge of optimum stand density, the investors have a guide to choosing thinnings for intermediate returns while at the same time maintaining maximum timber production.

Generally, good sites produce greater yields than poor sites, implying that the economic returns from managing good sites are better than from poor sites (Carmean, 1975). As an example, Wambach and Lundgren (1965) observed that thinned red pine stands of site index 15 m produced a yield of about 626 $m^3.ha^{-1}$. In contrast for site index 18 m, the yield was about 853 $m^3.ha^{-1}$. These observations agree with those from Eyre and Zehngraff (1948) and Lundgren (1984), which showed that thinning can be used to increase the yield of merchantable timber volume. Lundgren showed that in a site index stand of 18, which is the average red pine site quality in the Great Lakes Forest region of the United States, the potential mean annual increment for the unthinned stands was about 6.4 $m^3.ha^{-1}.a^{-1}$ and that thinning could raise this productivity to about 7.1 $m^3.ha^{-1}.a^{-1}$, an increase of 12 per cent. He also observed that the gain in thinning on a site index 24 m stand was about 20 per cent.

Von Althen et al. (1978) found that financial yield is generally higher with thinned than with non-thinned stands. This is because thinning can salvage natural mortality and thereby increase yield although it might not increase the total volume production of a fully stocked stand. In this latter case, thinning is important in that it concentrates produced volume of wood on a smaller number of stems reserved for quality final crop in addition to earning the investor a sound early economic return.

Sutherland (1980) studied the Hogarth plantation, a privately owned red pine plantation (site index 21 m), thinned two times at ages 27 and 35, and at thinning weights of 11.7 and 6.2 $m^2.ha^{-1}$ of basal area/ha, respectively. He found a maximum present net worth of $ 34.04 per hectare over a projected 65-year rotation at a four per cent interest rate. Further investigations need to be made using alternative thinning regimes to determine if the above value was the maximum possible return from the Hogarth plantation. The present study is explicitly aimed at providing a means for answering such important questions.

Lundgren (1981) observed that the initial number of trees per unit area had a major effect on the amount and quality of yield, and that the more trees planted per unit area the higher was the cubic volume yield. However, he also pointed out that to realize the advantage of a large number of trees per unit area, thinning should be practiced. Allison (1954) observed mean annual increments of between 6 to 8 $m^3.ha^{-1}.a^{-1}$ for red pine planted at different spacings in northern Minnesota. Allison found that denser stockings of 1250 or more trees/ha at age 50 resulted in generally higher volume production, but less dense stands produced larger trees with greater value per unit volume. These findings closely agree with results by Day and Rudolph (1966) who reported that growth in basal area and merchantable volume is related directly to the density of the residual stand after thinning. Day and Rudolph found that heavier thinning resulted in higher rates of basal area growth than light or no thinning. It should be pointed out that there is a definite lower limit on basal area per hectare below which volume production will be lost due to inadequate growing stock density (F.W. Von Althen 1987, personal comm.).

Lothner and Bradley (1984) studied the potential of red pine investments and how these should be managed to achieve the best financial performance. They observed that with current prices for sawlogs and pulpwood, forestry investors could earn real returns of 5, 6, and 7 per cent on red pine sites with site indices 18, 21, and 24 m, respectively. The management strategies for achieving these real returns involved thinning the stands to a minimum basal area of 18 $m^2.ha^{-1}$. The clearcutting ages are 65, 60, and 55 years for site indices 18, 21, and 24, respectively. The soil expectation values for these three sites at a discount rate of 4 per cent were found to be approximately US$ 662, US$ 1384, and US$ 2081 per ha respectively. These values were achieved by thinning the stand in site index 18 to a minimum basal area of 18 $m^2.ha^{-1}$ and the rest to 23 $m^2.ha^{-1}$. The clearcutting ages were fixed at 65 years for site indices 18 and 21 m and 60 years for site index 24 m. The initial stocking for both stands was 988 trees per hectare.

The results of the above study show clearly that better sites can achieve better financial yield. The effect of site quality is that the shortest rotation can be followed for site index 24, followed by site indices 21 and 18. Two questions arise in connection with the above economic analysis: (1) are the rotations on the three sites the shortest and most profitable rotations on which individual investors can base their investment decisions?; and (2) are the financial yields the best possible in the three sites for the sawlog and pulpwood products?

## 2.4 DECISION MAKING IN FORESTRY

Rykiel et al. (1984) summarized the main problems facing a forestry decision maker as being: (1) determination of what information is available for a given problem; (2) gaining access to the information; and (3) organizing the information to solve that particular problem. Callahan (1981) criticized much of the forest research work as having been devoid of application, with many publications about forests and forestry that cannot be readily applied by practicing managers. He argued that most managers of research and development have had little experience with application, even though application should be the most important objective of research and development. Callahan further argued that since management for application is essentially management for change through people and communication, the application of research and development work should be focused on extending use of technology to particular audiences or users. The present study is implicitly related to the latter application . It attempts to make the work of forestry research and development available to individual investors, through use of a model which reflects forest research findings.

Decisions can be divided into four main categories including: (1) strategic planning which is concerned with setting policies, choosing objectives, and selecting resources; (2) management control which implies decisions related to assuring effectiveness of acquisition and use of resources; (3) operational control which implies decisions concerned with the proper implementation of operations; and (4) operational performance decisions which can be described as on the job decisions, or decisions made during working time (Antony 1965). Decisions fall in a continuum of structured/unstructured decisions depending on whether or not the decision-making process can be described in detail before the decision is made. A decision may be unstructured as a result of its novelty, time constraints, lack of knowledge, large search space, and the need for nonquantifiable data (Carlson 1978). A decision is structured if rules or algorithms exist for it (Simon 1960). Gorry and Morton (1971) gave examples of unstructured decisions in strategic planning, management control, operational control, and operational performance as product planning, budget preparation, cash management, and solving a crime, respectively. They also gave examples of structured decisions as tanker fleet mix, budget analysis, accounts receivable, and payroll production.

Decision making in unstructured decisions is difficult in decreasing order from strategic planning to operational performance. This is because of the need for varying complexities of solution methods to the problems along the continuum (Simon 1960). Decision-making in unstructured strategic planning and management control is more complex due to the large amounts of information required to be processed and sieved before the final solution can be used to aid the decision-making process.

Decision making in unstructured tasks is aided by the use of computer-based systems capable of utilizing data and selecting, generating, and operating system models to develop novel solution methods. These computer-based systems are referred to as Decision Support Systems (DSS) (Keen and Wagner 1979). Forestry investment decisions are quite difficult because they involve consideration of many factors about decision-making and investments. These factors broadly involve physical, biological, economic, institutional, and technical factors (Clawson 1977; Robak 1984; Prasad 1985). Physical factors require consideration of soils, climate, and input-output relationship or productive functions which relate wood volume to factors of production such as land , labour, capital, and management. Biological factors entail consideration of complementary and competitive relationships among species, and between trees and other vegetation, insects, and diseases. Other biological considerations include energy flow and energy balance, moisture flow and balance, and nutrient cycles. Economic factors mainly concern the relationships between costs and returns, the optimum scale and the most appropriate production method, economic equity consideration, and the degree of dissociation of costs and returns (i.e. the sharing of costs and revenues among producers and consumers). Institutional or cultural factors involve consideration of peoples' view about forestry. This is important because some methods of forestry practice may offend people irrespective of their biological and economic potentialities. Technical factors consider matters of operational practicality. For example, if a certain method happens to be the most efficient or most desirable, technical considerations determine if it can actually be carried out in practice (Clawson 1977).

Looking at the above factors for consideration in forestry investment decisions, one is led to believe that the decision-making process cannot be described in detail before the decision is made. In other words, the decision is unstructured and from the nature of the problem, the decision falls under the category of strategic planning decisions.

Studies of decision making in unstructured planning like forestry investment decisions have revealed that there is a large variety of processes involved in the decision making process ( Lindblom 1959; Gorry and Morton 1971; Mintzberg et al. 1976; Carlson et al. 1977; ). Despite this, the variety of decision making processes can be illustrated by three examples of methodologies of decision making. These include: (1) the rational or economic method which regards decision making processes as attempts to maximize the expected value of a decision by determining payoffs, costs, and risks for alternatives; (2) the cost-effective method which views the decision making process as one concerned with finding first a cost-effective solution using heuristic rather than optimal search methods; and (3) the successive alternatives comparison method which describes decision making as a process of successive limited comparisons in order to reach a consensus on one alternative (Cyert and March 1963; Lindblom 1959).

Generally, decision makers have trouble describing their decision making processes. They perform three main activities while making a decision. These are: (1) intelligence or problem finding which involves such activities as comparisons of current status with goals or standards, exception reporting, and preliminary computations; (2) design which deals with activities related to development of alternatives; and (3) choice which covers activities related to evaluation and selecting from available alternatives. The three activities are normally interactive and iterative though they can be distinctively identified in decision making (Simon 1960). Carlson et al. (1977) observed that decision makers rely on conceptualizations such as graphs, tables, and pictures when making or explaining a decision. This kind of decision makers' behaviour requires them to get access to tools which can simulate desired activities and or processes helping them to conceptualize a problem. Computer-based systems have the capabilities of providing important aids such as this to decision makers. The computer-based systems, DSS, are described below.

## 2.5 DECISION SUPPORT SYSTEMS

A Decision Support Sytem (DSS) is a coherent system of computer-based technology (hardware, software, and supporting documentation) used by managers as an aid to their decision making in semi-structured decision tasks (Keen and Morton 1978).

An unstructured decision task occurs when: (1) the objectives are ambiguous and nonoperational, or objectives are operational but numerous and conflicting; (2) it is difficult to determine the cause of changes in decision outcomes and to predict the effect of decision outcomes on the action taken by the decision maker; and (3) it is uncertain what actions taken by the decision maker might affect decision outcomes (Stabell 1979). Decisions on thinning practices and investments based on alternative thinning regimes are characteristic of unstructured decision tasks.

The main purpose of DSS is in supporting managerial judgement (Keen and Morton 1978). DSS focus on the improvement of effectiveness of decision making by addressing the process of identifying appropriate action to achieve the desired goal. In essence this implies a consideration of the important criteria that influence decisions. This task requires defining and searching a decision space to ensure a realistic and appropriate goal. DSS therefore demand acquaintance of the decision makers to making responsive adjustments to changes in the environment for and within which they make decisions (Keen and Morton 1978; Wagner 1981; Bennett 1983).

Computer-based DSS can be divided into two categories, namely, data-oriented and model-oriented systems. Data-oriented systems provide functions of data retrieval, analysis, and presentation. Model-oriented systems provide accounting, simulation, or optimization models to help in decision making (Alter 1980). The problem dealt with in this study uses model-oriented systems to construct a planning model which enables simulation studies to be conducted of physical and economic returns from alternative thinning regimes in red pine plantations.

The simulation technique for unstructured decisions is adaptive to computational facilities like computers. It provides understanding of how an existing system operates under various conditions. In simulation studies, a model of the system is constructed and by simulation, the performance of the model is investigated. The results obtained are interpreted in terms of the system behaviour. The basic steps of simulation study are: definition of the problem; planning of the study; formulation of a mathematical model; construction of a computer program for the model; validation of the model; design of experiments; execution of simulation runs; and analysis of results (Gordon 1969).

A number of model-oriented computer systems have been developed for use in forest management and related disciplines in the past three decades. For example, Sassaman et al. (1969) and Gibson et al. (1971) constructed the whole forest simulation models, SORAC and FORSIM respectively. Navon (1971) and Johnson and Jones (1980) constructed mathematical optimization models Timber RAM and MUSYC, respectively. Lundgen (1981) developed a model, REDPINE, for simulating growth and yield in red pine plantations in the Lake States region of the United States based on data-oriented models of Buckman (1962) and Wambach (1967). Other models include, OPPLAN, a microcomputer model constructed by Robak (1984) for use in forest operational planning, a modified Timber RAM model (Walker and Lougheed 1985) for designing forest management strategies, and "maximum allowable depletion" (MAD), models of the behaviour of forests under certain assumed conditions, in response to alternative choices of rotation ages in Ontario (Anon. 1986).

The use of computer-based DSS has two potential benefits including: (1) reduced cost ; and (2) added value (Carlson 1978; Moore and Chang 1980). Reduced cost of data collection, computation, and data presentation in support of decision making cuts down the overall spending in decision making. Added value results from investigating more alternatives, doing more sophisticated analyses of alternatives, using better methods of comparing alternatives, and making effective decisions in time.

Decision making in timber management is largely a function of available information and how such information can be managed (Rykiel et al. 1984). For good forest management decisions to be made, qualitative and quantitative information about the forest system must be used (Hall 1981). We cannot overemphasize the need expressed by Clawson (1977), Robak (1984), and Prasad (1985) for reliable physical, biological, economic, institutional, and technical information in the process of making decisions regarding timber growing. Sound decisions in the choice of the best forest product and product mix in relation to forest site quality and other important factors cannot be overemphasized in decisions concerning investments in timber growing. It is with the computer-based DSS that a variety of information can be combined and processed to aid decision making.

The realistic approach to solving forest management problems, therefore, entails the application of decision aiding tools such as computer systems, with capabilities for evaluating, qualitatively and quantitatively, the key decisions of the management unit. These tools, known in general as decision support systems (DSS), utilize managers' data, and select, generate, and operate developed system models as a means to develop sound problem-solving methods (Rykiel et al. 1984). The DSS approach is not only appropriate for complex unstructured forest management problems. It has also been applied in such fields as agricultural economics (McGrann 1985), animal breeding (Leymaster et al. 1985), management of schools (Pohl 1979), geographic allocation of resources and people (Rolph 1979), and production and scheduling in manufacturing industries (Keen and Morton 1978).

# 3 MODEL CONSTRUCTION

## 3.1 PROBLEM DEFINITION

The discussion on problems of private forestry investment in Ontario (Anon. 1947; Anon. 1982), as well as on thinning and its merit on physical and economic returns (Mulloy 1943; Stiell 1953; Fedkiw and Yoho 1960; Buckman 1962; Johnson et al. 1967; Day and Rudolph 1972; Von Althen et al. 1978), has shown that private forestry investment is mainly hampered by the lack of adequate information on which the investors can base their decisions. Scarcity of capital resources for investment purposes necessitates a careful evaluation of competing investment alternatives between and among forestry investments.

The evaluation of forestry project opportunities over the growing period is complicated by the large spatial and temporal problems characteristic of forestry investments. For example, competitive forestry opportunities associated with alternative thinning regimes which are critical to investment decisions are usually ignored due to the above problem-scale. Despite this, an evaluation of alternative forestry opportunities is vital for investment decisions. Forestry as a business must be able to demonstrate its competitiveness to attract potential investors. This factor necessitates an alternative to the large number of actual thinning studies located in a large number of plantations at various stages of growth. The use of simulation models to generate information for use to support investment decisions offers an approach to resolving spatial and temporal dimensions in forestry.

## 3.2 MODEL CONCEPT

The decision to thin or fell a forest stand (Figure 2) can be based on the stand condition which may be affected by thinning treatments and the effects of these treatments on tree growth and on economic returns. The decision about the time and type of thinning can be aided by a forecasting system, which, in essence, presents a dynamic growth relationship embracing a wide range of stand conditions and thinning treatments.

Future growth and yield of a stand is determined by the initial condition of the stand, and the ability of the stand to respond to thinning in the form of basal area or volume growth. Decisions on thinning or felling should be based on the biological aspects such as stand density and site quality. However, the ultimate decision to thin or fell depends upon the investors' immediate objectives, e.g., wood volumes, economic returns, or any other considerations. Determination of the economic returns for each treatment requires classifying wood volume by products, and then using unit prices and production costs for each of these products to calculate economic returns. The total economic returns for a particular regime is obtained by summing up all its discounted costs and revenues. Stand development over time following alternative thinning treatments provides a means for studying wood volume production and corresponding economic returns for each regime.

Knowledge about wood volume and economic returns for various thinning regimes will aid an investor in making decision about when to thin and kind of thinning for various sites and stand conditions. The model presented in this study provides a quantitative means for comparing various thinning practices. The indicators of performace criteria used are the average stand productivity MAI, NPV, IRR, and after-tax discounted cash flow (DCF). These indicators provide sensitive means for comparing and contrasting economics of different investments such as alternative thinning regimes and stands.

Occasionally, market and environmental conditions can cause investors to alter their management practices. For example, good prices in the market may stimulate more efforts in tree improvement programs which usually result in more volume outputs. Conversely, poor prices may result in reduced management efforts that normally reduce production. A means for helping investors to

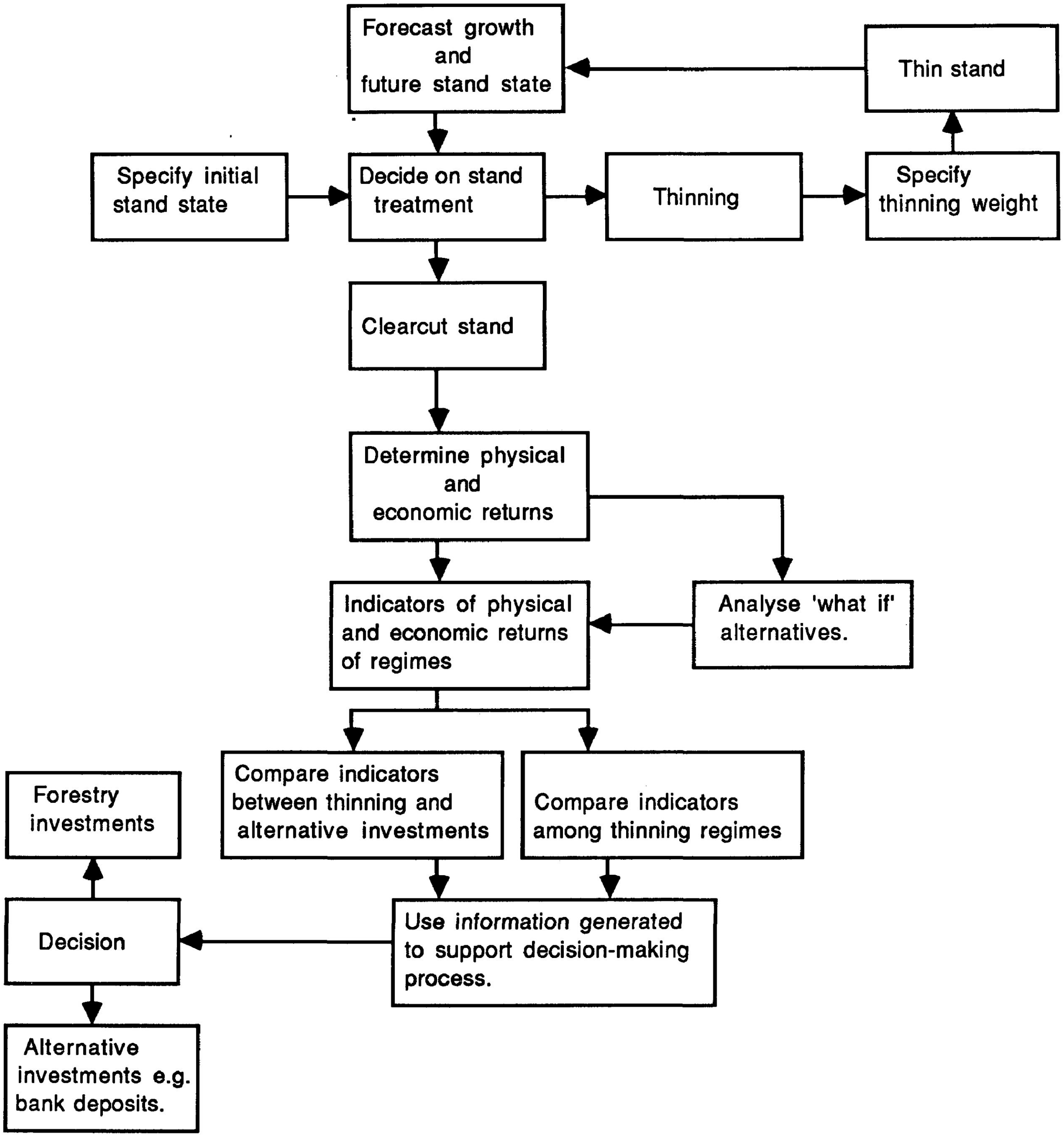


Figure 2. A conceptual view of the planning process.

decide possibilities for the future, foresee consequences, and identify, and select alternative solutions is a necessity in designing methods for evaluating forestry investments. This integral part of the decision process should be ensured by incorporating in the planning model, a mechanism which allows repeated analyses of "what if" alternatives.

The assessment of information generated and its behaviour under altered conditions in each alternate gives way to the choice of the preferred course of action. Through this information, decisions can be made between forestry and non-forestry investments, and among forestry investment options.

## 3.3 MODEL REQUIREMENTS

In order to construct the investment model with the features in Figure 2, it is necessary: (1) to specify the model's input/output information; (2) formulate a growth model typical of stand-level growth in red pine plantations responsive to silvicultural treatments; (3) formulate other models and inputs required to support the stand growth model in the construction of a computer system with the stated input/output characteristics; (4) construct a computer program which incorporates the above models and inputs; (5) use available real data to test the model; (6) design a set of typical thinning regimes for model testing; and (7) implement simulation runs using the above thinning regimes, and discuss the feasibility of the results. The inputs and outputs of the planning model of this study can be specified as shown in Figure 3.

A stand-level growth model can be classified as a dynamic responsive or predictive model. Static model characteristics can be found in many publications dealing with simulation models (e.g. Gordon 1969). Dynamic modelling (Baskerville and Kleinschmidt 1981) has a critical need for quantitative descriptions of functional relationships that are widely applicable. This ensures a wide range

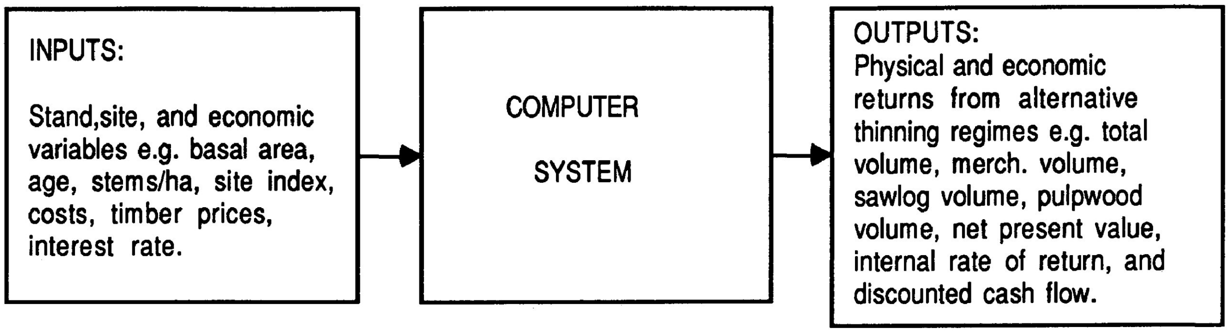


Figure 3. Input/output information of the planning model.

of application, consequently cutting down research costs. The various components of the dynamic planning model developed in this study are discussed below.

### 3.3.1 Basal area growth model

The planning model in this study used a stand-level basal area growth model developed by Beckwith et al.(1983). This model is based on 361 plot measurements from both thinned and unthinned plots. The plots were from the Bruce Peninsula to the Ottawa River in southern Ontario, and in the Kirkwood Forest of the Blind River District in central Ontario.

This growth model, which is quadratic in nature, uses present stand basal area and age, site index, and future stand age to predict future stand basal area. The model was derived by integration from an inverse basal area growth model obtained by ordinary least squares stepwise regression (Beckwith et al. 1983). The structure of this growth model is given below.

$$BF = [(BN)^2 + (72.2468(AF-AN) + 1126666.67(AF^{-3}-AN^{-3}) - 27388.0(AF^{-1}-AN^{-1}) - 0.000255\ S\ (AF^3-AN^3)]^{1/2} \qquad (3.1)$$

where:

BF = future stand basal area ($m^2.ha^{-1}$)

BN = present stand basal area ($m^2.ha^{-1}$)

AF = future stand age (a)

AN = present stand age (a)

S = site index (m).

The presence of stand and site variables in the growth model gives it flexibility of use over a wide range of red pine stands, provided the initial stand variables are known or can be determined in advance. The present stand basal area can be varied (e.g. by thinning) and then grown to another future basal area, using growth model 3.1. The newly generated future basal area can also be altered as above and the process repeated as the user may wish. The results of this process can enhance understanding of the stand dynamics under varied conditions as reflected by one or more of the model's inputs.

3.3.2 Height growth model

The height growth model used in this study was developed concurrently with model 3.1 by Beckwith et al. (1983) from the same number of plots. It was developed from a regression analysis of site quality and age. The model has an overall standard error of 0.652 m and an $r^2$ value of 0.7816 and is represented as follows:

$$H = 0.064374\ S(A/50 - (A/50)^2) + S(A/50) \quad (3.2)$$

where:

H = stand dominant height (m)

A = stand age (a)

S = site index (m at age 50)

Thrower (1986) developed height growth models on both breast height age and total age from 25 red pine plots in northern Ontario. His models are considered more precise than the conventional total age over height growth model because they are based on d.b.h. age which eliminates the influences of slow and erratic height growth before trees reach breast height. However, these models could not be used in the current study because Thrower's models require prior knowledge of breast height age which was not readily available. Presently, most published red pine growth and yield data, as well as growth models in Ontario are based on total age. Thus it was not feasible to incorporate Thrower's models in the planning model.

### 3.3.3 Gross volume model

The importance of basal area as a guide to silvicultural treatments (e.g., thinning) has been stated in Chapter 1. The outputs desired from the planning model are total volume, merchantable volume, and merchantable volume by products for assessment of physical and economic returns (Figure 3). Thus additional models which convert stand basal area and height to the above outputs are critical. The model developed by Spurr (1952) provides a means for estimating total wood volumes from the various basal areas generated using model 3.1 and height estimated by model 3.2. It is a regression model derived from data based on 393 plot measurements. This model has an overall standard error of 7.3632 $m^3.ha^{-1}$ and an $r^2$ value of 0.9957:

$$V = -6.0027 + 0.4745\ (BA \times H) \qquad (3.3)$$

where:

V = gross total underbark volume ($m^3.ha^{-1}$)

BA = stand basal area ($m^2.ha^{-1}$)

H = stand dominant height (m)

### 3.3.4 Merchantable volume factors

The gross volumes calculated from model 3.3 have to be converted to merchantable volumes since timber sales are based on merchantable volumes. The method of getting merchantable volume conversion factors at various stand ages was developed by the author using data from Berry (1984). A description of the method is given below.

The gross and merchantable volumes of yield tables for unmanaged red pine plantations (Site indices 15 - 27 m) planted at eight different espacements (1.25 - 4.00 m) were used to form a table of merchantable volume as a percentage of gross volume (Appendix 1). This table was then used to develop a model relating merchantable volume per cent (factor) to stand d.b.h. and height classes for incorporation into the computer-based planning model. The model developed is as follows:

$$M = 0.28228 + 0.30571D + 5.81205H - 0.10279H^2 \qquad (3.4)$$

where:

M = merchantable volume per cent of total volume,

D = average d.b.h. class of the stand (cm),

H = dominant height class (m).

To use model 3.4 we need to estimate the average d.b.h. of individual trees in the stand. This is accomplished by using stand basal area and number of stems/ha present at a particular time. The average d.b.h. of individual trees in the stand is then calculated from the relationship:

$$BA = 7.85 \times 10^{-5} D^2 N \qquad (3.5)$$

where:

BA = stand basal area ($m^2.ha^{-1}$)

D = average d.b.h. of individual trees in a stand (cm)

N = number of stems/ha

Rearranging model 3.5, the average d.b.h. of individual trees in the stand can be determined as follows:

$$D = [12732.4\ BA\ /\ N]^{1/2} \qquad (3.6)$$

3.3.5 Sawlog and pulpwood volume factors

One of the more important types of information needed for better economic decisions in forestry is the possibility of converting stand data (e.g. basal area, average d.b.h., and height) into usable products (Bonnor 1967). This factor is especially important where prices differ for various size classes of timber products. Two products, sawlog and pulpwood, require this kind of attention and form the main timber products considered in this study.

The classification of merchantable volume into sawlog and pulpwood volumes was accomplished using conversion factors for merchantable sawlog and pulpwood volumes which are generated by the sawlog factor models incorporated in the planning model. The author also developed conversion factors and a model for generating sawlog and pulpwood using lumber utilization data from the Ontario Department of Lands and Forests (1961). The method used to develop this model is explained below.

The lumber utilization data from the Ontario Department of Lands and Forests (Appendix 2) were used to generate sawlog volume as a percentage of total merchantable volume, for each 2.5 cm d.b.h. and 1.5 m height classes. Table 1 was derived by graphical interpolation of the sawlog factors observed for each 2.5 cm d.b.h. and 1.5 m height classes. The data were then used to develop a model of sawlog factor as a function of stand d.b.h. and height classes for incorporation into the planning model.

Table 1. Sawlog volume as a percentage of merchantable volume in red pine plantations (as derived from the Ontario Dept. of Lands and Forests (1961)

| D.B.H. CLASS (cm) (o.b.) | HEIGHT CLASS (m) 10 | 12 | 14 | 16 | 18 | 20 | 22 |
|---|---|---|---|---|---|---|---|
| | SAWLOG PER CENT | | | | | | |
| 18 | - | 41.8 | 37.8 | 37.1 | 36.0 | 36.4 | - |
| 20 | - | 64.0 | 62.8 | 61.5 | 59.0 | 61.9 | - |
| 22 | 71.8 | 75.1 | 74.3 | 75.8 | 73.6 | 76.9 | 76.8 |
| 24 | 76.6 | 80.9 | 81.6 | 83.4 | 82.0 | 85.7 | 86.6 |
| 26 | - | 85.8 | 87.3 | 87.7 | 87.4 | 90.8 | 91.2 |
| 28 | - | - | 90.4 | 91.3 | 92.1 | 93.3 | 92.4 |
| 30 | - | - | 93.4 | 92.6 | 93.7 | 94.1 | 94.8 |
| 32 | - | - | - | 94.9 | 94.9 | 95.1 | 95.9 |
| 34 | - | - | - | - | 96.3 | 95.8 | 96.8 |
| 36 | - | - | - | - | - | 96.5 | 97.6 |
| 38 | - | - | - | - | - | 98.0 | 98.4 |

The model developed which relates stand d.b.h. and height classes to sawlog factor is as follows:

$$S = -1.13513 + 4.34472D - 9.94622H + 0.71207DH - 0.0485D^2 - 0.01194\,D^2H \qquad (3.7)$$

where:

S = sawlog volume factor (%)

D = d.b.h. class of the stand (cm),

H = dominant height class (m).

It should be noted that Appendix 1 and Table 1 depend heavily on the volume table characteristics. This implies that the d.b.h. and height classes used in tables only represent values at various ages of stand development rather than stand growth itself.

### 3.3.6 Economic models

The estimation of economic returns requires inputs of economic variables such as costs, timber price, and discount rate (Figure 3). These inputs are combined with merchantable volume by products in models specific for economic evaluation, which give results in terms of NPV, IRR , and after tax cash flow. This study used NPV and IRR models adapted from Gregory (1972). The models for NPV and IRR are presented below as models (3.8) and (3.9), respectively.

$$NPV = \sum_{t=0}^{r} \frac{R_t - C_t}{(1+i)^t} \qquad (3.8)$$

where:

NPV=net present value ($/ha)

$R_t$ = revenue received at time t,

$C_t$ = cost incurred at time t,

r = rotation age,

i = discount rate,

t = 0 defines the present time.

$$\sum_{t=0}^{r} \frac{R_t - C_t}{(1+i)^t} = 0 \qquad (3.9)$$

where:

i = internal rate of return (IRR), and the other variables are as defined earlier.

### 3.3.7 Mortality

The basal area and hence volume loss due to mortality is accounted for by the basal area growth model 3.1 (Beckwith et al. 1983). However, mortality in the form of stems/ha is not accounted for in regimes involving thinnings. Despite this, it is not a serious problem with the model precision because as pointed out in Chapter 2, thinnings reduce losses due to mortality (Stiell 1964; Von Althen et al. 1978). Stiell (1964) found that a red pine stand lightly thinned 3 times at the rates of 27.6 per cent of basal area /ha at age 27, 21.8 per cent at age 40, and 26.5 per cent at age 50 experienced losses of 0.05 $m^2.ha^{-1}.a^{-1}$ from ages 27 - 50, which is an insignificant loss. This finding is consistent with observations by Smithers (1954) who found that mortality begins to be a factor in a stand when density exceeds approximately 85 per cent of the fully stocked basal area/ha for the site. In this respect, the assumption in the planning model of no mortality loss in stems/ha is acceptable. For his control stand, Stiell found a loss of 0.46 $m^2.ha^{-1}.a^{-1}$. This is a considerably large basal area loss which needs a consideration when planning investments in forestry. To increase the precision of the planning model for non-thinning regimes the stems/ha model developed by Beckwith et al. (1983) is used. This model shows a decaying number of stems/ha over time, accounting for stem mortality due to competition. Such stem losses may influence merchantable volume by products (i.e. sawlog and pulpwood) in two ways: (1) the stem losses reduce severity of competition hence result in better d.b.h. and quality wood development; (2) growth in less severe competition may achieve healthier stems with more merchantable volume than in a situation of many stems which are deformed and suppressed. The model for incorporating stem mortality in non-thinning regimes is as follows:

$$N = (41182.5219 - 5014.8230\ S + 181.5377\ S^2) \times A^{0.3574 - 0.0428\ S} \qquad (3.10)$$

where:

N=number of stems/ha

S=site index (m)

A=stand age (a)

This model enables comparisons of sawlog volume growth and yield for thinning and non-thinning regimes. It may therefore be used as a standard for comparing regimes, for better understanding of the influences of various thinning treatments.

As stated earlier, growth and yield data are all from publications dealing with southern Ontario red pine. However, the Thrower (1986) results for the 25 red pine plots from plantations in northern Ontario indicate that the local growth is similar to that of southern Ontario.

## 3.4 MODEL CONSTRUCTION

### 3.4.1 Data for model construction

As can be seen from Appendix 1 and Table 1, the d.b.h. and height data available for merchantable and sawlog volume models are quite limited in range. Generally, high site indices for red pine are reported in southern Ontario (SI 16 - 27 m) (Berry 1984), and also for the 25 red pine site plots located in Thunder Bay area (Thrower 1986). Thus the range of heights of 10 - 22 m in Table 1 indicates that the data represent only a limited part of stand life. The age range corresponding to the height class limits for Table 1 are shown in Table 2.

The height values for Appendix 1 are not a problem as they cover the rotation age of 60 years which is considered in this study. However, its d.b.h. range (8 - 36 cm) may limit evaluation of regimes beyond that range. Age limits predicted using d.b.h. are bound to vary with weight and intensity of thinning (see Chapter 4). For example, if a site index 16 m stand is assumed, using d.b.h. , the age range

Table 2. Stand age limits for model 3.7 of the planning model by range of site index.

| MIN. HEIGHT (m) | MAX. HEIGHT (m) | AGE RANGE BY SITE INDEX CLAS | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 16 | 18 | 20 | 22 | 24 | 26 | 27 |
| 10 | 22 | 30-72 | 26-63 | 24-56 | 22-50 | 20-46 | 19-42 | 18-40 |

represented by Table 1 is 32 - 60, 30 - 55, 28 - 48, or 27 - 44 years when the stand is thinned with repeated weights of 26, 31, 37, or 44 per cent of its basal area/ha. The thinning cycles considered are 5-years commencing at age 20. Thus, while the results in Table 2 could show the correct range within which the model can operate by site index classes, given the height range of 10 - 22 m, its ultimate range is tied to other factors which influence d.b.h. growth. The factors that influence d.b.h. growth are discussed in Chapter 4. Combining Table 2 with d.b.h. age range observations shown above for site index 16 m, it can be seen that the model may be useful in stands of roughly 20 - 45 years of age (i.e. in stands with a d.b.h range of 8 - 36 cm and and a height range of 7 - 31 m to satify the merchantable volume factor model, and a d.b.h. range of 18 - 38 cm and a height range of 10 - 22 m for the sawlog volume factor model ).

### 3.4.2 Model limits

The range within which the planning model operates accurately is generally set by the limits of the component models used in constructing the planning model. For example, model 3.1 for basal area growth is limited to stands of ages 0 to 65 years and site indices 16 to 26 m (Beckwith et al. 1983). The limits within which the deterministic models for merchantable and sawlog factors (models 3.4 and 3.7, respectively) operate accurately are theoretically fixed by the range of data used in their derivation. This means that the valid data ranges for d.b.h. and height classes for model 3.4 and 3.7 are 8.0 to 36.0 cm and 7.0 to 31 m, and 18.0 to 38.0 cm and 10.0 to 22.0 m, respectively. These are the data values corresponding to ages of 20 to 45 proposed above. In practice however, efforts are usually made to expand these ranges for generality of the model, with care taken not to sacrifice too much of the model's accuracy (Walker 1987). While generality and accuracy contradict each other if each one were considered on its own merit, it is possible to compromise between them in some way to achieve a more effective working plan. For example, a wider range of data than that used to develop the model can be used in planning if the accuracy of the model concerns only the most important dynamics of the stand development rather than its detailed information. Bearing this important issue in mind, the boundaries beyond the data ranges used in the construction of models 3.4 and 3.7 were investigated for possible expansion. This would enable the two models to be operated beyond their theoretical limits without serious errors in the quantities they predicted. To investigate this possibility, the outputs of the models beyond the lowest and highest scales of Appendix 1 and Table 1 were used. The values obtained when one variable (d.b.h. or height) was held constant, while the other was successively extended beyond the extreme sides of the appendix or table, were used to establish percentage deviations from the extreme values. The results from investigation of model 3.4 showed that:

(1) when height is held constant at 7 m and d.b.h. is successively reduced by 1 cm from 8 cm, the merchantable factor decreases by approximately 0.7 per cent for each cm drop in d.b.h. (Fig. 4 (a)),

(2) when d.b.h. is held constant at 8 cm and height is successively reduced by 1 m from 7.0 m, the average merchantable factor decreases by an average 9 per cent per m drop in height (Fig. 4 (b)),

(3) when height is held constant at 31 m and d.b.h. is successively increased by 1 cm from 36 cm, the merchantability factor increases by roughly 2 per cent for each cm rise in d.b.h. (Fig. 4 (c)), and

(4) when d.b.h. is held constant at 36 cm and height is successively increased by 1 m from 31 m, the merchantable factor decreases by an average of 8 per cent per m rise in height (Fig. 4 (d)).

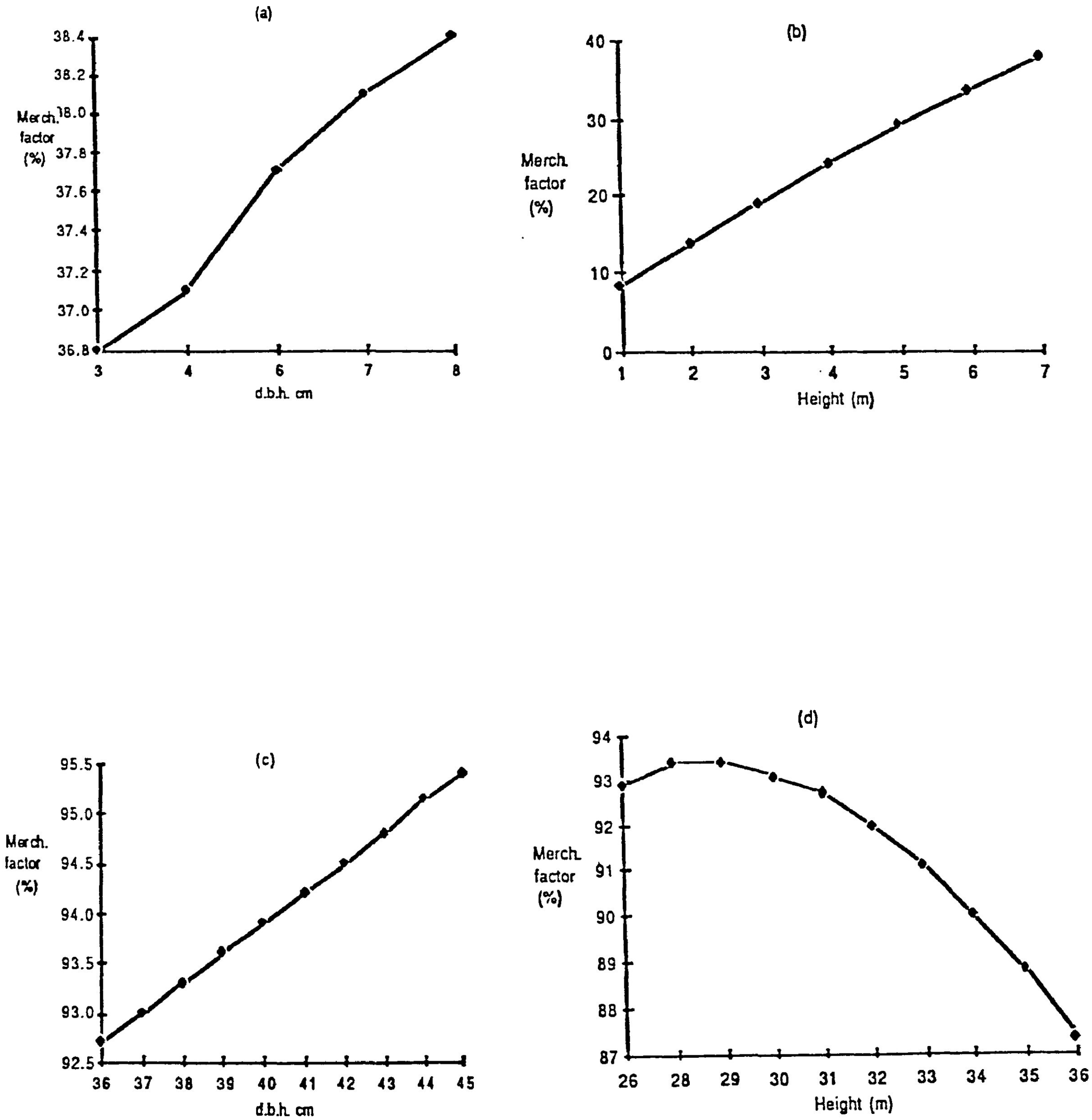


Figure 4. The effects of changing minimum and maximum d.b.h. and height on the merchantable volume factor output of the planning model.

It should be noted from Figure 4 (d) that a decline in merchantable factor due to increase in height above 31 m is more associated with the structure of the merchantable factor model than with the natural growth phenomenon. Figures 4 (a), (b), (c), and (d) show that model 3.4 can be used with data slightly greater or smaller than its current limits. The problems will be experienced if height is below 7 m while d.b.h. is held constant at 8 cm, and also when height is greater than 31 m when d.b.h. is held constant at 36 cm. The height less than 7 m while d.b.h. of 8 cm maintains may not be a serious drawback in using the model for two reasons: (1) the quantities estimated at such heights and d.b.h. are not likely to be much for at these values the stand is regarded as still too young for any economic harvests, and (2) occurrences that keep heights below 7 m while d.b.h. is 8 cm may only happen by chance, e.g., when deformed stems are encountered or the stand has been mismanaged for a long period of time. A problem occurs with heights greater than 31 m while d.b.h. maintains at 36 cm. Since increase in height above 31 m decreases merchantable factor by 8 per cent per m, extrapolation of height data should be minimized to secure model accuracy.

The results with model 3.7 show that:

(1) when height is held constant at 10 m and d.b.h. is successively decreased by 1 cm from 18 cm, the sawlog factor decreases by an average of 12 per cent per cm drop in d.b.h. (Fig. 5 (a)),

(2) when d.b.h. is held constant at 18 cm and height is successively reduced by 1 m from 10 m, the sawlog factor is decreased by an average of 2 per cent per m drop in height (Fig. 5 (b)),

(3) when height is held constant at 22 m and d.b.h. is successively increased by 1 cm from 38 cm, the sawlog factor decreases by an average of 5 per cent per cm increase in d.b.h. (Fig. 5 (c)), and

(4) when d.b.h. is held constant at 38 cm and height is successively increased by 1 m from 22 m, the sawlog factor increases by approximately 0.1 per cent per m increase in height (Fig. 5 (d)).

Again it should be noted from Figure 5(c) that the decrease in sawlog factor due to increase in d.b.h. has to do with the structure of model 3.7 rather than with the natural growth phenomenon.

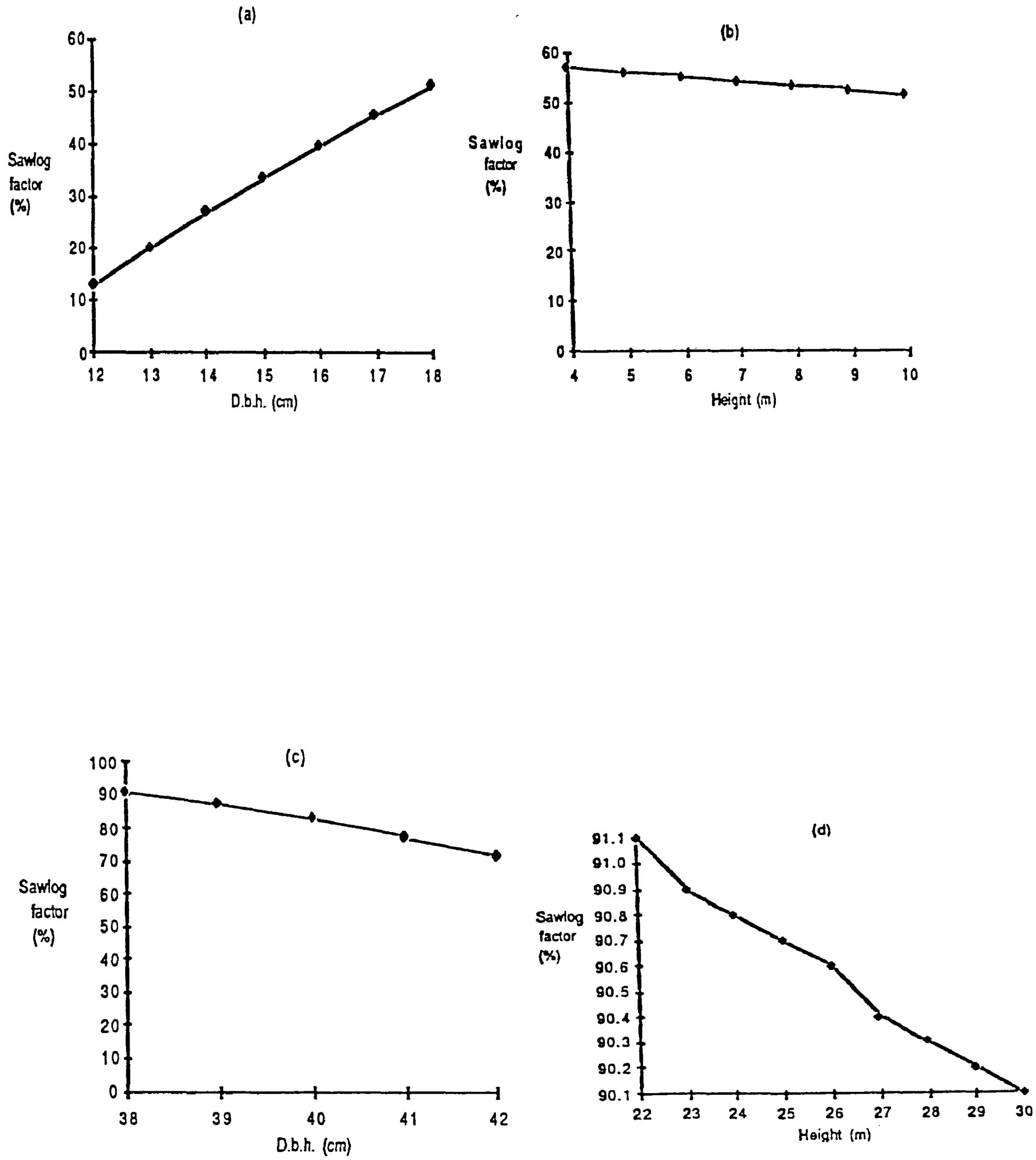


Figure 5. The effects of changing minimum and maximum d.b.h. and height on the sawlog volume factor output of the planning model. current range, although increased d.b.h. above 38 cm when height is held constant at 22 m should be limited to secure better accuracy.

Figures 5 (a), (b), (c), and (d) show that to some extent the model can employ data outside its To overcome some of the above planning model limits, the output component of the planning model was modified to some degree. Limits were set for dependent variables predictable by models 3.4 and 3.7. These are necessary to save the model from giving inconsistent values after reaching optimum points since the two models (3.4 and 3.7) are second degree polynomial models. Also data for Appendix 1 and Table 1, which were used to develop the models, might have come from the best selected trees.

Sticking to the generally higher recovery rates of Appendix 1 and Table 1 can mislead planning in the real world. For example, while Appendix 1 shows that the merchantable volume factor can reach 92 per cent at age 60, the values estimated from Plonski's (1974) yield tables show a value of 89.8 per cent for a 65-year planted stand which was moderately thinned. Table 1 shows a maximum sawlog factor of 98.4 per cent. Considering such environmental hazards as fire, acid rains, insects, and a host of other factors (Joyce and Breen 1986), such a high sawlog value will not hold in all stands. For example, attack by European pine shoot moth (*Rhyacionia buoliana*), can create a serious growth problem in red pine stands planted in poor or fair sites although generally, red pine is relatively free from principal insect and disease problems over much of its commercial range (Heikkenen and Miller 1960). Further, the chances for selecting resistant trees are small according to Holst (1960). Heikkenen and Miller suggested other pine species. If this barrier could be overcome, interspecific hybridization would provide a means for developing disease resistant traits. With these critical factors in mind, the highest value of the merchantability factor was fixed to be 90 and that of sawlog to be 95 per cent. These limits give the model some additional strengths as follows:

(1) the values predicted will never decrease after reaching the maximum level as would be the case without the limits. Instead the values at the top of the scale will continue to remain at maximum levels when growth is continued which is a phenomenon portrayed by growth under natural conditions where the stand is not injured by natural catastrophies; and (2) as long as the values are within the acceptable limits such

as the stocking chart limits, the model can be used to show the important stand dynamics under alternative thinning regimes for data values beyond the model limits. However, the accuracy of the values predicted may be suspect in this case.

## 3.5 THE PROGRAM

The preceding mathematical models formed the basis for the construction of an interactive computer program (i.e. the planning model). The program was written in Applesoft BASIC language on the Prodos system for use with Apple IIe and IIc computers (Haigh and Radford 1983). The flowchart and listing of the program are in Figure 6 and Appendix 3, respectively. To give the readers some ideas of how the program works, a short description of the flowchart is given below.

### 3.5.1 How to start

To start the program, a program disk is put in drive one (1) and the computer power turned on. A menu of programs will appear, and the computer will prompt the user to select one of the options. The user should select B for BASIC first. Then he should type LOAD RESPIN (i.e. *Pinus resinosa*) and then (RETURN) followed by a RUN command and (RETURN) too.

### 3.5.2 Inputs of stand, site, and economic variables

When the program is set to run, it prompts entery of present basal area, present stand age, number of stems/ha, site index, establishment costs, annual management costs, thinning cocts, felling costs, sawlog price, pulpwood price, and a discount rate.

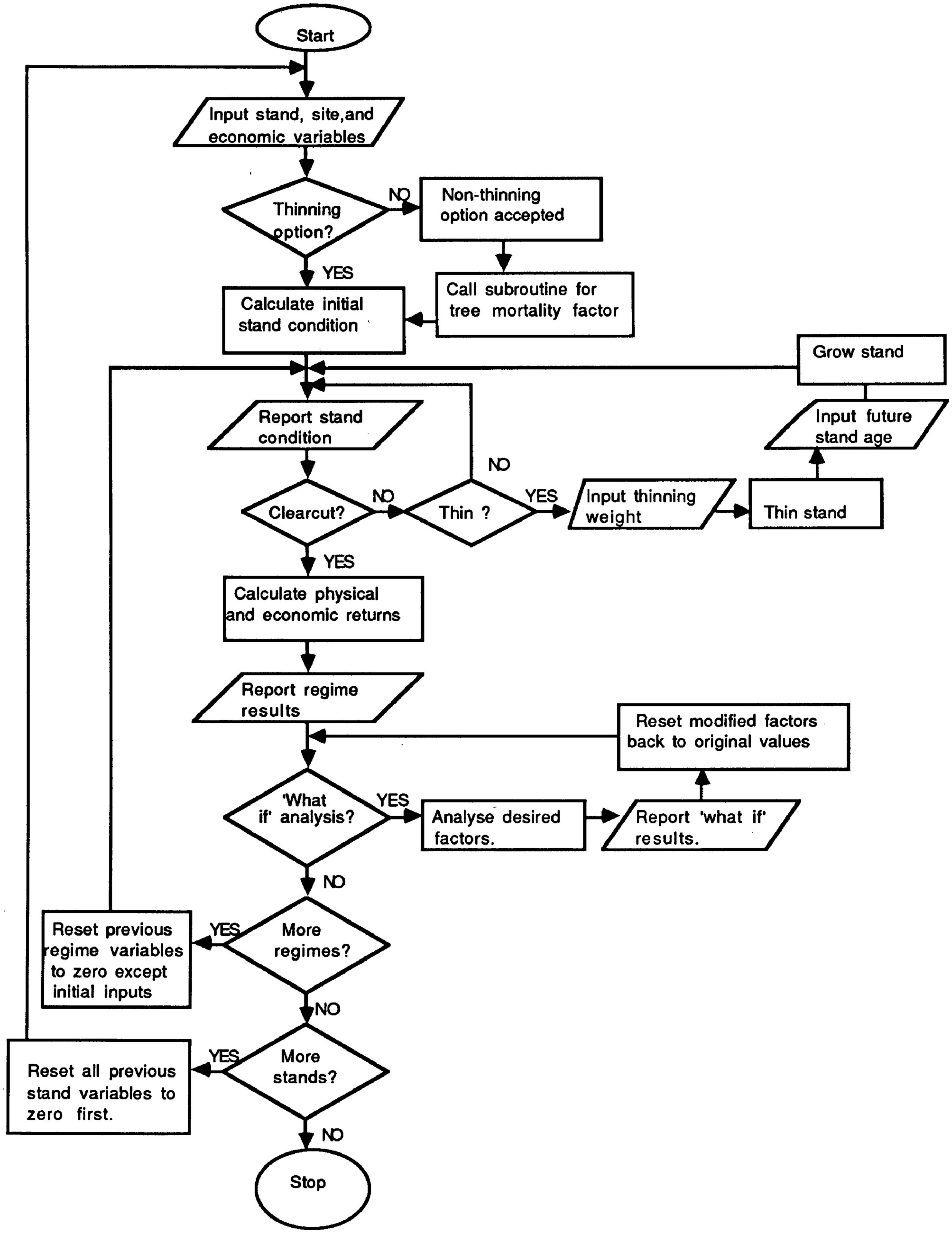


Figure 6. Flowchart of the computer program.

### 3.5.3 Choice of option

Two options are provided (1) thinning and (2) non-thinning options. The thinning option uses number of stems/ha entered at the terminal to estimate present and future merchantable and sawlog volumes. The non-thinning option uses stems/ha generated by stem model (3.10) which is incorporated into the program. This model estimates the number of stems/ha in a fully stocked stand, at any point in time. It therefore provides a means for comparing merchantable volume by products and financial yield for thinning and non-thinning regimes. It should be noted that once an option is chosen (option 1 for thinning, or option 2 for non-thinning regimes) there is no easy way of shifting directly to the other option. In this respect, the program has to be run down to "More stands? ", where new data can be entered for evaluation of the option.

### 3.5.4 Calculation of initial stand condition

The initial stand condition is calculated by the initialization routine which sets future stand age at zero.

### 3.5.5 Report of stand condition

After the initialization process, a report is displayed of stand age, basal area, number of stems/ha, gross volume, merchantable volume, sawlog volume, pulpwood volume, merchantable volume per cent, sawlog per cent, and pulpwood per cent.

### 3.5.6 Decision on stand treatment

The reported stand condition above equips the user with a quantitative means on which to base the decision on whether to clearcut (fell) , thin, or do nothing to the stand. The program prompts clearcutting first. If the user decides against clearcutting, the program prompts thinning. If thinning decision is made, the program prompts thinning weight in per cent of the basal area growing stock. The stand is then thinned according to the specified thinning weight.

The thinning operation is followed immediately by adjustments of stand variables and then growth is simulated at the desired future stand age. The adjusted stand variables include present basal area, present stand age, and number of stems/ha. The future stand condition is obtained by simulating growth to the chosen new future stand age prompted by the program. In this way, thinning treatments can be repeated a number of times before final felling. In the event of simultaneous decisions against both clearcutting and thinning, the program re-prompts clearcutting for at least one of the two treatments has to be accepted for the program to continue. Clearcutting treatment marks the end of a regime. When a clearcutting decision is made, the program calls subroutines for calculating stand volume yield over time and economic returns.

It should be pointed out that this model has been designed specifically for evaluation of alternative thinning regimes involving neutral thinning types. Further, the model has been designed to start its first thinning at the time of initial stand assessment. Any attempt to skip this initial thinning will cause errors in financial yield estimation at rotation age. Thus, if this thinning is not desirable for reasons of say small basal area/ha, the stand must be thinned by a ZERO per cent of basal area/ha before the growth period is extended to the future.

### 3.5.7 Report of the thinning regime results

The physical and economic results of each regime are summarized on the screen or printed out in three tables (Appendix 4). The first table shows simulated stand volume growth and yield by one-year intervals. The table shows stand age, gross volume, merchantable volume , sawlog volume, pulpwood volume, and thinned volume for the specified site index and rotation age. The second table shows the harvesting schedule. This includes thinned and felled volumes for each thinning regime by age. The total harvested volume, merchantable volume, average stand productivity (M.A.I.), sawlog volume and pulpwood volume for each regime are shown after this table. The third table shows discounted cash flow over time. It presents discounted costs and revenues for each thinning and for clearcutting and other periodic costs, for a given regime. The NPV and IRR for the regime are given after the table. Finally, the costs and revenues assumed for the thinning regime are displayed.

### 3.5.8 Analyses of 'what if' options

After the above report, the program provides a menu for assessing economic returns under varied conditions of growth and economy (i.e. sawlog volume, sawlog price, establishment costs, thinning costs, clearcutting costs, annual management costs, and capital costs). Each factor can be tested at any desired level. After the analysis of a selected factor, the program returns the user to the menu for further further analyses. This option gives the program considerable flexibility necessary for predicting returns both under risky and opportune conditions.

### 3.5.9 Decision on further action

The program prompts other regimes and then other stands before stopping down. If the user decides on more regimes, the initial stand condition is reported as before (see sect. 3.4.5). The program prompts entry of treatments to give the stand to start a new regime. This cycle is repeatable as long as the stand state allows. It should be noted that when stand basal area is too small (e.g. $< 10\ m^2/ha$), the program ceases to work for any thinning weight, showing illegal quantity error message on the screen or printout. This can be explained by the structural characteristics of models 3.1, 3.2, and 3.3.

The decision against other regimes causes the program to prompt other stands. If other stands is accepted, the program rprompts entry of new stand, site, and economic variables for the initialization process. The study of other stands provides a means for evaluating stands situated on different site qualities. The study thus provides a quantitative means for assessing the merits of the choice of sites on which to invest in timber production. The program stops when the user rejects the prompt on other stands. A printout of a sample program RUN is provided in Appendix 4.

# 4 MODEL TESTING

## 4.1 INTRODUCTION

The planning model was first tested with data used in the formation of its various components. This was necessary to establish whether the model components could reasonably simulate the conditions used to develop them (Leary et al. 1979). The model then was tested for reliability using independent data sets. The purpose of these tests was to establish whether the model could be used in aiding decisions on red pine investments in other areas of the province. The above two tests were based on the mean ratios and $r^2$ values of observed and predicted values. The model was further tested for physical and economic information using different thinning treatments. This latter test examined cubic volume, NPV, and IRR under varied thinning conditions. Finally, sensitivity analyses were performed to demonstrate the importance of knowledge of sawlog/pulpwood products, future product prices, and changes in discount rates to investment rankings.

## 4.2 MODEL TESTING WITH ORIGINAL DATA

The gross volume for a site index 16 stand in Appendix 5 was tested against the simulated volume predicted by the planning model. The appendix was chosen because the data used to develop this appendix, and model 3.1 which predicts basal area growth in the planning model, have a common origin. The merchantable and sawlog volume factors predicted by the planning model were tested against Appendix 1 and Table 1. Appendix 1 and Table 1 are the values that were used respectively in the derivation of merchantable and sawlog factor models incorporated in the planning model. In the tests, original data are constantly referred to as observed data while simulated data are referred to as predicted data. The results of the mean ratio tests and $r^2$ values are presented in Tables 3 and 4. The results in Table 3 show that the observed and predicted means for gross volume, merchantable, and sawlog volume factors are closely related. Simple regression equations for the observed and predicted values of gross volume, merchantable, and sawlog volume factors (Table 4) show strong linear relationships in that at least 94 per cent of the variabilities in predicted values are explained by the linear relationships with the observed values, as indicated by $r^2$ values.

Table 3. Mean ratios for observed and predicted means of gross volume, merchantable, and sawlog volume factors.

| VARIABLE | PREDICTED MEAN (PM) | OBSERVED MEAN (OM) | PM / OM |
|---|---|---|---|
| GROSS VOLUME | 250.49 | 243.88 | 1.03 |
| MERCH. VOL. FACTOR | 77.14 | 77.18 | 0.99 |
| SAWLOG VOL.FACT | 80.98 | 81.89 | 0.99 |

Table 4. Simple regression equations for observed and predicted values of gross volume, merchantable, and sawlog volume factors.

| VARIABLE | REGRESSION EQUATION | $r^2$ |
|---|---|---|
| GROSS VOLUME ($m^3$/ha) | PR = - 1.92 + 1.03 (OB) | 0.99 |
| MERCH. FACTOR (%) | PR = -7.76 + 1.10 (OB) | 0.95 |
| SAWLOG FACTOR (%) | PR = 2.44 + 0.96 (OB) | 0.94 |

where: PR =predicted value, OB =observed value.

## 4.3 MODEL TESTING WITH INDEPENDENT DATA

The independent data for gross volume testing was obtained from two sources: (1) the Rockland plantations (Von Althen et al. 1978) and (2) the Hogarth plantations.

### 4.3.1 Data from the Rockland plantation

Only total volume data were available for this test. Data for merchantable and sawlog volume factors could not be used for the test because a different type of thinning (low thinning) was used in that stand. The test with total volume data gave a mean predicted to observed ratio of 1.05 (i.e. 460.5/438.1 $m^3$/ha). A simple regression equation of predicted versus observed volume showed a strong linear relationship, with an $r^2$ value of 0.96. The simple regression equation is as follows:

$$\text{Predicted volume} = 30.24 + 0.96\ (\text{Observed volume}). \qquad (4.1)$$

The results (mean predicted to observed ratio and $r^2$ value) show that the planning model can provide a fair prediction of volume growth and yield for the Rockland plantations. However, more rigorous testing with data from a much wider geographic horizon is necessary to confirm this observation.

### 4.3.2 Data from the Hogarth plantations

Data from stands 3 and 4 of the Hogarth plantations (see map in Appendix 6) provided the second set of independent data for model testing. The previous treatments given to the two stands and their status as of October 1986 are summarized in Table 5.

It should be noted that the two stands were thinned twice in 1977 and 1985. The 1977 thinning was a neutral type of thinning which removed every third row in the two stands. The 1985 thinning was a crown thinning which removed the inferior codominants in the stands. The merchantable volume and merchantable volume by product were not available for the test. The available data records (total volume and basal area) were so few thus mean ratios and $r^2$ values could not be estimated as for the Rockland plantation. Basal area data were chosen for the test for they provided more replications (3 cases) as compared to gross volume (2 cases). The results of the test are shown graphically in Figures 7 and 8.

Table 5. The previous treatments and status of stands 3 and 4 (SI 21 m) of the Hogarth plantations as of October 1986.

| STAND NO. | Y.P. | AREA ha | IN. ST. stems/ha | BA(B.T) 1977 $m^2$/ha | BA(T) 1977 $m^2$/ha | BA(B.T.) 1985 $m^2$/ha | BA(T) 1985 $m^2$/ha | BA (1986) $m^2$/ha |
|---|---|---|---|---|---|---|---|---|
| | | | | OBSERVED VALUES | | | | |
| 3 | 1952 | 1.1 | 1289 | 37.3 | 12.4 | 29.7 | 9.9 | 24.6 |
| 4 | 1950 | 3.1 | 1604 | 39.6 | 13.2 | 32.4 | 10.7 | 26.8 |
| | | | | GROSS VOLUME ($m^3$/ha) | | | | |
| 3 | | | | 185.1 | | 194.4 | | |
| 4 | | | | 214.2 | | 224.8 | | |
| | | | | PREDICTED VALUES | | | | |
| | | | | BA(B.T.) 1977 | BA(T) 1977 | BA(B.T.) 1985 | BA(T) 1985) | BA(1986 |
| 3 | | | | 37.3 | 12.4 | 36.2 | 9.9 | 25.6 |
| 4 | | | | 39.6 | 13.2 | 36.7 | 10.7 | 25.9 |
| | | | | GROSS VOLUME ($m^2$/ha) | | | | |
| 3 | | | | 186.9 | | 237.5 | | |
| 4 | | | | 214.1 | | 255.4 | | |

where: Y.P=year planted, IN.ST=initial stocking, BA(B.T.)=basal area before thinning($m^2$/ha), BA(T)=basal area thinned ($m^2$/ha)

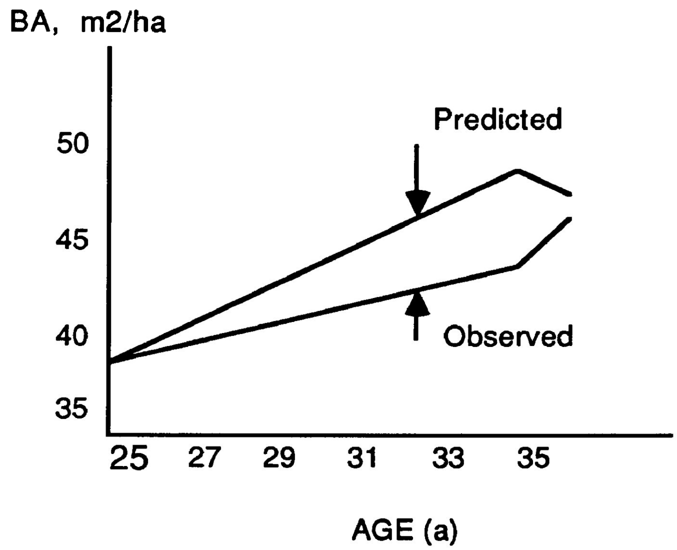


Figure 7. Comparisons of observed and predicted basal area growth and yield for stand 3 of the Hogarth plantations (1977-1986).

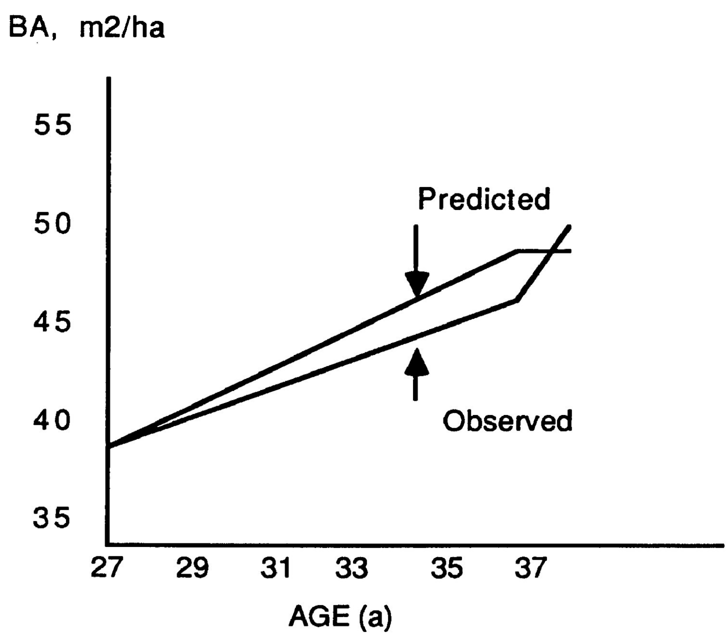


Figure 8. Comparisons of observed and predicted basal area growth and yield for stand 4 of the Hogarth plantations (1977-1986).

The results (Figures 7 and 8) show close relationships between values observed in the field and those predicted using the planning model. The predicted values first rise slightly above the actual stand values and then gently drop tending to agree closely with actual values. It should be noted that Hogarth's stands 3 and 4 had very low initial stocking that might have caused very fast basal area growth until competition started to take place. This should explain the reason for the abnormal growth predicted by the planning model in Figures 7 and 8 above. However, the number of replications is too small to allow any strong conclusions about the behaviour of the model for stand growth under alternative thinning regimes in Thunder Bay. Large volumes of data of basal area (density) by age and site index classes, collected from wide geographic ranges within the Thunder Bay district, are necessary for better tests. These data may also be collected by levels of site index to provide testing for a range of site quality: good, medium, and poor. The simulated gross volume yield for unthinned stands 3 and 4 of the Hogarth plantations using (1) the planning model and (2) Buckman's (1962) equation were compared with normal volume yield of site index 22 m of Beckwith et al. (1983) (Appendix 5), and site index 22 m (control stand) of Von Althen et al. (1978). The results of the comparisons are shown in Figure 9.

The results (Figure 9) show that the Hogarth's stands 3 and 4 volume yields estimated with the planning model compare fairly well with published data of site index 22 m of Beckwith et al. (1983). However, the values of the stands estimated with the use of Buckman's equation do not compare well with Beckwith et al. (1983). Also the data from the control stand, site index 22 m, of Von Althen et al. (1978) do not compare well with the simulated Hogarth plantations using the planning model. However, the data of the control stand tend to agree closely with those of the Hogarth plantations estimated using Buckman's equation. The possible reason for this close agreement is perhaps the large number of stems per hectare and the high mortality rate recorded with the control stand. Buckman's equation which was developed from natural red pine stands with usually large numbers of stems/ha tends to agree with the control stand. Hogarth stands are discussed further in Chapter 5.

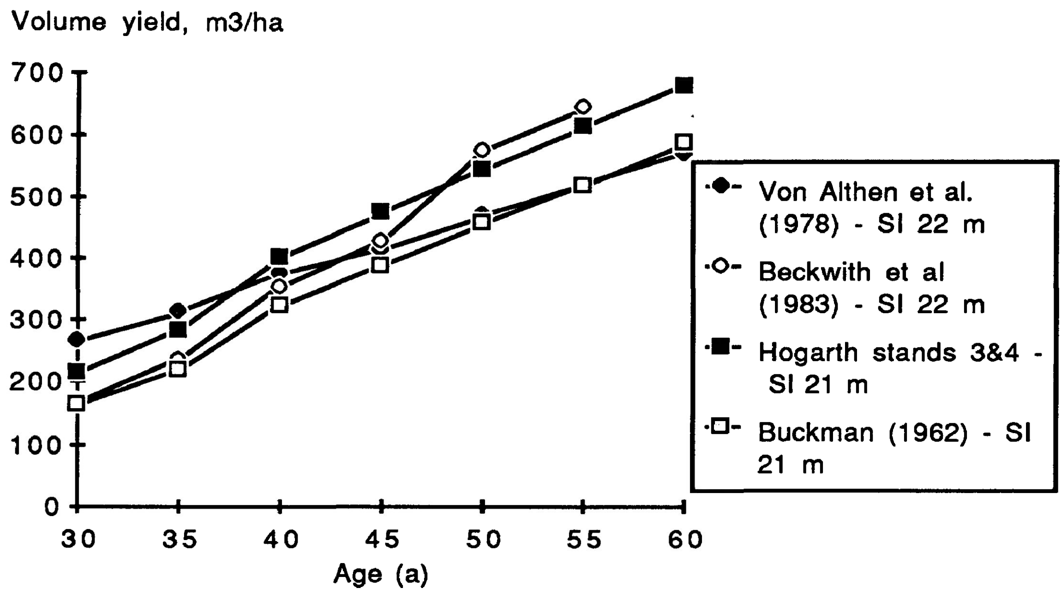


Figure 9. Comparisons of the simulated Hogarth plantations volume yield data using the planning model and Buckman's (1962) equation with Von Althen et al. (1978) and Beckwith et al. (1983).

## 4.4 EFFECTS OF DIFFERENT THINNING TREATMENTS ON PHYSICAL AND ECONOMIC RETURNS

### 4.4.1 Data

A test of the model for volume and financial yield information using alternative thinning regimes required using hypothetical stand, cost, and financial data. The hypothetical stand used was a site index 16 m stand of basal area 20 $m^2$/ha, age 20 years, and 2750 stems/ha. This stand was approximated from published yield tables by Beckwith et al. (1983) to avoid too much deviation from the real world.

Costs and financial data applied for various operations and products, respectively, were approximated from published sources and / or obtained from reliable sources (e.g., Sutherland 1980; Baskerville 1986). These data included: (1) establishment cost of $200/ha; (2) management costs of $20.ha$^{-1}$.a$^{-1}$; (3) thinning costs of $10/m$^3$; (4) felling costs of $10/m$^3$; (5) sawlog price of $ 34.50/m$^3$*; (6) pulpwood price of $ 21.75/m$^3$**; and (7) a discount rate of 4 per cent. A rotation age of 60 years was used for all the tests. Since individual characteristics of each of the factors characterizing the thinning regimes can be of help in understanding the behaviour of alternative thinning regimes, efforts were made to get separate information on how each factor influences the outputs.

The value of land was not incorporated in the estimation of financial yield because there is no one method of treating land value that has been unanimously accepted by forest economists (Openshaw 1980). As such, an assumption was made that land is sold upon felling the stand at a value equal to that used to acquire it at the onset of stand establishment, in real terms. The same data were used for sensitivity analyses shown at the end of this chapter. The tests together with their findings are described below.

### 4.4.2 Type of thinning

Only one type of thinning (neutral) is usable in the planning model, hence no individual tests were made in regard to the type of thinning. Despite this, there is a convincing argument that different types of thinning have different effects on the growth rate of the residual crop. For example, results for Sitka spruce (Johnson et al. 1967) shows that low thinning (v/V<1) results in faster growth of the

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* Telephone conversation, purchasing department, Port Arthur Lumber and Planing Mill Ltd.

** Telephone conversation, purchasing department, Great Lakes Forest Products Ltd.

residual crop after thinning. Neutral thinning (v/V=1) is intermediate in growth, while high thinning (v/V>1) has the least growth. A biological explanation for this kind of stand behaviour is that low thinning removes suppressed and intermediate trees making available more growing space to vigorously growing trees, while neutral thinning removes rows and or individual trees indiscriminately providing more growing space for a mixture of suppressed, intermediate, and vigorously growing dominant and codominant trees. High thinning has the least growth because it removes vigorously growing larger trees (dominants and codominants) leaving slower growing trees (generally lower crown class intermediate and suppressed trees) whose vigour may have been lost through competition and suppression.

4.4.3 Timing of thinning and thinning weight

The age of the stand at first thinning and subsequent thinnings can be important in the management of red pine plantations. This is believed to be so because delayed thinnings, for example, may have little or no effects on future development of the stand (Maw 1909). Such thinnings normally reduce growing stock levels. Although these reduced levels of growing stock may produce quality sawlogs, the sawlog values may sometimes fail to compensate for the economic losses due to volume production losses (Benzie 1977). This factor may further depend on the age and intensity of thinning.

The incomes realized from delayed thinnings incur such heavy interest charges that their contribution to the economic returns may not be significant (Carmean 1975; Duerr et al. 1979). Such thinnings may further necessitate stand release, for example, from hardwood species that may invade open canopy stands. Silvicultural activities like these may diminish the economic returns of a stand. Age should be reflected in the resulting volumes of various wood products, and this may have different consequences in the profitability of the stand. Three tests were made in this respect: (1) the effects of age of first thinning alone; and (2) the influence of thinning cycles and their timing, and (3) the influence of number (frequency) of thinnings on physical and economic returns. The three tests are introduced briefly before their results.

4.4.3.1 Age of first thinning

Four different ages of first thinning (20, 25, 30, and 35 years) were tested with three thinning weights (12.5, 25, and 33.3 per cent of basal area/ha). The test involved a single thinning followed by felling at the rotation age earlier stated. The results of this test are shown in Table 6.

The table shows that there are growth and yield differences between stands receiving equal thinning treatments begun at different ages. The table also shows that these growth and yield differences vary between thinning weights. Specifically, the results show that: (1) average stand basal area/ha, and hence d.b.h. of the growing stock after thinning, decreases with delayed thinnings; (2) heavier removals of basal area/ha reduce the level of growing stock after thinning but increase the average d.b.h. of individual trees; (3) gross volume, merchantable volume, and sawlog volume recovered from the alternative thinning regimes indicate better volumes with earlier rather than with delayed thinnings; consequently, the financial yields are better with earlier than with delayed thinnings; (4) thinning the stand by a 12.5 per cent of basal area/ha show slightly better merchantable volume recovery than the 25 and 33.3 per cent weights. However, 33.3 per cent weights offer bigger sawlog volumes than either of the other two.

4.4.3.2 Thinning cycle and thinning weight

Four thinning cycles of 5, 10, 15, and 20 years were tested with four ages of first thinning of 20, 25, 30, and 35 years. To facilitate comparisons of returns from different thinning cycles begun at the same stand ages, the 5-year cycle was repeated at ages 25, 30, and 35 while the 10-year cycle was repeated at ages 30 and 35. The 15 year cycle was repeated at age 35. A constant thinning intensity of 1.4 $m^2.ha^{-1}.a^{-1}$ was maintained. The results of the test are presented in Table 7.

Table 6. Effects of age of first thinning on wood volume and financial yield of a hypothetical red pine stand (SI 16 m).[1]

| HARVEST TYPE | TH | FE | TH | FE | TH | FE | TH | FE |
|---|---|---|---|---|---|---|---|---|
| AGE (a) | 20 | 60 | 25 | 60 | 30 | 60 | 35 | 60 |
| HEIGHT (m) | 6.6 | 18.9 | 8.2 | 18.9 | 9.8 | 18.9 | 11.4 | 18.9 |
| BA (B.T) ($m^2$/ha) | 20.0 | | 30.6 | | 37.4 | | 42.6 | |
| DBH (B.T.) (cm) | 9.6 | | 11.9 | | 13.2 | | 14.0 | |

| TR.NO | T.W. (%BA) | TH 20 / FE 60 | TH 25 / FE 60 | TH 30 / FE 60 | TH 35 / FE 60 |
|---|---|---|---|---|---|
| | | STAND BASAL AREA AT FE- ($m^2$/ha) | | | |
| 1 | 12.5 | 55.9 | 54.8 | 53.7 | 52.8 |
| 2 | 25 | 55.2 | 53.0 | 51.0 | 49.2 |
| 3 | 33.3 | 54.7 | 51.9 | 49.4 | 47.0 |
| | | STAND D.B.H. AT FELLING AGE- (cm) | | | |
| 1 | | 17.2 | 17.0 | 16.8 | 16.7 |
| 2 | | 18.4 | 18.1 | 17.7 | 17.4 |
| 3 | | 19.5 | 18.9 | 18.5 | 18.0 |
| | | GROSS VOLUME (TH.+FE) - ($m^3$/ha) | | | |
| 1 | | 498.5 | 495.5 | 493.3 | 492.1 |
| 2 | | 499.9 | 494.6 | 490.7 | 488.5 |
| 3 | | 501.2 | 495.1 | 490.5 | 487.7 |
| | | MERCHANTABLE VOLUME (TH.+FE)- ($m^3$/ha) | | | |
| 1 | | 391.9 | 387.0 | 383.8 | 382.1 |
| 2 | | 391.6 | 382.8 | 377.1 | 374.2 |
| 3 | | 392.1 | 381.1 | 373.9 | 370.3 |
| | | SAWLOG VOLUME (TH.+FE) -($m^3$/ha) | | | |
| 1 | | 140.5 | 132.5 | 126.0 | 120.7 |
| 2 | | 178.8 | 162.4 | 148.9 | 137.6 |
| 3 | | 208.0 | 185.8 | 167.1 | 151.4 |
| | | PULPWOOD VOLUME (TH.+FE) -($m^3$/ha) | | | |
| 1 | | 251.4 | 254.5 | 257.8 | 261.4 |
| 2 | | 212.8 | 220.3 | 228.2 | 236.6 |
| 3 | | 184.1 | 195.3 | 206.8 | 218.8 |
| | | NET PRESENT VALUE - NPV - (4% DISC. RATE) - ($/ha) | | | |
| 1 | | -41.1 | -43.7 | -45.7 | -48.5 |
| 2 | | 18.5 | 14.1 | 9.3 | 2.0 |
| 3 | | 63.4 | 57.9 | 51.1 | 40.2 |
| | | INTERNAL RATES OF RETURN -IRR- (%) | | | |
| 1 | | 3.90 | 3.85 | 3.85 | 3.85 |
| 2 | | 4.10 | 4.10 | 4.05 | 4.05 |
| 3 | | 4.25 | 4.25 | 4.20 | 4.20 |

where: TH=thinning, FE=felling, BA(B.T.)=basal area before thinning, D.B.H.(B.T.)=D.B.H. before thinning, TR.NO.=treatment number, T.W.=thinning weight.

[1] Table format adapted from Table 62 of Johnson et al. (1967)

Table 7. Physical and economic returns from thinning cycles of a constant thinning intensity starting at different stand ages for a hypothetical red pine stand (SI 16 m).[1]

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| AGE | 20 | 25 | | 30 | | | 35 | | | |
| BA (B.T.) | 20 | 30.6 | | 37.4 | | | 42.6 | | | |
| DBH (B.T.) | 9.6 | 11.9 | | 13.2 | | | 14.0 | | | |
| REGIME NO. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| TH.CY. | 5 | 5 | 10 | 5 | 10 | 15 | 5 | 10 | 15 | 20 |
| BA(T) | 7.0 | 7.0 | 14.0 | 7.0 | 14.0 | 21.0 | 7.0 | 14.0 | 21.0 | 28.0 |
| BA(T) % G.S[2] | 25.8 | 22.7 | 43.7 | 20.3 | 39.0 | 56.0 | 18.2 | 36.3 | 52.0 | 69.5 |
| D.B.H(FE) | 34.8 | 26.2 | 31.3 | 22.8 | 24.1 | 27.3 | 19.2 | 20.9 | 23.3 | 29.5 |
| G.V. (TH.+FE.) | 479.6 | 469.3 | 501.4 | 463.3 | 488.9 | 504.5 | 462.8 | 481.3 | 496.3 | 518.5 |
| M.V. | 352.8 | 342.5 | 364.3 | 340.8 | 356.5 | 367.6 | 345.0 | 354.6 | 363.3 | 380.2 |
| S.W. | 299.6 | 248.5 | 288.7 | 194.2 | 232.0 | 274.6 | 156.0 | 182.3 | 216.6 | 262.0 |
| P.W. | 53.2 | 94.0 | 75.6 | 146.6 | 124.5 | 93.0 | 189.0 | 172.3 | 146.7 | 118.2 |
| NPW ($/ha)(4%) | 448.3 | 295.0 | 438.9 | 168.1 | 279.1 | 374.8 | 75.3 | 163.4 | 521.3 | 359.2 |
| IRR (%) | 5.6 | 5.1 | 5.5 | 4.6 | 5.0 | 5.3 | 4.3 | 4.6 | 4.9 | 5.2 |

where: AGE.=age of first thinnings, TH.CY.=thinning cycle, BA(T)=basal area thinned, BA(T)% G.S.= basal area thinned as % of growing stock, G.V.=gross volume, M.V.=merchantable volume, S.V.=sawlog volume, P.V.=pulpwood volume. Other abbreviations are as explained under Table 7.

[1] Table format adopted from Table 63 of Johnson et al. (1967).

[2] G.S. means the standing crop where tests are conducted as against growing stock of the yield tables.

The table shows that: (1) average stand d.b.h. increases with earlier age of thinning. For example, d.b.h. at felling for the 5-year cycle are 34.8, 26.2, 22.8, and 19.2 cm for cycles begun at 20, 25, 30, and 35 years of age, respectively. Also d.b.h. at felling for 10-year cycles beginning at ages 25, 30, and 35 are 31.3, 24.1, and 20.9 cm, respectively. Similarly, the d.b.h. for 15 year cycles beginning at ages 30 and 35 are 27.3 and 23.3 cm, respectively;

(2) average tree diameter increases with heavier rather than lighter thinnings. For example, d.b.h. at felling for thinning weights of 7 and 14 $m^2$/ha started at age 25 are 26.2 and 31.3 cm, respectively. Also the d.b.h. at felling for thinning weights of 7, 14, and 21 $m^2.ha^{-1}$ started at age 30 are, respectively, 22.8, 24.1, and 27.3 cm. The d.b.h. for thinning weights of 7, 14, 21 and 28 $m^2.ha^{-1}$ started at age 35 are 19.2, 20.9, 23.3, and 29.5 cm, respectively;

(3) gross thinning regime volume decreases with delayed thinning. For example, the gross volumes based on the 5-year cycles begun at ages 20, 25, 30, and 35 are, respectively, 479.6, 469.3, 463.3, and 462.8 $m^3$/ha. The gross volume based on 10-year cycles beginning at ages 25 and 35 are, respectively, 548.9 and 527.2 $m^3.ha^{-1}$;

(4) delayed thinnings diminish merchantable and sawlog volumes. For example, thinnings started at ages 20, 25, 30, and 35 for the 5-year cycle give sawlog volumes of 299.6, 248.5, 194.2, and 156.0 $m^3$/ha. Also sawlog volumes for the 10-year cycles beginning at ages 25, 30 and 35 years are 288.7, 232.0, and 226.6 $m^3.ha^{-1}$, respectively. Similarly, sawlog volumes for 15-year cycles beginning at ages 30 and 35 are, respectively, 374.8 and 262.2 $m^3$/ha;

(5) heavier thinning in repeated series of thinning cycles results in more merchantable and sawlog volumes, hence better financial yields than in delayed thinnings. For example, the IRR for 7 and 14 $m^2$/ha thinning weights in cycles begun at age 25 are 5.1 and 5.5 per cent, respectively. Also IRR for 7, 14, and 21 $m^2.ha^{-1}$ beginning at age 30 are, respectively 4.60, 5.0, and 5.3 per cent. IRR for thinning weights of 7, 14, 21, and 28 $m^2.ha^1$ starting from age 35 are 4.3, 4.6, 4.9, and 5.2 per cent, respectively.

The number of thinnings carried out during the growing period of the stand can have significant effects on wood volume and financial returns of the stand. To investigate the effects of frequency of thinning on physical and economic returns, a thinning intensity of 7 $m^2$/ha/cycle was applied to the hypothetical stand with 5-year thinning cycles. Five frequencies ( 1, 2, 3, 4, and maximum) were simulated for each of the thinning regimes beginning from ages 20, 25, 30, and 35 years. It should be noted that the maximum frequencies correspond with regimes 1, 2, 4, and 7 in Table 7. The effects of thinning frequency on the physical and economic returns of the stand are provided in Table 8.

The table shows that for the tested frequencies, sawlog volume is maximized by a regime with four thinnings beginning from age 20 (312.2 $m^3$/ha). On the other hand, a regime with maximum thinning frequency, also beginning at age 20 optimizes financial yield (IRR 5.60 %). In general, regimes with a single thinning provide the largest gross volume in each particular age of first thinning. Also, the sawlog volume production and financial yield decline with: (1) decreasing thinning frequency; and (2) delayed age of first thinning.

Table 8. The effects of thinning frequency on physical and economic returns of a hypothetical red pine stand assuming a constant thinning intensity and cycle.

| AGE | FREQ. | G.V. | M.V. | S.W. | P.W. | NPW | IRR |
|---|---|---|---|---|---|---|---|
| | 1 | 501.2 | 392.2 | 214.4 | 177.8 | 73.3 | 4.25 |
| | 2 | 495.7 | 384.0 | 266.9 | 117.1 | 169.2 | 4.60 |
| | 3 | 489.9 | 375.0 | 297.1 | 77.9 | 248.2 | 4.85 |
| | 4 | 485.4 | 367.2 | 312.2 | 55.0 | 314.4 | 5.10 |
| | MAX. | 479.6 | 352.9 | 299.7 | 53.2 | 448.3 | 5.60 |
| 25 | 1 | 494.7 | 383.6 | 154.7 | 228.9 | -0.6 | 4.00 |
| | 2 | 486.2 | 372.1 | 188.3 | 183.8 | 69.7 | 4.30 |
| | 3 | 479.6 | 362.0 | 212.4 | 149.5 | 133.8 | 4.50 |
| | 4 | 475.1 | 354.0 | 229.5 | 124.5 | 192.7 | 4.75 |
| | MAX. | 469.3 | 342.5 | 248.5 | 94.0 | 295.1 | 5.10 |
| 30 | 1 | 490.5 | 380.6 | 135.5 | 245.1 | -22.5 | 3.95 |
| | 2 | 482.0 | 367.4 | 157.5 | 209.9 | 33.6 | 4.15 |
| | 3 | 474.8 | 357.3 | 173.3 | 184.0 | 81.7 | 4.35 |
| | 4 | 469.7 | 349.7 | 184.3 | 165.4 | 122.1 | 4.50 |
| | MAX. | 463.3 | 340.8 | 194.2 | 146.6 | 168.1 | 4.65 |
| 35 | 1 | 487.7 | 379.6 | 125.0 | 254.6 | -35.2 | 3.90 |
| | 2 | 480.5 | 366.7 | 138.3 | 228.4 | 6.0 | 4.05 |
| | 3 | 473.0 | 356.9 | 147.9 | 209.0 | 40.3 | 4.20 |
| | 4 | 467.4 | 349.9 | 153.7 | 196.2 | 64.2 | 4.25 |
| | MAX. | 462.8 | 345.0 | 156.0 | 189.0 | 75.3 | 4.30 |

where: variables are as defined in Table 7

### 4.4.4 Thinning intensity

Four different thinning intensities of five-year cycles were tested for volume production and financial returns. Thinning weights were varied accordingly. The age of first thinning was fixed at 20 years. The results of this test are presented in Table 9.

Table 9. Influences of thinning intensity on the physical and economic returns of a hypothetical red pine stand (SI 16 m).

| T.I. ($m^2$/ha/cycle) | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|
| BA (B.T.) | 20 | 20 | 20 | 20 | 20 | 20 |
| D.B.H. (B.T.) | 9.6 | 9.6 | 9.6 | 9.6 | 9.6 | 9.6 |
| D.B.H. (FE) | 24.8 | 29.1 | 34.8 | 43.4 | 59.1 | 86.0 |
| BA(T)% G.S. | 16.6 | 21.2 | 25.8 | 30.8 | 36.8 | 43.1 |
| BA AT FE | 31.2 | 26.8 | 23.6 | 20.9 | 18.6 | 16.8 |
| G.S VOL. AT FE | 273.1 | 235.2 | 206.5 | 182.3 | 162.0 | 145.7 |
| M.V. AT FE | 221.6 | 193.9 | 173.8 | 158.3 | 145.8 | 131.2 |
| S.V. AT FE | 186.5 | 184.2 | 165.2 | 150.3 | 138.5 | 124.6 |
| P.V. AT FE | 35.1 | 9.7 | 8.7 | 8.0 | 7.3 | 6.6 |
| G.V. | 454.2 | 465.1 | 479.6 | 498.6 | 525.4 | 556.9 |
| M.V. | 338.6 | 343.3 | 352.9 | 368.2 | 391.6 | 417.6 |
| S.V. | 255.5 | 286.0 | 299.7 | 317.5 | 342.3 | 369.2 |
| P.V. | 83.1 | 57.3 | 53.3 | 50.7 | 49.3 | 48.4 |
| NPV | 240.1 | 351.9 | 448.3 | 559.6 | 702.3 | 851.9 |
| IRR (%) | 4.90 | 5.25 | 5.60 | 5.95 | 6.40 | 6.80 |

T.I= thinning intensity, and other abbreviations are as defined earlier.
[1] Table format adopted from Table 65 of Johnson et al. (1967).

Table 9 shows that higher intensities of thinning maximize both volume and value of the stand. However, the results from this table need to be treated with skepticism for some of its values, e.g., number of stems/ha are too low and average stand d.b.h. too large in regimes of 9 and 10 $m^2.ha^{-1}$ per cycle. The results of Table 9 are evaluated in the light stocking chart limits in Table 10.

Table 10. Evaluation of alternative thinning regimes using stocking chart limits (based on Table 9).

| T.I | N (FE) | D.B.H.(FE) | WITHIN STOCKING CHART |
|---|---|---|---|
| 5 | 645 | 24.8 | YES |
| 6 | 403 | 29.1 | YES |
| 7 | 248 | 34.8 | YES |
| 8 | 141 | 43.4 | YES |
| 9 | 68 | 59.1 | NO |
| 10 | 29 | 86.0 | NO |

where: N(FE)=stems/ha at felling,

Table 10 shows that of the results reported for the six thinning intensities in Table 9, only those of intensities of 5, 6, 7, and 8 $m^2$/ha per cycle are within the stocking chart limits. That is, from Figure 1 it can be seen that 645, 403, 248, and 141 stems/ha and their respective d.b.h. of 24.8, 29.1, 34.8, and 43.4 cm for regimes of 5, 6, 7, and 8 $m^2.ha^{-1}$per cycle are within the chart limits. The figure also shows that 68 and 29 stems /ha and their respective d.b.h. of 59.1 and 86.0 cm for the regimes of 9 and 10 $m^2.ha^{-1}$ per cycle fall outside the chart limits. If only values of thinning regimes falling within the stocking chart limits are acceptable as guides for valid regimes, the values for regimes of intensities of 9 and 10 $m^2.ha^{-1}.cycle^{-1}$ from Table 11 are rejected. And, since of the four acceptable regimes in the light of stocking chart, the regime with intensity of 8 $m^2.ha^{-1}.cycle^{-1}$ takes precedent over the 7, 6, and 5 $m^2.ha^{-1}$per $cycle^{-1}$ regimes both in terms of volume and financial yield, the observation made earlier that higher intensities maximize stand volume and value compared to lower intensities continues to hold. Considerations of only regimes that fall within the stocking chart limits is critical to avoid erroneous predictions beyond the known levels. For example, there is a possibility that the model overestimates basal area and hence volume growth with stocking that is far too low from normal stocking for a given stand age and site. However, more tests are necessary with actual data to crystallize these finding.

## 4.5 SENSITIVITY ANALYSIS OF THE PLANNING MODEL

Table 7 was used to monitor sensitivity of the economic returns of the planning model to changes in sawlog volume, sawlog price, and discount rates. Economic returns were monitored for changes in sawlog volumes and prices of up to 20 per cent, while those due to changes in the discount rate were examined for rate changes of up to 50 per cent of the standard 4 per cent. The results of the analyses are presented in Table 11.

The table shows that the model is very sensitive to both changes in sawlog volume and price as measured by the IRR. However, the model appears to be more sensitive to changes in sawlog prices than to changes in sawlog volumes. For example, raising sawlog volume and price by 10 and 20 per cent in regime 1 (Table 7) results in the increase of IRR by 0.25 and 0.45 for sawlog volume, and 0.35 and 0.65 per cent for sawlog price, respectively. Similarly, lowering sawlog volume and price by 10 and 20 per cent lowers the IRR by 0.25 and 0.60 for sawlog volume, and 0.35 and 0.80 per cent for sawlog price, respectively. Thus, for the same proportional changes in sawlog volume and price, a greater change in financial yield is experienced with changes in prices. It also shows that the NPV changes with a change in discount rate. Although the NPV experiences a sharp rise when the discount rate is reduced by one half, it experiences only a gentle drop when the discount rate is raised by the same one half. This behaviour in the financial yield curves can be explained by the fact that contribution of any cost or revenue to the NPV decreases as the discount rate increases (Duerr et al. 1979). The table further shows that the sensitivity to changes in sawlog volume, price, and discount rate increases with earlier ages of beginning thinning cycles. For example, compare regimes 1, 2, 4, and 7 or 3, 5, and 8 or 6 and 9. The sensitivity of the model to changes in sawlog volume for regimes 1, 2, 4, and 7 is shown in Figure 10. On the other hand, the model's sensitivity decreases with increasing level of growing stock or decreasing thinning weights (e.g. compare regimes 2 and 3 or 4, 5, and 6 or 7, 8, 9, and 10) in Tables 7 and 11.

Table 11. Sensitivity of the planning model to changes in sawlog volume, sawlog prices, and discount rates (based on Table 7)

| REGIME NO. | VARIABLE NAME | VARIABLE PROPORTION | NPV ($/ha) | IRR (%) |
|---|---|---|---|---|
| | SAWLOG VOLUME | 0.80 | 235.43 | 5.00 |
| | | 0.90 | 341.89 | 5.35 |
| | | 1.00 | 448.35 | 5.60 |
| | | 1.10 | 554.80 | 5.85 |
| | | 1.20 | 661.26 | 6.05 |
| 1 | SAWLOG PRICE | 0.80 | 181.83 | 4.80 |
| | | 0.90 | 315.09 | 5.25 |
| | | 1.00 | 448.35 | 5.60 |
| | | 1.10 | 581.60 | 5.95 |
| | | 1.20 | 714.86 | 6.25 |
| | DISCOUT RATE | 0.50 | 1967.51 | 5.60 |
| | | 0.75 | 1005.98 | 5.60 |
| | | 1.00 | 448.35 | 5.60 |
| | | 1.25 | 122.96 | 5.60 |
| | | 1.50 | - 67.58 | 5.60 |
| | SAWLOG VOLUME | 0.80 | 159.46 | 4.70 |
| | | 0.90 | 227.25 | 4.90 |
| | | 1.00 | 295.05 | 5.10 |
| | | 1.10 | 362.85 | 5.25 |
| | | 1.20 | 430.64 | 5.45 |
| 2 | SAWLOG PRICE | 0.80 | 88.27 | 4.40 |
| | | 0.90 | 191.65 | 4.80 |
| | | 1.00 | 295.05 | 5.10 |
| | | 1.10 | 398.44 | 5.40 |
| | | 1.20 | 501.83 | 5.65 |
| | DISCOUNT RATE | 0.50 | 1636.70 | 5.10 |
| | | 0.75 | 783.05 | 5.10 |
| | | 1.00 | 295.05 | 5.10 |
| | | 1.25 | 15.44 | 5.10 |
| | | 1.50 | - 144.45 | 5.10 |
| 3 | SAWLOG VOLUME | 0.80 | 261.97 | 5.10 |
| | | 0.90 | 350.50 | 5.35 |
| | | 1.00 | 438.96 | 5.55 |
| | | 1.10 | 527.46 | 5.75 |
| | | 1.20 | 615.96 | 5.90 |

TABLE 11. CONT.

TABLE 11. CONT'D

| | | | | |
|---|---|---|---|---|
| 3 | SAWLOG PRICE | 0.80 | 189.28 | 4.80 |
| | | 0.90 | 314.12 | 5.20 |
| | | 1.00 | 438.96 | 5.55 |
| | | 1.10 | 563.81 | 5.85 |
| | | 1.20 | 688.64 | 6.15 |
| | DISCOUNT RATE | 0.50 | 1959.17 | 5.55 |
| | | 0.75 | 996.73 | 5.55 |
| | | 1.00 | 438.96 | 5.55 |
| | | 1.25 | 113.99 | 5.55 |
| | | 1.50 | - 75.84 | 5.55 |
| | SAWLOG VOLUME | 0.80 | 84.51 | 4.40 |
| | | 0.90 | 126.32 | 4.55 |
| | | 1.00 | 168.12 | 4.65 |
| | | 1.10 | 209.92 | 4.80 |
| | | 1.20 | 251.72 | 4.90 |
| 4 | SAWLOG PRICE | 0.80 | 10.98 | 4.05 |
| | | 0.90 | 89.56 | 4.40 |
| | | 1.00 | 168.12 | 4.65 |
| | | 1.10 | 246.69 | 4.90 |
| | | 1.20 | 325.25 | 5.15 |
| | DISCOUNT RATE | 0.50 | 1348.74 | 4.65 |
| | | 0.75 | 593.94 | 4.65 |
| | | 1.00 | 168.12 | 4.65 |
| | | 1.25 | - 75.57 | 4.65 |
| | | 1.50 | - 205.32 | 4.65 |
| | SAWLOG VOLUME | 0.80 | 168.04 | 4.70 |
| | | 0.90 | 223.55 | 4.90 |
| | | 1.00 | 279.06 | 5.05 |
| | | 1.10 | 334.56 | 5.20 |
| | | 1.20 | 390.07 | 5.30 |
| 5 | SAWLOG PRICE | 0.80 | 89.00 | 4.40 |
| | | 0.90 | 184.03 | 4.75 |
| | | 1.00 | 279.06 | 5.05 |
| | | 1.10 | 374.08 | 5.30 |
| | | 1.20 | 469.11 | 5.55 |
| | DISCOUNT RATE | 0.50 | 1608.87 | 5.05 |
| | | 0.75 | 761.98 | 5.05 |
| | | 1.00 | 279.06 | 5.05 |
| | | 1.25 | 3.16 | 5.05 |
| | | 1.50 | - 153.99 | 5.05 |

TABLE 11. CONT.

TABLE 11. CONT'D

| | | | | |
|---|---|---|---|---|
| | SAWLOG VOLUME | 0.80 | 230.42 | 4.94 |
| | | 0.90 | 302.63 | 5.15 |
| | | 1.00 | 374.84 | 5.35 |
| | | 1.10 | 447.07 | 5.50 |
| | | 1.20 | 519.28 | 5.65 |
| 6 | SAWLOG PRICE | 0.80 | 151.01 | 4.65 |
| | | 0.90 | 262.93 | 5.00 |
| | | 1.00 | 374.84 | 5.35 |
| | | 1.10 | 486.77 | 5.60 |
| | | 1.20 | 598.68 | 5.85 |
| | DISCOUNT RATE | 0.50 | 1848.51 | 5.35 |
| | | 0.75 | 911.22 | 5.35 |
| | | 1.00 | 374.84 | 5.35 |
| | | 1.25 | 66.50 | 5.35 |
| | | 1.50 | - 110.94 | 5.35 |
| | SAWLOG VOLUME | 0.80 | 19.76 | 4.10 |
| | | 0.90 | 47.55 | 4.20 |
| | | 1.00 | 75.33 | 4.30 |
| | | 1.10 | 103.11 | 4.40 |
| | | 1.20 | 130.90 | 4.50 |
| 7 | SAWLOG PRICE | 0.80 | - 47.57 | 3.80 |
| | | 0.90 | 13.87 | 4.10 |
| | | 1.00 | 75.33 | 4.30 |
| | | 1.10 | 136.79 | 4.55 |
| | | 1.20 | 198.24 | 4.70 |
| | DISCOUNT RATE | 0.50 | 1153.52 | 4.30 |
| | | 0.75 | 460.33 | 4.30 |
| | | 1.00 | 75.33 | 4.30 |
| | | 1.25 | - 136.88 | 4.30 |
| | | 1.50 | - 251.85 | 4.30 |
| | SAWLOG VOLUME | 0.80 | 99.29 | 4.45 |
| | | 0.90 | 131.35 | 4.55 |
| | | 1.00 | 163.41 | 4.65 |
| | | 1.10 | 195.47 | 4.75 |
| | | 1.20 | 227.54 | 4.85 |
| 8 | SAWLOG PRICE | 0.80 | 16.27 | 4.10 |
| | | 0.90 | 89.84 | 4.40 |
| | | 1.00 | 163.41 | 4.65 |
| | | 1.10 | 236.98 | 4.90 |
| | | 1.20 | 310.56 | 5.10 |
| | DISCOUNT RATE | 0.50 | 1349.56 | 4.65 |
| | | 0.75 | 591.21 | 4.65 |
| | | 1.00 | 163.41 | 4.65 |
| | | 1.75 | - 77.11 | 4.65 |
| | | 1.50 | - 210.94 | 4.65 |

TABLE 11. CONT'D.

| | | | | |
|---|---|---|---|---|
| | SAWLOG VOLUME | 0.80 | 161.90 | 4.65 |
| | | 0.90 | 206.64 | 4.80 |
| | | 1.00 | 251.38 | 4.95 |
| | | 1.10 | 296.13 | 5.05 |
| | | 1.20 | 340.87 | 5.15 |
| 9 | SAWLOG PRICE | 0.80 | 75.97 | 4.35 |
| | | 0.90 | 163.68 | 4.65 |
| | | 1.00 | 251.38 | 4.95 |
| | | 1.10 | 339.10 | 5.15 |
| | | 1.20 | 426.80 | 5.40 |
| | DISCOUNT RATE | 0.50 | 1558.85 | 4.95 |
| | | 0.75 | 725.63 | 4.95 |
| | | 1.00 | 251.38 | 4.95 |
| | | 1.25 | - 18.49 | 4.95 |
| | | 1.50 | - 171.23 | 4.95 |
| | SAWLOG VOLUME | 0.80 | 241.91 | 4.95 |
| | | 0.90 | 300.59 | 5.10 |
| | | 1.00 | 359.26 | 5.25 |
| | | 1.10 | 417.94 | 5.40 |
| | | 1.20 | 426.61 | 5.50 |
| 10 | SAWLOG PRICE | 0.80 | 147.83 | 4.60 |
| | | 0.90 | 253.55 | 4.95 |
| | | 1.00 | 359.26 | 5.25 |
| | | 1.10 | 464.98 | 5.50 |
| | | 1.20 | 570.70 | 5.75 |
| | DISCOUNT RATE | 0.50 | 1839.89 | 5.25 |
| | | 0.75 | 898.27 | 5.25 |
| | | 1.00 | 359.26 | 5.25 |
| | | 1.25 | 50.18 | 5.25 |
| | | 1.50 | - 126.65 | 5.25 |

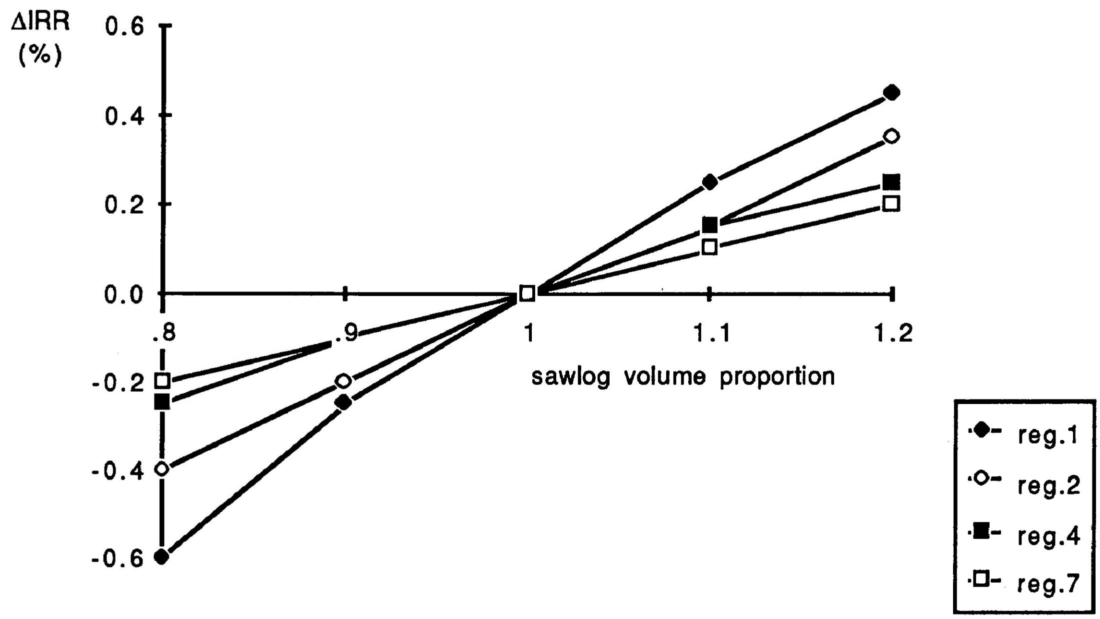


Figure 10. Sensitivity of the planning model by age of beginning thinning cycles.

## 4.7 SAWLOG VOLUME COMPARISONS BETWEEN ALTERNATIVE THINNING REGIMES AND CONTROL

Comparisons of total sawlog yield development over time were made for alternative thinning regimes in Table 7 and a control regime (i.e. sawlog yield in a fully stocked stand). The purpose of these comparisons was to observe the merits of thinning under different treatments in terms of quality product development. The results of the comparisons are presented in Table 12 and illustrated in Figure 11.

The results (Table 12 and Figure 11) show that sawlog volume yield may decrease below that of an unmanaged stand if the thinnings are improperly scheduled. For example, the volumes produced by the control stand are superior to those of regimes 4, 7, and 8 at age 60. On the other hand, the IRR for the

Table 12. Sawlog volume yield comparisons for alternative thinning regimes and control for the hypothetical red pine stand (SI 16 m) ($m^3$/ha).

| AGE | SV1 | SV2 | SV3 | SV4 | SV5 | SV6 | SV7 | SV8 | SV9 | SV10 | SVC |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.7 |
| 30 | 34.0 | 21.2 | 26.1 | 18.9 | 18.9 | 18.9 | 18.9 | 18.9 | 18.9 | 18.9 | 33.7 |
| 40 | 103.3 | 66.0 | 84.6 | 51.9 | 58.8 | 73.6 | 46.3 | 49.2 | 54.5 | 63.5 | 80.9 |
| 50 | 205.5 | 143.8 | 180.8 | 109.9 | 130.3 | 163.6 | 91.0 | 102.7 | 115.6 | 145.0 | 141.9 |
| 60 | 299.7 | 248.5 | 288.2 | 194.2 | 232.0 | 274.6 | 156.0 | 182.2 | 216.6 | 262.0 | 209.1 |

where SV1......8= sawlog volume yield over time for regimes 1 to 8 of Table 7.
SVC= sawlog volume yield for the control regime.

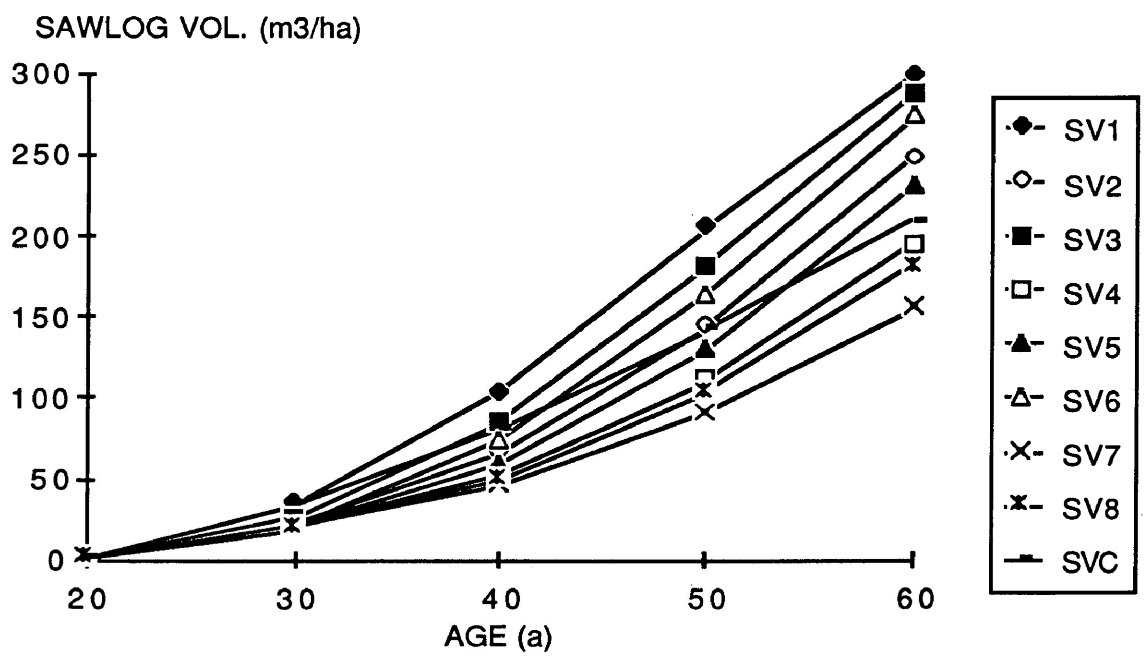


Figure 11. Sawlog volume yield/age comparisons for alternative thinning regimes and control.

control stand was determined to be 4.20 per cent while those of regimes 4, 7, and 8 of Table 7 are respectively 4.65, 4.30, and 4.65 per cent. Clearly, these results show that regime 7 can be left out for greater sawlog volume production from a non-thinning regime without losing much in financial yield. Regimes 4 and 8 show slightly better economic returns than the control, perhaps because of the influence of early income from thinnings on the discounted revenues.

# 5 DEMONSTRATION OF THE PLANNING MODEL

As stated in Chapter 1, one of the objectives of this study is to guide planning investments in red pine stands in the Thunder Bay area. The tests of stands 3 and 4 of the Hogarth plantations (Section 4.3.2) have shown that the model predicts fairly well the growth and yield of the stands (Table 5 and Figures 7, 8, and 9). In this Chapter, stands 3 and 4 of the Hogarth plantations are used to demonstrate physical and economic returns from alternative thinning regimes. Alternative rotations are not investigated, although the model could be readily used for this purpose. The thinning history and status of the two stands as of October 1986 is summarized in Table 13.

Table 13. The history and status of stands 3 and 4 of the Hogarth plantations.

| ST.NO. | AREA (ha) | Y.E. | INIT. STOCKING (stems/ha) | BA(B.T.) 1977 ($m^2.ha^{-1}$) | BA(T) 1977 ($m^2.ha^{-1}$) | BA(B.T) 1985 ($m^2.ha^{-1}$) | BA(T) 1985 ($m^2.ha^{-1}$) |
|---|---|---|---|---|---|---|---|
| 3 | 1.1 | 1952 | 1289 | 37.3 | 12.4 | 29.7 | 9.9 |
| 4 | 3.1 | 1950 | 1604 | 39.6 | 13.2 | 32.4 | 10.7 |

where: ST.NO.=stand number, Y.E.=year of establishment, and other abbreviations are as defined earlier.

Given the thinning treatments the stands received from 1977, the alternative management strategies for each of the stands and their consequences in terms of physical and economic returns are presented below.

## 5.1 STAND 3

Thinning of every third row at age 25 and removal of inferior codominants at age 33 have been done and future alternatives are:

Regime 1: grow the stand to age 60 and fell;

Regime 2: grow the stand to age 41 and thin one third of the remaining growing stock, and then grow it to age 60 and fell;

Regime 3: grow the stand to age 41 and thin one third of the remaining growing stock. Continue to grow it to age 49 and again thin one third of the remaining stock. Finally grow it to age 60 and fell;

Regime 4: grow the stand to age 41 and thin one quarter of the remaining growing stock, and then grow it to age 60 and fell; or

Regime 5: grow the stand to age 41 and thin one quarter of the remaining growing stock. Continue to row it to age 49 and again thin one quarter of the remaining stock. Finally grow it to age 60 and fell.

The physical and economic consequences of the above treatments are shown in Table 14.

Table 14. Physical and economic consequences of alternative stand management options (stand 3 Hogarth plantations).

| REGIME NO. | G.V. ($m^3$/ha) | M.V. ($m^3$/ha) | S.V. ($m^3$/ha) | P.V. ($m^3$/ha) | NPW (4%) ($/ha) | IRR (%) |
|---|---|---|---|---|---|---|
| 1 | 643.8 | 544.7 | 494.8 | 49.8 | 930.6 | 6.65 |
| 2 | 637.4 | 529.1 | 477.8 | 51.3 | 1060.1 | 7.10 |
| 3 | 635.4 | 523.7 | 472.7 | 50.0 | 1145.9 | 7.30 |
| 4 | 635.6 | 530.1 | 479.4 | 50.7 | 1018.3 | 6.95 |
| 5 | 629.7 | 521.7 | 471.4 | 50.3 | 1076.5 | 7.10 |

where: G.V.=gross volume, M.V.=merchantable volume, S.V.=sawlog volume, and P.V=pulpwood volume.

The table shows that if the regimes were to be ranked in terms of volume production, the ranking would be in order of superiority regimes 1, 2, 4, 3, and 5. However, based on the financial yield, the ranking would follow regimes 3, 5, 2, 4, and 1.

The results show that, with this set of alternative regimes, volume production can be maximized with two thinnings of every third row at ages 25 and 33 years. However, the results also show that intermediate thinnings sacrificed for the above maximum volume have adverse financial consequences to the management of the stand. Three thinnings of every third row at ages 25, 33, and 41 years (regime 2) compare favourably in terms of volume production with four thinnings, two removing every third row at ages 25 and 33 and the other two removing the remaining growing stock by one quarter each at ages 41 and 49 (regime 5). However, the three thinnings compare unfavourably with the four thinnings in terms of financial yield. It is therefore important that attempts to pursue a certain management objective be preceded by a careful analysis of physical and economic consequences through successive comparison of alternative courses of action (see Cyert and March 1963; Lindblom 1959).

## 5.2 STAND 4

Thinning of every third row at age 27 and removal of inferior codominants at age 35 have been done and future alternatives are:

Regime 1: grow the stand to age 60 and fell;

Regime 2: grow the stand to age 43 and thin one third of the remaining growing stock, and then grow it to age 60 and fell;

Regime 3: grow the stand to age 43 and thin one third of the remaining growing stock. Continue to grow it to age 51 and again thin one third of the remaining stock. Finally grow it to age 60 and fell;

Regime 4: grow the stand to age 43 and thin one quarter of the remaining growing stock, and then grow it to age 60 and fell; or

Regime 5: grow the stand to age 43 and thin one quarter of the remaning growing stock. Continue to grow it to age 51 and again thin one quarter of the remaining stock. Finally grow it to age 60 and fell.

The physical and economic consequences of the above treatments are presented in Table 15.

Table 15. Physical and economic consequences of alternative stand management options (stand 4 Hogarth plantations).

| REGIME NO. | G.V. ($m^3$/ha) | M.V. ($m^3$/ha) | S.V. ($m^3$/ha) | P.V. ($m^3$/ha) | NPW (4%) ($/ha) | IRR (%) |
|---|---|---|---|---|---|---|
| 1 | 640.8 | 539.0 | 475.8 | 63.2 | 887.1 | 6.50 |
| 2 | 635.3 | 526.3 | 454.3 | 72.0 | 990.3 | 6.85 |
| 3 | 633.4 | 521.0 | 449.3 | 71.7 | 1056.6 | 7.05 |
| 4 | 633.4 | 527.1 | 457.6 | 69.5 | 957.1 | 6.75 |
| 5 | 627.8 | 519.1 | 449.8 | 69.3 | 1000.5 | 6.90 |

where: abbreviations are as defined earlier.

## 5.3 THE PREFERRED REGIMES

Tables 15 shows that the trend of results of stand 4 follow that of stand 3 (Table 14) since the two stands are identical in terms of site index class. The slight difference between their volume production and financial yield stems from the timing of thinning with stand 3 showing slightly better volumes and financial yield. From the two tables (Tables 14 and 15) it can be seen that some good management alternatives for the Hogarth plantations now include:

(1) two more thinnings removing one third of the remaining growing stock each in 1993 and year 2001 and then clearcutting in years 2012 and 2010 for stands 3 and 4, respectively, the maximum financial yield regimes (see regime 3 in Tables 14 and 15);

(2) do nothing to the stands until clearfelling in years 2012 and 2010 for stands 3 and 4, respectively, the maximum volume yield regimes ( see regime 1 in Table 14 and Table 15); or

(3) carry out one more thinning which removes one third of the remaining growing crop in 1993, and then clearfelling in years 2012 and 2010 for stands 3 and 4, respectively, a regime which combines rationally the volume production and financial yield (see regime 2 in Table 14 or 15).

Consideration of alternative rotation ages would likely identify other good management regimes.

The financial yield for the evaluated alternative thinning regimes depend on the initial expenses and financial data realized at harvest. The values of costs used in the evaluation are only estimates made by the author; while the revenues are the current product prices from forest product industries in Thunder Bay. Therefore, the financial yield of the various thinning regimes of stands 3 and 4 of the Hogarth plantations may not be the same if costs differ from estimates used in running the model. This is one reason why the financial yield obtained in this study are well above that estimated by Sutherland (1980) for stand 4. Another reason for this discrepancy is the fact that Sutherland predicted growth and yield of the Hogarth plantations using Buckman's equation for natural red pine stands in northern Minnesota which appears to underestimate growth and yield in red pine plantations in Ontario (refer to Figure 9). Sutherland's NPV of $ 34.04/ha at a four per cent value discount rate was based on a 65-year rotation but this wouldn't make a big difference with the returns of the 60 year-rotations observed above. Given the cost estimates used, the evaluated 5 regimes each for stands 3 and 4 are therefore only examples rather than a precise evaluation for guiding management of those stands. These examples far from exhaust the available alternatives. For example, more information can be sought about the output characteristics by doing thinnings involving different weights and thinning cycles. In this respect, 10 more options on how each of the two stands could also have been managed are summarized in Tables 16 and 17.

Table 16. Alternative thinning treatments for stand 3 of the Hogarth plantations

| REGIME NO. | NO.OF THIN. | THIN CYCLE | AGE OF THIN. | THIN WT. % BA | ROTATION AGE | TOTAL VOL. ($m^3$/ha) | MERCH. VOL. ($m^3$/ha) | SAWLOG VOL. ($m^3$/ha) | NPW (4%)($/ha) | IRR (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 5 | 25 | 25 | 60 | 646.2 | 555.7 | 510.4 | 849.4 | 6.30 |
| 2 | 3 | 5 | 25 | 25 | 60 | 636.4 | 537.2 | 487.0 | 931.0 | 6.65 |
| 3 | 4 | 5 | 25 | 25 | 60 | 631.0 | 525.4 | 473.7 | 1016.4 | 6.95 |
| 4 | 2 | 10 | 25 | 25 | 60 | 642.3 | 551.3 | 505.6 | 862.3 | 6.35 |
| 5 | 3 | 10 | 25 | 25 | 60 | 629.8 | 533.8 | 484.9 | 936.0 | 6.60 |
| 6 | 4 | 10 | 25 | 25 | 60 | 622.3 | 525.6 | 477.1 | 957.3 | 6.65 |
| 7 | 2 | 10 | 25 | 33.3 | 60 | 642.6 | 543.0 | 493.4 | 936.4 | 6.65 |
| 8 | 3 | 10 | 25 | 33.3 | 60 | 634.0 | 528.1 | 478.9 | 1053.4 | 7.00 |
| 9 | 4 | 10 | 25 | 33.3 | 60 | 629.3 | 523.3 | 474.4 | 1090.1 | 7.10 |
| 10 | 2 | 13 | 30 | 33.3 | 60 | 636.4 | 541.3 | 487.9 | 938.5 | 6.55 |

Table 16 shows that more volume production could be achieved with a regime involving two thinnings of every fourth row than with thinning removing every third row (compare 646.2 $m^3$/ha of regime 1 in Table 16 with 643.8 $m^3$/ha of regime 1 in Table 14). However, the financial yield from two thinnings of every third row is much better than that of two thinnings of every fourth row (compare IRR of 6.30 % of regime 1 in Table 16 with 6.65 % of regime 1 in Table 14). The table further shows that a regime involving four thinnings removing 25 per cent of basal area/ha conducted at ages 25, 30, 35, and 40 (regime 3) achieves the same financial yield as a regime involving four thinnings, two removing every third row each at ages 25 and 33, and the other two removing a quarter of the remaining crop each at ages 41 and 49 (regime 4 in Table 14).

Table 17. Alternative thinning treatments for stand 4 of the Hogarth plantations

| REGIME NO. | NO.OF THIN. | THIN CYCLE | AGE OF THIN. | THIN WT. % BA | ROTATION AGE | TOTAL VOL. ($m^3$/ha) | MERCH. VOL. ($m^3$/ha) | SAWLOG VOL. ($m^3$/ha) | NPW (4%) ($/ha) | IRR (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 5 | 27 | 25 | 60 | 642.9 | 546.4 | 465.9 | 781.6 | 6.15 |
| 2 | 3 | 5 | 27 | 25 | 60 | 633.7 | 532.3 | 467.7 | 885.1 | 6.50 |
| 3 | 4 | 5 | 27 | 25 | 60 | 628.9 | 522.5 | 451.5 | 953.4 | 6.75 |
| 4 | 2 | 10 | 27 | 25 | 60 | 639.7 | 543.1 | 450.6 | 773.7 | 6.15 |
| 5 | 3 | 10 | 27 | 25 | 60 | 628.0 | 528.3 | 448.5 | 851.7 | 6.40 |
| 6 | 4 | 10 | 27 | 25 | 60 | 621.1 | 523.7 | 451.4 | 872.5 | 6.44 |
| 7 | 2 | 10 | 27 | 33.3 | 60 | 639.2 | 537.4 | 473.4 | 888.0 | 6.50 |
| 8 | 3 | 10 | 27 | 33.3 | 60 | 632.1 | 525.5 | 453.7 | 975.0 | 6.80 |
| 9 | 4 | 10 | 27 | 33.3 | 60 | 627.1 | 520.0 | 448.5 | 989.9 | 6.80 |
| 10 | 2 | 15 | 30 | 33.3 | 60 | 635.5 | 535.3 | 445.5 | 846.3 | 6.35 |

The trend of results in Table 17 agrees with that obtained with Table 16. Briefly the results show that:

(1) A better volume production than that obtained with regime 1 of Table 15 could be obtained with regime 1 of Table 17 (compare 642.9 $m^3$/ha for regime 1 above with 640.8 $m^3$/ha for regime 1 in Table 15).

(2) The financial yield for regime 1 of Table 15 is better that that of regime 1 of Table 17 (compare IRR

of 6.15 % for regime 1 above with 6.50 % for regime 1 of Table 15).

(3) A regime involving four thinnings of 25 per cent of basal area/ha each carried out at ages 25, 30, 35, and 40 (regime 3 above) achieves the same financial yield as a regime involving four thinnings, two removing every third row at ages 27 and 35, and the other two removing a quarter of basal area/ha of the remaining growing stock each at ages 43 and 51 ( regime 4 of Table 17).

The results obtained for Tables 14 and 16 and Tables 15 and 17 suggest a thorough evaluation of alternative thinning regimes before choosing the most attractive regime.

# 6 DISCUSSION AND CONCLUSIONS

## 6.1 THE PLANNING ASPECT OF THE MODEL

### 6.1.1 Data for planning

As shown in Figure 2, the first step in the planning process is specification of the initial stand condition. Simple stand and site variables which are easily measurable from the stand such as basal area, age, stems/ha, and site index are used to generate data for planning purposes (e.g., gross and merchantable volume by products). Then, using a suitable forecasting system for the stand, gross and merchantable volumes are predicted for any future point. Simulation of a thinning, which regulates stand basal area per hectare makes it possible to observe the performance of a stand both physically and economically for a wide range of density conditions. This in turn helps guide the choice of effective thinning regimes for the volume and end products. For example, choice can be made of the thinning regime involving a thinning weight of 33.3 per cent of basal area/ha for its superiority over 12.5 and 25 per cent weights both in terms of gross volume production and financial yield (Table 6).

### 6.1.2 Sorting of products

The sorting of projected outputs by products is considered a critical issue in this study because of the differences in prices which are assigned to different sized products. For example, pulpwood logs whose minimum top diameter is 10 cm have less value per cubic metre than sawlogs (minimum top diameter 18 cm). In the city of Thunder Bay, for instance, a typical price of pulpwood in 1987 is \$ 21.75/$m^3$ while sawlog price is \$ 34.50/$m^3$. Under price conditions like these, the value of stand volume over time can be estimated more precisely if the planning model is designed to express stand volume by products.

### 6.1.3 Indicators

Gross volume, merchantable volume, sawlog and pulpwood volumes are the indicators for physical returns of the planning model; NPV and IRR indicate the financial yield associated with the above physical indicators. NPV for different thinning regimes may change their ranks depending on the discount rate used. The influence of the chosen discount rate on the ranking of thinning regimes on the other hand depends on the size of the cost-benefit flow, timing, and duration of the cash flow (Duerr et al. 1979). For example, consider the returns from four alternative thinning regimes in Table 18.

The Table shows that when a discount rate of 2 or 4 per cent is used, the ranking of regime follows the order of regimes 4, 3, 2, and 1. This ranking changes to regimes 2, 3, 1, and 4 when a discount rate of 6 per cent is used. Based on NPV, the above observations show that lower discount rates favour longer rotations; while higher discount rates favour shorter rotations. It is therefore evident that an investor considering a discount rate of 2 or 4 per cent as satisfactory will maximize his profits by adopting regime 4. However, when a discount rate of 6 per cent is desirable, regime 2 becomes more attractive. The implication of these observations is that individual investors will tend to fell their crops earlier if maximum NPV is their criterion of investment. This stems from the fact that individual investors have a high time preference for money invested in a business (Gourlay 1976). Governments, which have a generally low time preference, benefit more by adopting longer rotations.

IRR remains constant whatever discount rate is used (also see Table 11). Thus, in places where a maximum financial yield is considered as a sole criterion of judging thinning regimes or forest investments, IRR should be used. For example, based on IRR, the ranking of the regimes in Table 18 follows the order regimes 2, 3, 4, and 1. However, the maximum financial yield as measured by IRR will only represent an economically feasible investment if it is larger than the discount rate adopted by the investor. In the event IRR is smaller than the discount rate, the investment ceases to be economically feasible in that it does not pay its total production costs (Duerr et al. 1979). Under such conditions, the NPV is negative. The volume outputs can be compared to identify the best investment in terms of volume production. This is crucial for investors seeking maximum volume production as a quantitative criterion for their investment decisions.

Table 18. The influence of discount rate, duration and size of cash flow, and timing on the ranking of forest investments.

| TREATMENT | AGE | REGIME 1 | | REGIME 2 | | REGIME 3 | | REGIME 4 | |
|---|---|---|---|---|---|---|---|---|---|
| | | C | R | C | R | C | R | C | R |
| | | $/ha | | $/ha | | $/ha | | $/ha | |
| EST. COST | 0 | 200 | - | 200 | - | 200 | - | 200 | - |
| 1 ST TH. | 20 | - | 46.71 | - | 46.71 | - | 46.71 | - | 46.71 |
| 2 ND TH. | 25 | - | 142.22 | - | 142.22 | - | 142.22 | - | 142.22 |
| 3 RD TH. | 30 | - | 251.85 | - | 251.85 | - | 251.85 | - | 251.85 |
| 4 TH TH. | 35 | - | 375.86 | - | 375.86 | - | 375.86 | - | 375.86 |
| FELLING | 40 | 3041.97 | 3421.01 | - | - | - | - | - | - |
| FELLING | 45 | - | - | 4041.68 | 5026.21 | - | - | - | - |
| FELLING | 50 | - | - | - | - | 5176.86 | 6738.34 | - | - |
| FELLING | 60 | - | - | - | - | - | - | 7912.34 | 10309.44 |
| G.V. ($m^3$/ha) | | | 271.0 | | 326.9 | | 380.8 | | 482.6 |
| M.V. ($m^3$/ha) | | | 163.0 | | 211.0 | | 261.2 | | 364.1 |
| S.V. ($m^3$/ha) | | | 92.6 | | 136.7 | | 185.2 | | 289.8 |
| NPV (2%) ($/ha) | | | 730.42 | | 1052.01 | | 1331.22 | | 1731.24 |
| NPV (4%) ($/ha) | | | 126.50 | | 216.10 | | 267.27 | | 275.42 |
| NPV (6%) ($/ha) | | | - 138.93 | | - 121.34 | | - 124.32 | | - 165.84 |
| IRR (%) | | | 4.79 | | 5.09 | | 5.15 | | 4.99 |

where: C = costs, R = revenue

### 6.1.4 Comparison of indicators between alternative investments

Investments competing with forestry are many. The output of the planning model in the form of IRR is comparable with the projected average bank interest rates that the capital can earn when invested in a bank rather than in forestry. Sensitivity analyses can help to assess risk and uncertainty. This should provide quantitative information for aiding decisions on alternative investments. Similarly, a comparison of the volumes and IRR for alternative thinning regimes should provide the quantitative means for the choice of best thinning regime depending on the preferred measurement criterion (volume or financial yield). The final decision to choose between forestry and alternative investment will remain the personal judgment of the investor. For example, the interest rate in banks may be larger than the anticipated IRR from forestry and also bank investment is less risky, but forestry still can be a choice if consideration is given to intangible benefits. Similarly, one regime may be marginally superior to an alternative in terms of financial yield but inferior in volume production. If the alternative regime has a much better overall volume production, the investor, though interested in financial yield, may decide to utilize both indicators to choose an optimum thinning regime.

## 6.2 RED PINE INVESTMENT DECISIONS

From the various tests conducted (Tables 6 - 9) it appears that the critical information about stand level management of red pine include: (1) age of first thinning; (2) the length of thinning cycles; (3) the weight or intensity of thinning; and (4) average stand diameter (d.b.h.).

### 6.2.1 Age of first thinning

The age of first thinning appears to be critical in red pine investments to the extent that earlier ages of thinning show consistently better physical and economic returns than delayed thinnings (Table 6). The results were observed for three different thinning weights all of which showed better returns with the earlier thinning ages. This observation is confirmed by the fact that the returns decreased in the order of ages 35 < 30 < 25 < 20. The better volume produced with the earlier thinning ages can be explained by reduced biological competition between trees which allows less inhibited tree growth. The precedence of financial yield with earlier ages of first thinning appear to have been influenced by two factors: (1) reduced period of discounting the thinnings; and (2), increased volume yield.

### 6.2.2 Thinning weight

Differences exist between physical and economic outputs from stands treated with different thinning weights (Table 6). Heavier thinnings produce better sawlog volumes than lighter thinnings, consequently improving the value of the product as well as the financial yield. Table 6 shows that a thinning weight of 33.3 per cent of basal area/ha earns an IRR of 4.25 per cent while a 25 per cent weight earns only 4.10 per cent for the thinning at age 20. A thinning weight of 12.5 per cent of basal area/ha has only an IRR of 3.90 per cent. The sawlog production for the three thinning weights are respectively 208.0, 178.8, and 140.5 $m^3$/ha. Thus, although the level of growing stock is reduced more by heavier thinnings than lighter thinnings (e.g., compare basal areas for the three thinning weights at felling in Table 6), the gross volume and sawlog volumes are better with the heavier than with the lighter thinnings. The influence of heavier thinnings on the improved gross and sawlog volume and financial yield can be explained as follows:

(1) gross volume - the larger volume removed at thinning more than compensates for the loss of growing stock volume associated with heavier thinnings.

(2) sawlog - the larger logs resulting from heavy thinning add considerable volume to the relatively large volume obtained from the heavy thinnings.

(3) financial yield - the later the revenues or costs occur the less they count to the NPV (Duerr et al. 1979). Thus, the earlier returns from heavier thinnings add much heavier weights to the NPV. These early returns from thinnings together with returns from the sales of larger sawlogs at clearfelling make the financial returns from heavier thinnings better than for lighter thinnings.

### 6.2.3 Thinning cycle

If a standardized thinning intensity is contemplated (this may be necessary for a constant supply of raw material to an industry), longer thinning cycles should be preferred to shorter rotations because they offer better returns (Table 9). The supporting argument behind this is that longer cycles remove a larger part of the growing stock, allowing more space for tree growth than would be the case with shorter cycles. Heavier thinnings with shorter thinning cycles are undesirable because they may cause windfalls in addition to inefficient site use (Maw 1909; Johnson et al. 1967; Benzie 1977).

### 6.2.4 Average stand diameter

Height growth remains constant for a wide range of stand density levels (Lemmien and Rudolph 1959; Stiell 1964; Von Althen et al. 1978; Anon. 1983), while in contrast, average d.b.h. changes with density levels (Anon. 1983; Berry 1984). Thus the planning model is more sensitive to d.b.h. levels than heights (also see Table 6). The importance of d.b.h. in the planning model is demonstrated by data on sawlog volume factors under various d.b.h. and ages in the various phases of thinning regime assessments. These data are shown in Table 19 and are illustrated in Figures 12 and 13.

Table 19. The relationship between age, d.b.h., and sawlog volume factors as observed from various phases of alternative thinning regimes (based on Table 9)

| | | T.I. 5 | | T.I. 6 | | T.I. 7 | | T.I. 8 | |
|---|---|---|---|---|---|---|---|---|---|
| AGE | HEIGHT (m) | D.B.H. (cm) | S.F (%) | D.B.H. (cm) | S.F (%) | D.B.H. (cm) | S.F (%) | D.B.H. (cm) | S.F (%) |
| 20 | 6.6 | 9.6 | 8.3 | 9.6 | 8.3 | 9.6 | 8.3 | 9.6 | 8.3 |
| 25 | 8.3 | 13.0 | 25.1 | 13.3 | 27.2 | 13.7 | 29.5 | 14.2 | 32.1 |
| 30 | 9.8 | 15.3 | 36.1 | 16.0 | 40.1 | 16.7 | 44.6 | 17.6 | 49.6 |
| 35 | 11.4 | 17.2 | 45.5 | 18.2 | 51.6 | 19.5 | 58.3 | 20.9 | 65.6 |
| 40 | 12.9 | 18.9 | 54.2 | 20.4 | 62.4 | 22.2 | 71.2 | 24.3 | 80.1 |
| 45 | 14.5 | 20.5 | 62.3 | 22.5 | 72.7 | 24.9 | 82.8 | 28.1 | 95.0 |
| 50 | 16.0 | 22.0 | 70.2 | 24.6 | 82.1 | 27.9 | 92.5 | 32.3 | 95.0 |
| 55 | 17.5 | 23.4 | 77.5 | 26.8 | 90.4 | 31.2 | 95.0 | 37.3 | 95.0 |
| 60 | 18.9 | 24.8 | 84.2 | 29.1 | 95.0 | 34.8 | 95.0 | 43.4 | 95.0 |

where: T.I. (i), i=5, 6, .....8 =sawlog factor for thinning regimes of intensity of 5 to 8 $m^2$. $ha^{-1}$ per cycle.

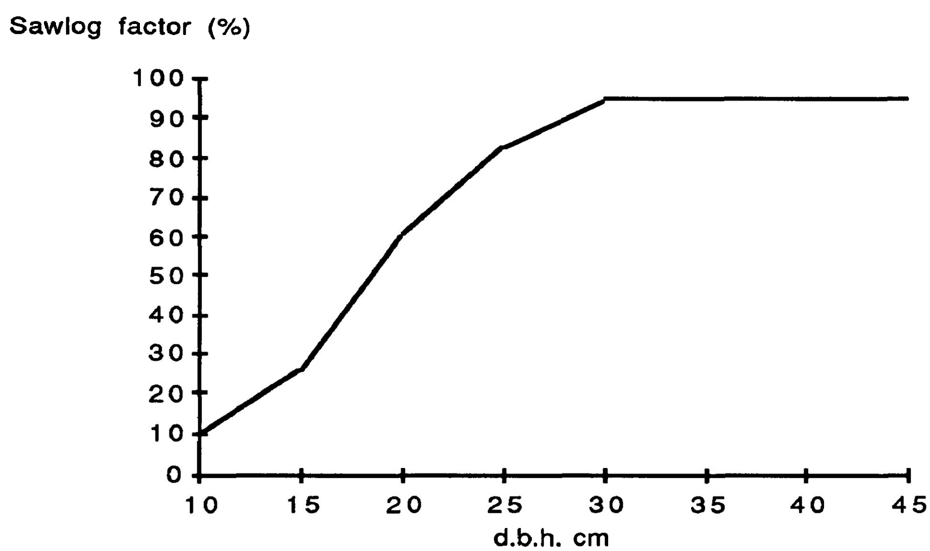


Figure 12. Sawlog factor/d.b.h. relationship as obtained from the planning model (based on Table 9).

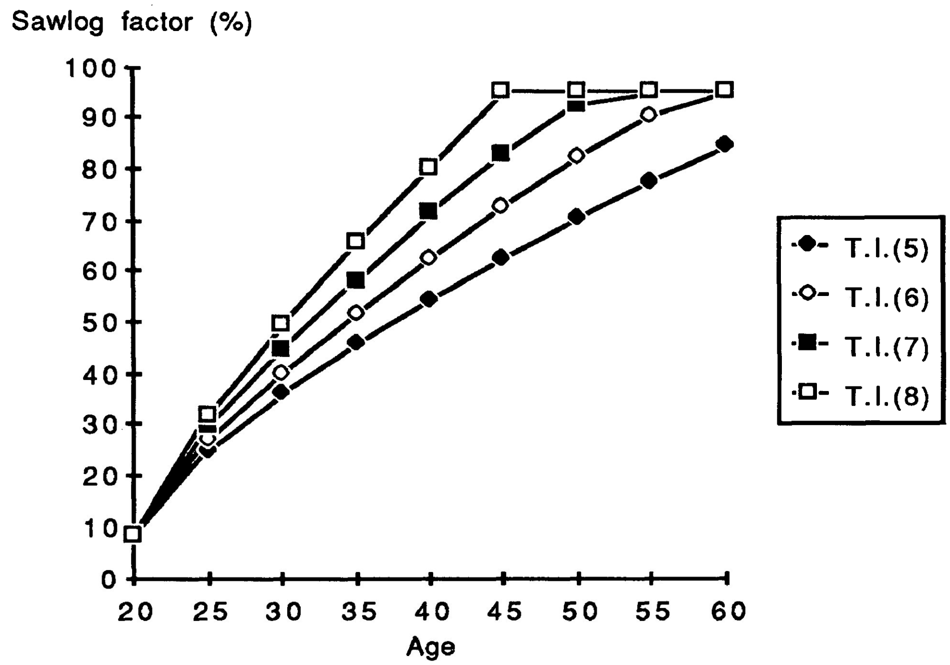


Figure 13. Sawlog factor/age relationships for four different thinning intensities as obtained from the planning model (based on Table 9).

From Table 19 and Figures 12 and 13 it can be seen that d.b.h. and age are important factors in determining sawlog factors. However, Table 19 and Figure 12 show that sawlog factor depends more on d.b.h. than age for within the same age, various sawlog factors can be obtained with different thinning intensities. More sawlog output is obtained with heavier, larger intensities of thinning. Given that height growth does not vary much with stand density (Table 19), it follows that sawlog development under various heights will follow the trend shown by Figure 13. In general, these results imply that the management of red pine stands for various wood products, sawlog, pulpwood etc. can be enhanced by the use of alternative thinning regimes that result in faster and larger diameter growth. Indeed these finding agree with model 3.2 which shows that height growth depends exclusively on age and site index. A better model could perhaps be one which links height growth with d.b.h. (Thrower 1986).

## 6.3 CONCLUSIONS

The objective of this study was to develop a microcomputer-based planning model which could be used to guide choices between alternative forestry investments as well as other nonforestry investments. This model has a special focus on alternative thinning regimes in red pine plantations.

The model has been built from stand-level growth models for southern Ontario which work within red pine stands of : (1) 10 $m^2$.ha-1 minimum basal area; (2) 0 - 65 years of age; (3) site indices 16 - 26 m. Also, new models were built which predict stand volume by products at any stand age. However, the construction of these latter models was constrained by a lack of adequate data, thus their ranges are quite limited. These limits reduce the overall range of the entire planning model to plantations between 20 and 45 years of age. Some modifications were made to the products models using computer programming techniques. These modifications allow use of the planning model beyond the current ranges of the products models although the precision of the values estimated cannot be assured.

Close agreement was obtained when the model was tested using limited data from a few sources such as the Rockland plantation and the Hogarth plantations. This makes the model tentatively suitable as a decision aiding tool. The model was also run for information on red pine plantation management using alternative thinning treatments. Among the treatments tested were: (1) age of first thinning; (2) thinning weight; (3) thinning cycle under a constant thinning intensity; (4) thinning frequency; and (5) thinning intensity. The results of these tests showed that earlier age of first thinning, heavier thinnings, longer thinning cycles for a constant thinning intensity, and higher thinning intensities maximized both volume production and financial yield compared to delayed thinnings, lighter thinnings, shorter thinning cycles , and lower thinning intensities, respectively. The results also showed that financial yield increased with increasing thinning frequency; the converse was the case with volume production. The model needs a rigorous test with large volumes of data to confirm these early results.

Such tests would require designed field experiments lasting several decades. This study therefore, provides a tool for focussing expensive, long-term growth studies on certain areas within red pine stand development.

The models used in this study and the results obtained from the various tests made to the planning model lead to the following recommendations for future research needs in investment modelling in red pine plantations in the Thunder Bay District.

(i) A better height growth model based on diameter and planting or total age should be built for use with the planning model. This would ensure consistent growth in height and product factors; the present height growth varies with age instead of diameter which varies with product factors.

(ii) Better product factor models should be developed to replace the ones used in this study. With the merchantable volume factor, the same site index, d.b.h., and height ranges (i.e. SI 15 - 27, d.b.h. 8 - 36 cm, height 7.0 - 31 m) can be repeated for data from the Thunder Bay District. For sawlog volume factor, a model should be built with d.b.h. and height ranges equivalent to those of merchantable volume factor. This would reduce the limitations imposed by one model to the other, such as is the present case.

(iii) Designed field experiments to test the effects of age of first thinning, thinning weights, thinning cycles, thinning frequency, and thinning intensity should be set up for future corroboration of earlier results of the planning model.

(iv) Representative models for various pole product classes should be built so that these models can be incorporated in the planning model to increase the number of products for evaluating alternative thinning regimes. This would consequently increase the effectiveness of this tool in the decision-making process.

This planning model could be modified for use with other species such as white pine, black spruce, and others, by substituting red pine growth and yield models with those of the desired species. However, this will only be possible if such models are available. Thus, future research needs also should ensure availability of stand-level growth and product factor models for other important forest tree species in the district.

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# APPENDICES

# APPENDIX 1

PLANTATION RED PINE MERCHANTABLE VOLUME AS A PERCENTAGE OF GROSS VOLUME (AS DERIVED FROM BERRY 1984).

| SITE INDEX (m) | $HT_{DOM.}$ (m) | D.B.H. (cm) | %M.V. | SITE INDEX (m) | $HT_{DOM.}$ (m) | D.B.H. (cm) | %M.V. |
|---|---|---|---|---|---|---|---|
| 15 | 7.0 | 7.4 | 17 | 18 | 8.4 | 8.1 | 27 |
| | | 8.5 | 25 | | | 9.3 | 35 |
| | | 9.5 | 33 | | | 10.4 | 43 |
| | | 10.5 | 39 | | | 11.5 | 49 |
| | | 12.4 | 48 | | | 13.6 | 58 |
| | | 14.3 | 52 | | | 15.6 | 64 |
| | | 16.0 | 53 | | | 17.5 | 66 |
| | | 17.7 | 55 | | | 19.3 | 68 |
| | 10.0 | 8.9 | 36 | | 12.0 | 9.9 | 49 |
| | | 10.2 | 44 | | | 11.2 | 54 |
| | | 11.3 | 52 | | | 12.5 | 60 |
| | | 12.5 | 57 | | | 13.7 | 63 |
| | | 14.7 | 66 | | | 16.1 | 70 |
| | | 16.9 | 70 | | | 18.4 | 76 |
| | | 19.0 | 73 | | | 20.6 | 78 |
| | | 21.0 | 75 | | | 22.8 | 81 |
| | 12.6 | 10.2 | 50 | | 15.2 | 11.0 | 60 |
| | | 11.5 | 57 | | | 12.9 | 65 |
| | | 12.8 | 62 | | | 14.2 | 69 |
| | | 14.0 | 65 | | | 15.5 | 71 |
| | | 16.5 | 73 | | | 18.0 | 78 |
| | | 18.8 | 78 | | | 20.6 | 82 |
| | | 21.1 | 80 | | | 23.0 | 84 |
| | | 23.3 | 82 | | | 25.4 | 86 |
| | 15.0 | 11.5 | 60 | | 18.0 | 13.3 | 68 |
| | | 12.8 | 64 | | | 14.5 | 71 |
| | | 14.1 | 69 | | | 15.8 | 75 |
| | | 15.4 | 72 | | | 17.1 | 77 |
| | | 17.9 | 78 | | | 19.7 | 82 |
| | | 20.4 | 82 | | | 22.3 | 84 |
| | | 22.9 | 84 | | | 24.9 | 87 |

APPENDIX 1. CONT.

APPENDIX 1. CONT'D.

| SITE INDEX (m) | $HT_{DOM.}$ (m) | D.B.H. (cm) | %M.V. | SITE INDEX (m) | $HT_{DOM.}$ (m) | D.B.H. (cm) | %M.V. |
|---|---|---|---|---|---|---|---|
| 21 | 9.8 | 8.8 | 35 | 24 | 11.1 | 9.5 | 44 |
| | | 10.0 | 43 | | | 10.7 | 50 |
| | | 11.2 | 50 | | | 12.0 | 56 |
| | | 12.4 | 55 | | | 13.2 | 61 |
| | | 14.6 | 65 | | | 15.5 | 69 |
| | | 16.7 | 69 | | | 17.7 | 74 |
| | | 18.8 | 72 | | | 19.9 | 76 |
| | | 20.8 | 75 | | | 22.0 | 77 |
| | 14.0 | 10.9 | 56 | | 15.9 | 12.0 | 63 |
| | | 12.3 | 61 | | | 13.3 | 66 |
| | | 13.5 | 67 | | | 14.6 | 70 |
| | | 14.8 | 70 | | | 15.9 | 74 |
| | | 17.3 | 76 | | | 18.5 | 78 |
| | | 19.8 | 80 | | | 21.0 | 83 |
| | | 22.2 | 82 | | | 23.3 | 86 |
| | | 24.5 | 83 | | | 25.9 | 87 |
| | 17.7 | 13.1 | 68 | | 20.2 | 14.8 | 73 |
| | | 14.4 | 71 | | | 16.0 | 75 |
| | | 15.6 | 73 | | | 17.1 | 77 |
| | | 16.9 | 77 | | | 18.4 | 81 |
| | | 19.5 | 82 | | | 21.0 | 84 |
| | | 22.1 | 85 | | | 23.7 | 87 |
| | | 24.7 | 87 | | | 26.3 | 89 |
| | | 27.2 | 88 | | | 28.9 | 90 |
| | 21.0 | 15.4 | 74 | | 24.0 | 17.9 | 77 |
| | | 16.5 | 75 | | | 18.7 | 80 |
| | | 17.7 | 78 | | | 19.8 | 82 |
| | | 18.9 | 81 | | | 29.9 | 84 |
| | | 21.5 | 85 | | | 23.4 | 86 |
| | | 24.1 | 87 | | | 25.9 | 89 |
| | | 26.8 | 88 | | | 28.6 | 90 |
| | | 29.4 | 90 | | | 31.3 | 91 |
| | 23.8 | 17.7 | 77 | | 27.2 | 20.7 | 82 |

APPENDIX 1. CONT.

APPENDIX 1. CONT'D.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 18.6 | 80 | | | 21.5 | 83 |
| | | | 19.7 | 81 | | | 22.3 | 85 |
| | | | 20.8 | 84 | | | 23.3 | 87 |
| | | | 23.3 | 87 | | | 25.5 | 88 |
| | | | 25.8 | 89 | | | 28.0 | 90 |
| | | | 28.5 | 90 | | | 30.6 | 91 |
| | | | 31.1 | 91 | | | 33.2 | 91 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 27 | 12.5 | 10.2 | 51 | 27 | 22.8 | 22.6 | 86 | |
| | | | 11.5 | 57 | | | 25.2 | 88 |
| | | | 12.7 | 62 | | | 27.9 | 90 |
| | | | 14.0 | 64 | | | 30.5 | 90 |
| | | | 16.4 | 72 | | 27.0 | 20.5 | 81 |
| | | | 18.8 | 77 | | | 21.3 | 83 |
| | | | 21.0 | 79 | | | 22.1 | 85 |
| | | | 23.2 | 82 | | | 23.1 | 87 |
| | | 17.9 | 13.3 | 67 | | | 25.4 | 88 |
| | | | 14.5 | 71 | | | 27.9 | 90 |
| | | | 15.7 | 75 | | | 30.5 | 91 |
| | | | 17.0 | 76 | | | 33.1 | 91 |
| | | | 19.6 | 82 | | 30.7 | 24.1 | 84 |
| | | | 22.2 | 85 | | | 24.7 | 85 |
| | | | 24.8 | 87 | | | 25.3 | 86 |
| | | | 27.4 | 88 | | | 26.2 | 88 |
| | | 22.8 | 16.9 | 76 | | | 28.1 | 89 |
| | | | 17.8 | 78 | | | 30.4 | 90 |
| | | | 19.0 | 81 | | | 32.8 | 91 |
| | | | 20.1 | 82 | | | 35.4 | 92 |

Where: $HT_{DOM.}$=dominant height, D.B.H. = breast height diameter, %M.V.= merchantable volume per cent of gross volume.

# APPENDIX 2

PRODUCT YIELD TABLES FOR ALTERNATIVE PRODUCTS - LUMBER UTILIZATION (AS ADAPTED FROM THE ONTARIO DEPT.OF LANDS AND FORESTS, 1961) - IN SI UNITS.

| D.B.H. CLASS (cm) | PRODUCT | TREE HEIGHT CLASS (m) 9.1 | 10.7 | 12.2 | 13.7 | 15.2 | 16.8 | 18.3 | 19.8 | 21.3 | 22.9 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MERCHANTABLE VOLUME ($m^3$) | | | | | | | | | |
| 17.8 | SV | - | - | 0.04 | 0.04 | 0.05 | 0.05 | 0.06 | 0.07 | 0.07 | - |
| | PV | - | - | 0.062 | 0.074 | 0.091 | 0.105 | 0.116 | 0.136 | 0.142 | - |
| 20.3 | SV | 0.06 | 0.065 | 0.075 | 0.09 | 0.12 | 0.125 | 0.13 | 0.17 | 0.175 | 0.175 |
| | PV | 0.028 | 0.031 | 0.045 | 0.045 | 0.059 | 0.071 | 0.079 | 0.088 | 0.096 | 0.113 |
| 22.9 | SV | 0.07 | 0.08 | 0.12 | 0.135 | 0.175 | 0.195 | 0.205 | 0.285 | 0.31 | 0.315 |
| | PV | 0.025 | 0.028 | 0.031 | 0.039 | 0.042 | 0.045 | 0.057 | 0.062 | 0.059 | 0.065 |
| 25.4 | SV | - | 0.125 | 0.15 | 0.175 | 0.225 | 0.25 | 0.28 | 0.365 | 0.39 | 0.45 |
| | PV | - | 0.028 | 0.028 | 0.028 | 0.031 | 0.042 | 0.045 | 0.045 | 0.042 | 0.042 |
| 27.9 | SV | - | 0.16 | 0.185 | 0.235 | 0.275 | 0.34 | 0.365 | 0.445 | 0.47 | 0.515 |
| | PV | - | 0.017 | 0.014 | 0.025 | 0.028 | 0.031 | 0.031 | 0.031 | 0.040 | 0.042 |
| 30.5 | SV | - | - | 0.225 | 0.295 | 0.33 | 0.42 | 0.45 | 0.505 | 0.565 | 0.66 |
| | PV | - | - | 0.014 | 0.017 | 0.028 | 0.028 | 0.028 | 0.031 | 0.031 | 0.028 |
| 33.0 | SV | - | - | - | 0.37 | 0.385 | 0.515 | 0.56 | 0.605 | 0.675 | 0.825 |
| | PV | - | - | - | 0.014 | 0.017 | 0.017 | 0.028 | 0.028 | 0.028 | 0.028 |
| 35.6 | SV | - | - | - | - | - | 0.59 | 0.685 | 0.705 | 0.81 | 0.94 |
| | PV | - | - | - | - | - | 0.014 | 0.017 | 0.028 | 0.025 | 0.017 |
| 38.1 | SV | - | - | - | - | - | - | - | 0.865 | 0.915 | 1.06 |
| | SV | - | - | - | - | - | - | - | 0.017 | 0.017 | 0.014 |

APPENDIX 3. A LISTING OF THE PROGRAM

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]LIST

 10  REM  THIS PROGRAM USES STAND GROWTH MODELS TO SIMULATE GROWTH AND
 20  REM  YIELD FROM ALTERNATIVE THINNING REGIMES IN RED PINE PLANTATIONS
 25  REM  IN ONTARIO.
 30  REM  IT ALLOWS THE USER TO SPECIFY ALTERNATIVE THINNING REGIMES FROM
 40  REM  WHICH PHYSICAL AND ECONOMIC RETURNS CAN BE CALCULATED.
 50  REM
 60  REM
 70  REM  THE PROGRAM IS INTENDED TO ASSIST DECISION MAKING IN RED PINE
 80  REM  PLANTATION INVESTMENTS.
 90  REM
 100  REM  CONSTRUCTED BY A.K. KAJIAS, 1987.
 110  REM
 120  REM  VARIABLES
 130  REM
 140  REM    CA,CB....=CONSTANTS, E=MATH. EXPRESSIONS, AF=FUTURE STAND AGE
 145  REM  V=THINNED VOL.,NT=THINNED STEMS/ha,NR=RESIDUAL STEMS/ha,
 150  REM  M=THINNED MERCH.VOL.,D=D.B.H.,F=MERCH.VOL.FACTOR (%),
 155  REM  H=HEIGHT,BF=FUTURE BASAL AREA,W=NET PRESENT VALUE,
 160  REM  BR=RESIDUAL BASAL AREA,BT=THINNED BASAL AREA,
 165  REM  PS=SAWLOG FACTOR(%),PP=PULPWOOD FACTOR(%),SL=SAWLOG VOL.,
 170  REM  PW=PULPWOOD VOL.,Z=THINNING AGE,Y=NET REVENUE(THINNING),
 175  REM  C1=LIMIT FOR MERCH.VOL.FACTOR,C2=LIMIT FOR SAWLOG FACTOR
 180  REM  ALL UNITS ARE IN SI UNITS.
 185  HOME
 190 CA = 72.2468
 200 CB = 1126666.67
 210 CC =  - 27388
 220 CD =  - .000255
 230 CE = .064374
 240 CF =  - 6.0027
 250 CG = .4745
 260 CH = 50:CI = 12732.4:CJ = .28228
 270 CK = .30571:CL = 5.81205:CM =  - .10279
 280 CN =  - 1.13513:CO = 4.34472:CP =  - 9.94622:CQ = .71207:CS =  - .0485:CU =
 - .01194
 290 :
 300 :
 310  DIM V(100): DIM N(100): DIM NT(100)
 320  DIM NR(100): DIM M(100): DIM D(100): DIM F(100): DIM H(100)
 330  DIM BN(100): DIM AN(100): DIM AF(100): DIM BF(100): DIM W(100)
 340  DIM BR(100): DIM BT(100): DIM PS(100): DIM PP(100): DIM SL(100)
 350  DIM PW(100): DIM Z(100): DIM Y(100)
 360 :
 370 :
 380 :
 390 I = 1
 400 STD = 1: PRINT "STAND ";STD
 410 REGIME = 1: PRINT "REGIME ";REGIME
 430  PRINT
 440  INPUT "ENTER PRESENT BASAL AREA      ,M2/HA ";DU
 441  PRINT "IS "DU" THE VALUE OF BASAL AREA YOU WANTED?
 442  INPUT "Y/N";Y$
 443  IF Y$ = "Y" THEN BN(I) = DU: GOTO 450
 444  GOTO 440
 450  INPUT "ENTER PRESENT STAND AGE     ,YEARS";DU
 451  PRINT "IS "DU" THE VALUE OF AGE YOU WANTED?
 452  INPUT "Y/N ";Y$
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453  IF Y$ = "Y" THEN AN(I) = DU: GOTO 460
454  GOTO 450
460  INPUT "ENTER SITE INDEX    ,M AT AGE 50 ";DU
461  PRINT "IS "DU" THE VALUE OF SITE INDEX YOU WANTED?
462  INPUT "Y/N ";Y$
463  IF Y$ = "Y" THEN S = DU: GOTO 470
464  GOTO 460
470  INPUT "ENTER NUMBER OF STEMS/HA,        ";DU
471  PRINT "IS "DU" THE NUMBER OF STEMS/HA YOU WANTED?
472  INPUT "Y/N ";Y$
473  IF Y$ = "Y" THEN N(I) = DU: GOTO 480
474  GOTO 470
480 AF(I) = AN(I)
510  INPUT "ENTER ESTAB.COSTS,   ,$/HA         ";DU
511  PRINT "IS "DU" THE ESTAB.COSTS YOU WANTED?
512  INPUT "Y/N ";Y$
513  IF Y$ = "Y" THEN A1 = DU: GOTO 520
514  GOTO 510
520  INPUT "ENTER ANNUAL MANAGEMENT COSTS    ,$/HA ";DU
521  PRINT "IS "DU" THE MANAG. COSTS YOU WANTED?
522  INPUT "Y/N ";Y$
523  IF Y$ = "Y" THEN A2 = DU: GOTO 530
524  GOTO 520
530  INPUT "ENTER THINNING COSTS,    ,$/M3     ";DU
531  PRINT "IS "DU" THE THINNING COSTS YOU WANTED?
532  INPUT "Y/N ";Y$
533  IF Y$ = "Y" THEN A3 = DU: GOTO 535
534  GOTO 530
535  INPUT "ENTER CLEARCUTTING COSTS,$/M^3     ";DU
536  PRINT "IS "DU" THE CLEARCUT COST YOU WANTED?
537  INPUT "Y/N ";Y$
538  IF Y$ = "Y" THEN A4 = DU: GOTO 540
539  GOTO 535
540  INPUT "ENTER SAWLOG PRICE,$/M^3           ";DU
541  PRINT "IS "DU" THE SAWLOG PRICE YOU WANTED?
542  INPUT "Y/N ";Y$
543  IF Y$ = "Y" THEN A5 = DU: GOTO 545
544  GOTO 540
545  INPUT "ENTER PULPWOOD PRICE,$/M^3         ";DU
546  PRINT "IS "DU" THE PULPWOOD PRICE YOU WANTED?
547  INPUT "Y/N ";Y$
548  IF Y$ = "Y" THEN A6 = DU: GOTO 550
549  GOTO 545
550  INPUT "ENTER DISCOUNT RATE, IN PER CENT   ";DU
551  PRINT "IS "DU" THE DISCOUNT RATE YOU WANTED?
552  INPUT "Y/N ";Y$
553  IF Y$ = "Y" THEN A7 = DU: GOTO 555
554  GOTO 550
555  PRINT "1 = THINNING OPTION": PRINT "2 = NON-THINNING OPTION"
560  INPUT "WHICH OPTION DO YOU WISH TO ANALYSE?";QQ
565  IF QQ = 1 GOTO 595
570  IF QQ = 2 THEN  GOSUB 45000
595  GOSUB 3000
600  PRINT "REPORT OF STAND CONDITION"
610  PRINT
620  PRINT "STAND AGE,YRS=                    ";AF(I)
630  PRINT "BASAL AREA,M^2/HA=                ";BF(I)
640  GOSUB 7000
650  PRINT "NUMBER OF STEMS/HA=               ";N(I)
660  PRINT "TOTAL VOLUME,M^3/HA=              ";V(I)
670  PRINT "MERCH. VOLUME,M^3/HA=             ";M(I)
680  PRINT "SAWLOG VOLUME,M^3/HA=             ";SL(I)
690  PRINT "PULPWOOD VOLUME,M^3/HA=           ";PW(I)
700  PRINT "PER CENT MERCH. VOLUME=           ";F(I)
710  PRINT "PER CENT SAWLOG VOLUME=           ";PS(I)
720  PRINT "PER CENT PULPWOOD VOLUME=         ";PP(I)
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 730  PRINT
 760  INPUT "DO YOU WANT TO CLEARCUT STAND? Y/N ";Y$
 770  IF Y$ = "Y" THEN  GOSUB 7000: GOSUB 17000: GOSUB 23000: GOTO 870
 795  INPUT "DO YOU WANT TO THIN STAND? Y/N ";Y$
 800  IF Y$ = "Y" THEN  GOSUB 4000: GOSUB 11000: GOSUB 19000: GOSUB 22000: GOSUB
 2000: GOSUB 3000: GOTO 600
 810  IF Y$ = "N" GOTO 600
 820  PRINT
 830  GOSUB 7000: GOSUB 17000: GOSUB 23000
 840  GOSUB 11000: GOSUB 19000: GOSUB 22000
 870  PRINT "REPORT OF PHYSICAL AND ECONOMIC RETURNS FROM REGIME ";REGIME
 880  PRINT
 890  PRINT "1. STAND VOLUME DEVELOPMENT OVER TIME"
 900  PRINT
 910  PRINT "A"; TAB( 4);"G.V"; TAB( 8);"G.M"; TAB( 10);"G.S"; TAB( 12);"G.P"; T
AB( 14);"T.V"
 920  PRINT
 930 C1 = 0
 940 C2 = 0
 950  IF I = 1 GOTO 1310
 960  FOR K = 1 TO I - 1
 970 X = AF(K + 1) - AF(K)
 980  FOR J = 0 TO X - 1
 990 E1 = (AF(K) + J) - AF(K)
 1000 E2 = ((AF(K) + J) ^  - 3) - (AF(K) ^  - 3)
 1010 E3 = ((AF(K) + J) ^  - 1) - (AF(K) ^  - 1)
 1020 E4 = S * (((AF(K) + J) ^ 3) - (AF(K) ^ 3))
 1030 E5 = BN(K + 1) ^ 2
 1040 E6 = CA * E1 + CB * E2 + CC * E3 + CD * E4 + E5
 1050 GB = E6 ^ (1 / 2)
 1060 AH = CE * S * (((AF(K) + J) / CH) - ((AF(K) + J) / CH) ^ 2) + S * (AF(K) +
 J) / CH
 1070 DB = (CI * GB / N(K + 1)) ^ (1 / 2)
 1080 FM = CJ + CK * DB + CL * AH + CM * AH ^ 2
 1100  IF C1 = 1 GOTO 1130
 1110  IF FM <  = 90 GOTO 1140
 1120 C1 = 1
 1130 FM = 90
 1140 LP = CN + CO * DB + CP * AH + CQ * AH * DB + CS * DB ^ 2 + CU * DB ^ 2 * A
H
 1145  IF LP < 0 THEN LP = 0
 1150  IF C2 = 1 GOTO 1180
 1160  IF LP <  = 95 GOTO 1200
 1170 C2 = 1
 1180 LP = 95
 1200 GV =  INT ((CF + CG * GB * AH) * 100 + .5) / 100
 1210 GM =  INT ((GV * FM / 100) * 100 + .5) / 100
 1220 GS =  INT ((GM * LP / 100) * 100 + .5) / 100
 1230 GP =  INT ((GM - GS) * 100 + .5) / 100
 1240  IF J <  > 0 GOTO 1270
 1250  PRINT AF(K); TAB( 3);VT(K) - V(K); TAB( 6);MT(K) - M(K); TAB( 9);ST(K) -
SL(K); TAB( 12);PT(K) - PW(K); TAB( 16);V(K)
 1260  GOTO 1280
 1270  PRINT AF(K) + J; TAB( 3);GV; TAB( 6);GM; TAB( 9);GS; TAB( 12);GP
 1280  NEXT J
 1290  NEXT K
 1310  PRINT AF(K); TAB( 3);V1; TAB( 5);M1; TAB( 9);S1; TAB( 13);PU
 1320  PRINT "A=STAND AGE"
 1330  PRINT "G.V=GROWING STOCK"
 1340  PRINT "G.M=MERCH.VOL.OF GROWING STOCK"
 1350  PRINT "G.S=SAWLOG VOLUME OF GROWING STOCK"
 1360  PRINT "G.P=PULPWOOD VOLUME OF GROWING STOCK"
 1370  PRINT "T.V.=THINNED VOLUME"
 1380  PRINT
 1390  PRINT "2. PHYSICAL RETURNS FROM A THINNING REGIME"
 1400  PRINT
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1410  PRINT "AGE"; TAB( 5);"T.V."; TAB( 15);"C.C.V."
1420  PRINT
1430  FOR K = 1 TO I - 1
1440  PRINT AF(K); TAB( 5);V(K); TAB( 15);"0"
1450  NEXT K
1460  PRINT AF(I); TAB( 5);"0"; TAB( 15);V1
1470  PRINT
1480  PRINT "T.V.=THINNED VOLUME": PRINT "C.C.V.=CLEARCUT VOLUME"
1490  PRINT "ROTATION AGE=                      ";AF(I)
1500  PRINT "TOTAL REGIME VOLUME,M^3/HA=     ";V2 + V1
1510  PRINT "TOTAL REGIME MERCH.VOL.,M^3/HA= ";M2 + M1
1520  PRINT "AVERAGE STAND PRODUCTIVITY,M^3/HA/YR= ";(V2 + V1) / AF(I)
1530  PRINT "TOTAL REGIME SAWLOG VOL.,M^3/HA=  ";S1 + S2
1540  PRINT "PULPWOOD VOL.,M^3/HA=             ";PU + P2
1560  PRINT
1570  PRINT "3. ECONOMIC RETURNS FROM THE REGIME"
1580  PRINT
1590  PRINT "AGE"; TAB( 7);"D.C."; TAB( 10);"D.R."
1600  PRINT
1610  PRINT "0"; TAB( 7);A1; TAB( 10);"0"
1620  FOR K = 1 TO I - 1
1630  PRINT AF(K); TAB( 5);KT(K); TAB( 10);RT(K)
1640  NEXT K
1650  PRINT AF(I); TAB( 5);B6 + B7; TAB( 10);B5
1660  PRINT
1670  PRINT "D.C.=DISCOUNTED COSTS": PRINT "D.R.=DISCOUNTED REVENUE"
1680  PRINT
1690  PRINT "REGIME'S NPW (EXCLUDING LAND VALUE), $/HA= ";W1 + W2
1700  PRINT "REGIME'S INTERNAL RATE OF RETURN (IRR)=    ";R * 100"%"
1710  PRINT
1720  PRINT "ASSUMPTIONS MADE ON THE COSTS AND REVENUE ARE AS FOLLOW:"
1730  PRINT
1740  PRINT "SAWLOG PRICE,$/M^3=                  ";A5
1750  PRINT "PULPWOOD PRICE,$/M^3=                ";A6
1760  PRINT
1770  PRINT "INITIAL ESTAB. COSTS,$/HA=           ";A1
1780  PRINT "THINNING COSTS,$/M^3=                ";A3
1790  PRINT "CLEACUTTING COSTS,$/M^3=             ";A4
1800  PRINT "ANNUAL MANAGEMENT COSTS,$/HA=        ";A2
1810  PRINT
1840  INPUT "DO YOU WANT TO ANALYSE 'WHAT IF' OPTIONS? Y/N ";Y$
1845  IF Y$ = "Y" THEN  GOSUB 28000
1860  INPUT "MORE REGIMES? Y/N ";Y$
1870  IF Y$ = "Y" THEN  GOSUB 25000: GOTO 1930
1880  PRINT
1890  INPUT "MORE STANDS? Y/N ";Y$
1900  IF Y$ = "Y" THEN  GOSUB 25000: GOSUB 27000: GOTO 1950
1910  IF Y$ = "N" THEN 1970
1920  PRINT
1930 REGIME = REGIME + 1:I = 1: PRINT "REGIME ";REGIME: GOTO 610
1940  PRINT
1950 STD = STD + 1:I = 1: PRINT "STAND ";STD: GOTO 410
1960  PRINT
1970  PRINT : PRINT "PROGRAM STOPS"
1980  END
1990 :
2000  INPUT "ENTER NEW FUTURE STAND AGE ";AF(I)
2010  IF QQ = 1 GOTO 2030
2020  IF QQ = 2 THEN  GOSUB 45000
2030  RETURN
2040 :
3000  REM  BASAL AREA FORECASTING SYSTEM
3005 E1 = AF(I) - AN(I)
3020 E2 = (AF(I) ^  - 3) - (AN(I) ^  - 3)
3030 E3 = (AF(I) ^  - 1) - (AN(I) ^  - 1)
3040 E4 = S * ((AF(I) ^ 3) - (AN(I) ^ 3))
```

```
3050 E5 = BN(I) ^ 2
3060 E6 = CA * E1 + CB * E2 + CC * E3 + CD * E4 + E5
3070 BF(I) = E6 ^ (1 / 2)
3080  RETURN
3090 :
4000  INPUT "ENTER PER CENT OF BASAL AREA THIN ";P
4020 P1 = P / 100
4030 BT(I) = BF(I) * P1
4040 BR(I) = BF(I) - BT(I)
4050 NT(I) = N(I) * P1
4060 NR(I) = N(I) - NT(I)
4080 I = I + 1
4090 BN(I) = BR(I - 1)
5000 AN(I) = AF(I - 1)
5010 N(I) = NR(I - 1)
5020  RETURN
5030 :
7000  REM  ESTIMATE VOLUME CLEARCUT,V1
7010 H(I) = CE * S * ((AF(I) / CH) - (AF(I) / CH) ^ 2) + S * (AF(I) / CH)
7030 V(I) = CF + CG * BF(I) * H(I)
7040 V1 = V(I)
7050 V1 =  INT (V1 * 100 + .5) / 100
7065  PRINT "BASAL AREA=";BF(I)
7070 D(I) = (CI * BF(I) / N(I)) ^ (1 / 2): PRINT "DBH= ";D(I)
7075  PRINT "HEIGHT= ";H(I)
7090 F(I) = CJ + CK * D(I) + CL * H(I) + CM * H(I) ^ 2
8000  IF C1 = 1 GOTO 8030
8010  IF F(I) <  = 90 GOTO 8060
8020 C1 = 1
8030 F(I) = 90
8060 M(I) = V(I) * F(I) / 100
8070 M1 = M(I)
8080 M1 =  INT (M1 * 100 + .5) / 100
9000 PS(I) = CN + CO * D(I) + CP * H(I) + CQ * H(I) * D(I) + CS * D(I) ^ 2 + CU
* D(I) ^ 2 * H(I)
9005  IF PS(I) < 0 THEN PS(I) = 0
9010  IF C2 = 1 GOTO 9040
9020  IF PS(I) <  = 95 GOTO 9060
9030 C2 = 1
9040 PS(I) = 95
9060 PP(I) = 100 - PS(I)
9080 SL(I) = M1 * PS(I) / 100
9090 S1 = SL(I)
10000 S1 =  INT (S1 * 100 + .5) / 100
10020 PW(I) = M1 - S1
10030 PU = PW(I)
10040 PU =  INT (PU * 100 + .5) / 100
10050  RETURN
10060 :
11000  REM  ESTIMATE THINNED VOLUME,V2
11010 V2 = 0
11020 M2 = 0
11030 S2 = 0
11040 P2 = 0
11050 C1 = 0
11060 C2 = 0
11080  FOR K = 1 TO I
11090 H(K) = CE * S * ((AF(K) / CH) - (AF(K) / CH) ^ 2) + S * (AF(K) / CH)
12000 VT(K) =  INT ((CF + CG * BF(K) * H(K)) * 100 + .5) / 100
12010 V(K) = CF + CG * BT(K) * H(K)
12020 V(K) =  INT (V(K) * 100 + .5) / 100
12030  IF V(K) < 0 THEN V(K) = 0
12040 V2 = V2 + V(K)
12050 V2 =  INT (V2 * 100 + .5) / 100
12065  PRINT "BF(";K;")=";BF(K)
12070 D(K) = (CI * BF(K) / N(K)) ^ (1 / 2)
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12075  PRINT "H(";K;")=";H(K)
12090 F(K) = CJ + CK * D(K) + CL * H(K) + CM * H(K) ^ 2
13000  IF C1 = 1 GOTO 13030
13010  IF F(K) <  = 90 GOTO 13060
13020 C1 = 1
13030 F(K) = 90
13060 MT(K) =  INT ((VT(K) * F(K) / 100) * 100 + .5) / 100
13070 M(K) = V(K) * F(K) / 100
13080 M(K) =  INT (M(K) * 100 + .5) / 100
13090  IF M(K) < 0 THEN M(K) = 0
14000 M2 = M2 + M(K)
14010 M2 =  INT (M2 * 100 + .5) / 100
14030 PS(K) = CN + CO * D(K) + CP * H(K) + CQ * H(K) * D(K) + CS * D(K) ^ 2 + C
U * D(K) ^ 2 * H(K)
14035  IF PS(K) < 0 THEN PS(K) = 0
14040  IF C2 = 1 GOTO 14070
14050  IF PS(K) <  = 95 GOTO 15000
14060 C2 = 1
14070 PS(K) = 95
15000 PP(K) = 100 - PS(K)
15020 ST(K) =  INT ((MT(K) * PS(K) / 100) * 100 + .5) / 100
15030 SL(K) = M(K) * PS(K) / 100
15040 SL(K) =  INT (SL(K) * 100 + .5) / 100
15050  IF SL(K) < 0 THEN SL(K) = 0
15060 S2 = S2 + SL(K)
15070 S2 =  INT (S2 * 100 + .5) / 100
15090 PT(K) =  INT ((MT(K) - ST(K)) * 100 + .5) / 100
16000 PW(K) = M(K) - SL(K)
16010 PW(K) =  INT (PW(K) * 100 + .5) / 100
16020  IF PW(K) < 0 THEN PW(K) = 0
16030 P2 = P2 + PW(K)
16040 P2 =  INT (P2 * 100 + .5) / 100
16050  NEXT K
16060  RETURN
16070 :
17000  REM  ESTIMATE NPW FROM CLEARCUT,W2
17010 A8 = A7 / 100
17020 B1 = (SL(I) * A5) + (PW(I) * A6)
17030 B2 = M(I) * A4
17040 B3 = (1 + A8) ^ AF(I)
17050 B4 = ((B3) - 1) * A2
17060 B5 = B1 / B3
17070 B5 =  INT (B5 * 100 + .5) / 100
17080 B6 = B2 / B3
17090 B6 =  INT (B6 * 100 + .5) / 100
18000 B7 = B4 / (A8 * B3)
18010 B7 =  INT (B7 * 100 + .5) / 100
18020 BB = B5 - B6 - B7 - A1
18030 W1 = BB
18035  PRINT "W1= ";W1
18037  PRINT "I=";I
18040  RETURN
18050 :
19000  REM  ESTIMATE NPW FROM THINNING,W2
19010 A8 = A7 / 100
19020 W2 = 0
19030 U1 = 0
19040 RT = 0
19050 KT = 0
19060  FOR K = 1 TO I - 1
19070 G1 = (SL(K) * A5) + (PW(K) * A6)
19080 G2 = M(K) * A3
19090 G3 = (1 + A8) ^ AF(K)
20000 G4 = G1 / G3
20010 G5 = G2 / G3
20020 G6 = G4 - G5
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20030 W(K) = G6
20040  IF W(K) < 0 THEN W(K) = 0
20050 W2 = W2 + W(K)
20060 RT(K) = (SL(K) * A5 + PW(K) * A6) / (1 + A8) ^ AF(K)
20070  IF RT(K) < 0 THEN RT(K) = 0
20080 RT = RT + RT(K)
20090 RT(K) =  INT (RT(K) * 100 + .5) / 100
21000 KT(K) = (M(K) * A3) / (1 + A8) ^ AF(K)
21010  IF KT(K) < 0 THEN KT(K) = 0
21020 KT = KT + KT(K)
21030 KT(K) =  INT (KT(K) * 100 + .5) / 100
21040  NEXT K
21045  PRINT "W2=";W2
21047  PRINT "K= ";K
21050  RETURN
21060 :
22000  REM  INITIAL PART OF IRR ESTIMATION
22010  FOR K = 1 TO I - 1
22020 GX = SL(K) * A5 + PW(K) * A6
22030 GY = M(K) * A3
22040 GZ = AF(K)
22050 Y(K) = GX - GY
22060 Z(K) = GZ
22070  NEXT K
22080  RETURN
22090 :
23000  REM  FINAL PART OF IRR ESTIMATION
23010 R2 = 0.01
23020 R1 = 0.00
23030 R = (R2 + R1) / 2
23050 BP = 0
23055  FOR K = 1 TO I - 1
23070 BP = BP + Y(K) / (1 + R) ^ Z(K)
23080  NEXT K
23090 BP = BP + ((B1 - B2) / (1 + R) ^ AF(I))
24000 KX = (((1 + R) ^ AF(I)) - 1) * A2
24005 KY = R * (1 + R) ^ AF(I)
24010 DX = A1 + (KX / KY)
24020  IF (BP - DX) < 0.01 GOTO 24050
24030 R2 = R2 + 0.001
24040  GOTO 23030
24050 IRR = R
24060  RETURN
24070 :
25000  REM  SET PREVIOUS REGIME VARIABLES TO ZERO TO BEGIN NEW REGIMES AND RO S
TANDS
25010  FOR K = 1 TO I - 1
25020 V(K) = 0:H(K) = 0:NT(K) = 0:NR(K) = 0:M(K) = 0
25030 D(K) = 0:F(K) = 0:BT(K) = 0:W(K) = 0:BR(K) = 0
25040 PS(K) = 0:PP(K) = 0:SL(K) = 0:PW(K) = 0:Z(K) = 0:Y(K) = 0
25050  NEXT K
25060 C1 = 0
25070 C2 = 0
25090 :
26000 V1 = 0:V2 = 0:M1 = 0:M2 = 0:S1 = 0:S2 = 0
26040 PU = 0:P2 = 0:W1 = 0:W2 = 0:IRR = 0:NPW = 0
26050  RETURN
27000  REM  SET ALL PREVIOUS STAND VARIABLES TO ZERO TO BEGIN NEW STANDS
27005  FOR K = 1 TO I - 1
27010 BN(K) = 0:AN(K) = 0:AF(K) = 0:N(K) = 0
27020  NEXT K
27030 S = 0:A1 = 0:A2 = 0:A3 = 0:A4 = 0
27040 A5 = 0:A6 = 0:A7 = 0:A8 = 0
27050  RETURN
28000  REM  EVALUATION OF 'WHAT IF' OPTIONS
28055  PRINT "1 =SAWLOG VOL": PRINT "2 =SAWLOG PRICE": PRINT "3 =THIN COSTS
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      ": PRINT "4 =CLEARCUT COSTS": PRINT "5 =ESTAB.COSTS": PRINT "6 =ANN. MGMT
         COSTS": PRINT "7 =DISC. RATE"
28060  INPUT "WHICH ONE DO YOU WANT TO ANALYSE? 1/2/3/4/5/6/7 ";AA
28065  IF AA = 1 GOTO 30000
28070  IF AA = 2 GOTO 30200
28080  IF AA = 3 GOTO 30250
28090  IF AA = 4 GOTO 30300
29000  IF AA = 5 GOTO 30350
29010  IF AA = 6 GOTO 30400
29020  IF AA = 7 GOTO 30450
29030  REM
30000  INPUT "WHAT IS SAWLOG VOLUME,AS PROPORTION OF CURRENT SAWLOG VOL.
               =";IA
30010  FOR K = 1 TO I - 1
30020 SL(K) = SL(K) * IA
30025 PW(K) = PW(K) * (1 + 1 - IA)
30035  NEXT K
30040 SL(I) = SL(I) * IA
30050 PU = PU * (1 + 1 - IA)
30060  GOSUB 35000
30065  REM
30090  FOR K = 1 TO I - 1
30100 SL(K) = SL(K) / IA
30110 PW(K) = PW(K) / (1 + 1 - IA)
30120  NEXT K
30130 SL(I) = SL(I) / IA
30140 PU = PU / (1 + 1 - IA)
30150  GOTO 1840
30200  INPUT "WHAT IS SAWLOG PRICE,AS PROPORTION OF CURRENT PRICE=";IB
30210 A5 = IB * A5: PRINT "A5= ";A5: REM  NEW SAWLOG PRICE
30220  GOSUB 35000
30230 A5 = A5 / IB: PRINT "A5=";A5: REM   RESET BACK OLD PRICE.
30240  GOTO 1840
30250  INPUT "WHAT IS THINNING COST,AS PROPORTION OF CURRENT COST=";IC
30260 A3 = A3 * IC
30270  GOSUB 35000
30280 A3 = A3 / IC
30290  GOTO 1840
30300  INPUT "WHAT IS CLEARCUT COSTS,AS PROPORTION OF CURRENT COSTS= ";I
30310 A4 = A4 * ID
30320  GOSUB 35000
30330 A4 = A4 / ID
30340  GOTO 1840
30350  INPUT "WHAT IS ESTAB.COSTS,AS PROPORTION OF CURRENT COSTS= ";IE
30360 A1 = A1 * IE
30370  GOSUB 35000
30380 A1 = A1 / IE
30390  GOTO 1840
30400  INPUT "WHAT IS ANN.MGT.COSTS,AS PROPORTION OF CURRENT RATE= ";IG
30410 A2 = A2 * IG
30420  GOSUB 35000
30430 A2 = A2 / IG
30440  GOTO 1840
30450  INPUT "WHAT IS DISCOUNT RATE,AS PROPORTION OF CURRENT RATE=";IH
30460 A7 = A7 * IH
30470  GOSUB 35000
30480 A7 = A7 / IH
30490  GOTO 1840
35000  GOSUB 17000: GOSUB 19000: GOSUB 22000: GOSUB 23000: GOSUB 40000
35010  FOR K = 1 TO I - 1
35020 W(K) = 0
35030  NEXT K
35040 W(I) = 0
35050 R = 0:W1 = 0:W2 = 0
36000  RETURN
40000  PRINT "REGIME NPW AT "A7"% =";W1 + W2
```

```
40010  PRINT "REGIME INTERNAL RETURN= ";R * 100"%"
40020  RETURN
45000  REM  NORMAL GROWTH AND YIELD IN FULLY STOCKED STAND.
45005 N(I) = 0
45020 N(I) = (41182.5219 - 5014.8230 * S + 181.5377 * S ^ 2) * AF(I) ^ (.3574 -
.0428 * S): PRINT "STEMS=";N(I)
45030  RETURN
```

APPENDIX 4. A SAMPLE PROGRAM RUN

```
]RUN

STAND 1
REGIME 1

ENTER PRESENT BASAL AREA      ,M2/HA 20
IS 20 THE VALUE OF BASAL AREA YOU WANTED?
Y/NY
ENTER PRESENT STAND AGE     ,YEARS20
IS 20 THE VALUE OF AGE YOU WANTED?
Y/N Y
ENTER SITE INDEX     ,M AT AGE 50 16
IS 16 THE VALUE OF SITE INDEX YOU WANTED?
Y/N Y
ENTER NUMBER OF STEMS/HA,         2750
IS 2750 THE NUMBER OF STEMS/HA YOU WANTED?
Y/N Y
ENTER ESTAB.COSTS,    ,$/HA          200
IS 200 THE ESTAB.COSTS YOU WANTED?
Y/N Y
ENTER ANNUAL MANAGEMENT COSTS     ,$/HA 20
IS 20 THE MANAG. COSTS YOU WANTED?
Y/N Y
ENTER THINNING COSTS,     ,$/M3      10
IS 10 THE THINNING COSTS YOU WANTED?
Y/N Y
ENTER CLEARCUTTING COSTS,$/M^3      10
IS 10 THE CLEARCUT COST YOU WANTED?
Y/N Y
ENTER SAWLOG PRICE,$/M^3            34.50
IS 34.5 THE SAWLOG PRICE YOU WANTED?
Y/N Y
ENTER PULPWOOD PRICE,$/M^3          21.75
IS 21.75 THE PULPWOOD PRICE YOU WANTED?
Y/N Y
ENTER DISCOUNT RATE, IN PER CENT   4
IS 4 THE DISCOUNT RATE YOU WANTED?
Y/N Y
1 = THINNING OPTION
2 = NON-THINNING OPTION
WHICH OPTION DO YOU WISH TO ANALYSE?1
REPORT OF STAND CONDITION

STAND AGE,YRS=                        20
BASAL AREA,M^2/HA=                    20
BASAL AREA=20
DBH= 9.6228516
HEIGHT= 6.64719616
NUMBER OF STEMS/HA=                   2750
TOTAL VOLUME,M^3/HA=                  57.0791916
MERCH. VOLUME,M^3/HA=                 21.2997396
SAWLOG VOLUME,M^3/HA=                 1.76067837
PULPWOOD VOLUME,M^3/HA=               19.54
PER CENT MERCH. VOLUME=               37.31612
PER CENT SAWLOG VOLUME=               8.26609565
PER CENT PULPWOOD VOLUME=             91.7339044

DO YOU WANT TO CLEARCUT STAND? Y/N N
DO YOU WANT TO THIN STAND? Y/N Y
ENTER PER CENT OF BASAL AREA THIN 0
BF(1)=20
```

```
H(1)=6.64719616
BF(2)=0
H(2)=0
W2=0
K= 2
ENTER NEW FUTURE STAND AGE 25
REPORT OF STAND CONDITION

STAND AGE,YRS=                        25
BASAL AREA,M^2/HA=                    30.5823043
BASAL AREA=30.5823043
DBH= 11.8993679
HEIGHT= 8.257496
NUMBER OF STEMS/HA=                   2750
TOTAL VOLUME,M^3/HA=                  113.82433
MERCH. VOLUME,M^3/HA=                 51.1118497
SAWLOG VOLUME,M^3/HA=                 8.98148578
PULPWOOD VOLUME,M^3/HA=               42.13
PER CENT MERCH. VOLUME=               44.9041517
PER CENT SAWLOG VOLUME=               17.5728542
PER CENT PULPWOOD VOLUME=             82.4271458

DO YOU WANT TO CLEARCUT STAND? Y/N N
DO YOU WANT TO THIN STAND? Y/N Y
ENTER PER CENT OF BASAL AREA THIN 25
BF(1)=20
H(1)=6.64719616
BF(2)=30.5823043
H(2)=8.257496
BF(3)=0
H(3)=0
W2=56.4213182
K= 3
ENTER NEW FUTURE STAND AGE 30
REPORT OF STAND CONDITION

STAND AGE,YRS=                        30
BASAL AREA,M^2/HA=                    31.5139001
BASAL AREA=31.5139001
DBH= 13.9479132
HEIGHT= 9.84719617
NUMBER OF STEMS/HA=                   2062.5
TOTAL VOLUME,M^3/HA=                  141.245827
MERCH. VOLUME,M^3/HA=                 73.1814787
SAWLOG VOLUME,M^3/HA=                 19.7692104
PULPWOOD VOLUME,M^3/HA=               53.41
PER CENT MERCH. VOLUME=               51.811427
PER CENT SAWLOG VOLUME=               27.014499
PER CENT PULPWOOD VOLUME=             72.9855011

DO YOU WANT TO CLEARCUT STAND? Y/N N
DO YOU WANT TO THIN STAND? Y/N Y
ENTER PER CENT OF BASAL AREA THIN 25
BF(1)=20
H(1)=6.64719616
BF(2)=30.5823043
H(2)=8.257496
BF(3)=31.5139001
H(3)=9.84719617
BF(4)=0
H(4)=0
W2=131.1832
K= 4
ENTER NEW FUTURE STAND AGE 35
REPORT OF STAND CONDITION
```

```
STAND AGE,YRS=                          35
BASAL AREA,M^2/HA=                      31.1458811
BASAL AREA=31.1458811
DBH= 16.0113458
HEIGHT= 11.4162966
NUMBER OF STEMS/HA=                     1546.875
TOTAL VOLUME,M^3/HA=                    162.715558
MERCH. VOLUME,M^3/HA=                   94.5904376
SAWLOG VOLUME,M^3/HA=                   35.6240366
PULPWOOD VOLUME,M^3/HA=                 58.97
PER CENT MERCH. VOLUME=                 58.1323867
PER CENT SAWLOG VOLUME=                 37.6615251
PER CENT PULPWOOD VOLUME=               62.3384749

DO YOU WANT TO CLEARCUT STAND? Y/N N
DO YOU WANT TO THIN STAND? Y/N Y
ENTER PER CENT OF BASAL AREA THIN 25
BF(1)=20
H(1)=6.64719616
BF(2)=30.5823043
H(2)=8.257496
BF(3)=31.5139001
H(3)=9.84719617
BF(4)=31.1458811
H(4)=11.4162966
BF(5)=0
H(5)=0
W2=219.39269
K= 5
ENTER NEW FUTURE STAND AGE 40
REPORT OF STAND CONDITION

STAND AGE,YRS=                          40
BASAL AREA,M^2/HA=                      30.1636634
BASAL AREA=30.1636634
DBH= 18.1944503
HEIGHT= 12.9647974
NUMBER OF STEMS/HA=                     1160.15625
TOTAL VOLUME,M^3/HA=                    179.558015
MERCH. VOLUME,M^3/HA=                   114.771686
SAWLOG VOLUME,M^3/HA=                   56.9630184
PULPWOOD VOLUME,M^3/HA=                 57.81
PER CENT MERCH. VOLUME=                 63.9189992
PER CENT SAWLOG VOLUME=                 49.6323241
PER CENT PULPWOOD VOLUME=               50.3676759

DO YOU WANT TO CLEARCUT STAND? Y/N N
DO YOU WANT TO THIN STAND? Y/N Y
ENTER PER CENT OF BASAL AREA THIN 25
BF(1)=20
H(1)=6.64719616
BF(2)=30.5823043
H(2)=8.257496
BF(3)=31.5139001
H(3)=9.84719617
BF(4)=31.1458811
H(4)=11.4162966
BF(5)=30.1636634
H(5)=12.9647974
BF(6)=0
H(6)=0
W2=316.630348
K= 6
ENTER NEW FUTURE STAND AGE 50
REPORT OF STAND CONDITION
```

STAND AGE,YRS= 50
BASAL AREA,M^2/HA= 33.3725317
BASAL AREA=33.3725317
DBH= 22.0984005
HEIGHT= 16
NUMBER OF STEMS/HA= 870.117188
TOTAL VOLUME,M^3/HA= 247.361561
MERCH. VOLUME,M^3/HA= 182.346389
SAWLOG VOLUME,M^3/HA= 128.610806
PULPWOOD VOLUME,M^3/HA= 53.74
PER CENT MERCH. VOLUME= 73.716542
PER CENT SAWLOG VOLUME= 70.5296443
PER CENT PULPWOOD VOLUME= 29.4703558

DO YOU WANT TO CLEARCUT STAND? Y/N Y
BASAL AREA=33.3725317
DBH= 22.0984005
HEIGHT= 16
W1= -97.4
I=6
REPORT OF PHYSICAL AND ECONOMIC RETURNS FROM REGIME 1

1. STAND VOLUME DEVELOPMENT OVER TIME

| A | G.V | G.M | G.S | G.P | T.V |
|---|---|---|---|---|---|
| 20 | 57.08 | 21.3 | 1.76 | 19.54 | 0 |
| 21 | 68.92 | 26.83 | 2.96 | 23.87 | |
| 22 | 80.39 | 32.55 | 4.29 | 28.26 | |
| 23 | 91.64 | 38.49 | 5.74 | 32.75 | |
| 24 | 102.77 | 44.68 | 7.31 | 37.37 | |
| 25 | 89.87 | 40.36 | 7.09 | 33.27 | 23.95 |
| 26 | 95.7 | 44.37 | 8.92 | 35.45 | |
| 27 | 107.29 | 51.27 | 11.39 | 39.88 | |
| 28 | 118.7 | 58.36 | 14.02 | 44.34 | |
| 29 | 130.01 | 65.66 | 16.82 | 48.84 | |
| 30 | 110.44 | 57.22 | 15.46 | 41.76 | 30.81 |
| 31 | 116.47 | 61.91 | 18.4 | 43.51 | |
| 32 | 128.26 | 69.84 | 22.4 | 47.44 | |
| 33 | 139.86 | 77.92 | 26.6 | 51.32 | |
| 34 | 151.34 | 86.17 | 31.01 | 55.16 | |
| 35 | 126.54 | 73.56 | 27.7 | 45.86 | 36.18 |
| 36 | 132.79 | 78.83 | 32.05 | 46.78 | |
| 37 | 144.77 | 87.67 | 37.95 | 49.72 | |
| 38 | 156.53 | 96.6 | 44.07 | 52.53 | |
| 39 | 168.11 | 105.62 | 50.4 | 55.22 | |
| 40 | 139.17 | 88.95 | 44.14 | 44.81 | 40.39 |
| 41 | 145.58 | 94.7 | 50.06 | 44.64 | |
| 42 | 157.67 | 104.29 | 58.09 | 46.2 | |
| 43 | 169.49 | 113.89 | 66.3 | 47.59 | |
| 44 | 181.09 | 123.54 | 74.71 | 48.83 | |
| 45 | 192.5 | 133.22 | 83.3 | 49.92 | |
| 46 | 203.74 | 142.96 | 92.06 | 50.9 | |
| 47 | 214.84 | 152.74 | 100.98 | 51.76 | |
| 48 | 225.8 | 162.57 | 110.05 | 52.52 | |
| 49 | 236.64 | 172.44 | 119.27 | 53.17 | |
| 50 | 247.36 | 182.35 | 128.61 | 53.74 | |

A=STAND AGE
G.V=GROWING STOCK
G.M=MERCH.VOL.OF GROWING STOCK
G.S=SAWLOG VOLUME OF GROWING STOCK
G.P=PULPWOOD VOLUME OF GROWING STOCK
T.V.=THINNED VOLUME

2. PHYSICAL RETURNS FROM A THINNING REGIME

| AGE | T.V. | C.C.V. |
|---|---|---|
| 20 | 0 | 0 |
| 25 | 23.95 | 0 |
| 30 | 30.81 | 0 |
| 35 | 36.18 | 0 |
| 40 | 40.39 | 0 |
| 50 | 0 | 247.36 |

T.V.=THINNED VOLUME
C.C.V.=CLEARCUT VOLUME
ROTATION AGE= 50
TOTAL REGIME VOLUME,M^3/HA= 378.69
TOTAL REGIME MERCH.VOL.,M^3/HA= 255.91
AVERAGE STAND PRODUCTIVITY,M^3/HA/YR= 7.5738
TOTAL REGIME SAWLOG VOL.,M^3/HA= 155.55
PULPWOOD VOL.,M^3/HA= 100.36

3. ECONOMIC RETURNS FROM THE REGIME

| AGE | D.C. | D.R. |
|---|---|---|
| 0 | 200 | 0 |
| 20 | 0 | 0 |
| 25 | 40.33 | 96.75 |
| 30 | 49.21 | 123.97 |
| 35 | 53.29 | 141.5 |
| 40 | 53.78 | 151.02 |
| 50 | 686.22 | 788.82 |

D.C.=DISCOUNTED COSTS
D.R.=DISCOUNTED REVENUE

REGIME'S NPW (EXCLUDING LAND VALUE), $/HA= 219.230348
REGIME'S INTERNAL RATE OF RETURN (IRR)= 4.99999999%

ASSUMPTIONS MADE ON THE COSTS AND REVENUE ARE AS FOLLOW:

SAWLOG PRICE,$/M^3= 34.5
PULPWOOD PRICE,$/M^3= 21.75

INITIAL ESTAB. COSTS,$/HA= 200
THINNING COSTS,$/M^3= 10
CLEACUTTING COSTS,$/M^3= 10
ANNUAL MANAGEMENT COSTS,$/HA= 20

DO YOU WANT TO ANALYSE 'WHAT IF' OPTIONS? Y/N Y
1 =SAWLOG VOL
2 =SAWLOG PRICE
3 =THIN COSTS
4 =CLEARCUT COSTS
5 =ESTAB.COSTS
6 =ANN. MGMT. COSTS
7 =DISC. RATE
WHICH ONE DO YOU WANT TO ANALYSE? 1/2/3/4/5/6/7 1
WHAT IS SAWLOG VOLUME,AS PROPORTION OF CURRENT SAWLOG VOL.
=.8
W1= -222.27
I=6
W2=326.608725
K= 6
REGIME NPW AT 4% =104.338725
REGIME INTERNAL RETURN= 4.54999999%
DO YOU WANT TO ANALYSE 'WHAT IF' OPTIONS? Y/N Y
1 =SAWLOG VOL
2 =SAWLOG PRICE

```
3 =THIN COSTS
4 =CLEARCUT COSTS
5 =ESTAB.COSTS
6 =ANN. MGMT.          COSTS
7 =DISC. RATE
WHICH ONE DO YOU WANT TO ANALYSE? 1/2/3/4/5/6/7 1
WHAT IS SAWLOG VOLUME,AS PROPORTION OF CURRENT SAWLOG VOL.
  =1.2
W1= 27.4700002
I=6
W2=306.65197
K= 6
REGIME NPW AT 4% =334.12197
REGIME INTERNAL RETURN= 5.34999999%
DO YOU WANT TO ANALYSE 'WHAT IF' OPTIONS? Y/N Y
1 =SAWLOG VOL
2 =SAWLOG PRICE
3 =THIN COSTS
4 =CLEARCUT COSTS
5 =ESTAB.COSTS
6 =ANN. MGMT.          COSTS
7 =DISC. RATE
WHICH ONE DO YOU WANT TO ANALYSE? 1/2/3/4/5/6/7 3
WHAT IS THINNING COST,AS PROPORTION OF CURRENT COST=1.5
W1= -97.4
I=6
W2=218.327237
K= 6
REGIME NPW AT 4% =120.927237
REGIME INTERNAL RETURN= 4.54999999%
DO YOU WANT TO ANALYSE 'WHAT IF' OPTIONS? Y/N Y
1 =SAWLOG VOL
2 =SAWLOG PRICE
3 =THIN COSTS
4 =CLEARCUT COSTS
5 =ESTAB.COSTS
6 =ANN. MGMT.          COSTS
7 =DISC. RATE
WHICH ONE DO YOU WANT TO ANALYSE? 1/2/3/4/5/6/7 5
WHAT IS ESTAB.COSTS,AS PROPORTION OF CURRENT COSTS= 2
W1= -297.4
I=6
W2=316.630348
K= 6
REGIME NPW AT 4% =19.2303475
REGIME INTERNAL RETURN= 4.1%
DO YOU WANT TO ANALYSE 'WHAT IF' OPTIONS? Y/N Y
1 =SAWLOG VOL
2 =SAWLOG PRICE
3 =THIN COSTS
4 =CLEARCUT COSTS
5 =ESTAB.COSTS
6 =ANN. MGMT.          COSTS
7 =DISC. RATE
WHICH ONE DO YOU WANT TO ANALYSE? 1/2/3/4/5/6/7 5
WHAT IS ESTAB.COSTS,AS PROPORTION OF CURRENT COSTS= 2.5
W1= -397.4
I=6
W2=316.630348
K= 6
REGIME NPW AT 4% =-80.7696525
REGIME INTERNAL RETURN= 3.75%
DO YOU WANT TO ANALYSE 'WHAT IF' OPTIONS? Y/N Y
1 =SAWLOG VOL
2 =SAWLOG PRICE
3 =THIN COSTS
```

```
4 =CLEARCUT COSTS
5 =ESTAB.COSTS
6 =ANN. MGMT.          COSTS
7 =DISC. RATE
WHICH ONE DO YOU WANT TO ANALYSE? 1/2/3/4/5/6/7 7
WHAT IS DISCOUNT RATE,AS PROPORTION OF CURRENT RATE=.5
W1= 576.81
I=6
W2=611.025278
K= 6
REGIME NPW AT 2% =1187.83528
REGIME INTERNAL RETURN= 4.99999999%
DO YOU WANT TO ANALYSE 'WHAT IF' OPTIONS? Y/N Y
1 =SAWLOG VOL
2 =SAWLOG PRICE
3 =THIN COSTS
4 =CLEARCUT COSTS
5 =ESTAB.COSTS
6 =ANN. MGMT.          COSTS
7 =DISC. RATE
WHICH ONE DO YOU WANT TO ANALYSE? 1/2/3/4/5/6/7 7
WHAT IS DISCOUNT RATE,AS PROPORTION OF CURRENT RATE=1.5
W1= -309.89
I=6
W2=167.938536
K= 6
REGIME NPW AT 6% =-141.951464
REGIME INTERNAL RETURN= 4.99999999%
DO YOU WANT TO ANALYSE 'WHAT IF' OPTIONS? Y/N N
MORE REGIMES? Y/N N

MORE STANDS? Y/N N

PROGRAM STOPS
```

# APPENDIX 5

NORMAL YIELDS FOR UNTHINNED RED PINE PLANTATIONS (AS ADAPTED FROM BECKWITH et al. 1983).

| AGE (years) | | SITE INDEX (m at age 50) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 16 | 18 | 20 | 22 | 24 | 26 |
| 20 | stems/ha | 2776 | 2817 | 3023 | 3243 | 3402 | 3474 |
| | ba($m^2$/ha ) | 18.9 | 24.6 | 28.2 | 33.0 | 37.6 | 40.3 |
| | mean dbhob (cm) | 9.3 | 10.5 | 10.9 | 11.4 | 11.9 | 12.2 |
| | vol($m^3$/ha) | 54 | 81 | 105 | 137 | 172 | 202 |
| | dom.height (m) | 7 | 7 | 8 | 9 | 10 | 11 |
| 25 | stems/ha | 2580 | 2569 | 2704 | 2846 | 2929 | 2934 |
| | ba($m^2$/ha | 29.3 | 33.1 | 35.8 | 39.7 | 43.5 | 46.1 |
| | mean dbh | 12.0 | 12.8 | 13.0 | 13.3 | 13.8 | 14.1 |
| | vol($m^3$/ha) | 109 | 140 | 169 | 208 | 250 | 288 |
| | dom.height | 8 | 9 | 10 | 11 | 12 | 13 |
| 30 | stems/ha | 2430 | 2382 | 2469 | 2558 | 2592 | 2556 |
| | ba($m^2$/ha) | 36.0 | 39.1 | 41.3 | 44.6 | 48.0 | 50.3 |
| | mean dbh | 13.7 | 14.5 | 14.6 | 14.9 | 15.4 | 15.8 |
| | vol($m^3$/ha) | 162 | 200 | 235 | 281 | 330 | 376 |
| | dom.height | 10 | 11 | 12 | 14 | 15 | 16 |
| 35 | stems/ha | 2310 | 2235 | 2286 | 2337 | 2337 | 2275 |
| | ba($m^2$/ha ) | 41.0 | 43.7 | 45.6 | 48.5 | 51.5 | 53.6 |
| | mean dbhob | 15.0 | 15.8 | 15.9 | 16.3 | 16.8 | 17.3 |
| | vol($m^3$/ha) | 216 | 260 | 303 | 355 | 412 | 466 |
| | dom.height | 11 | 13 | 14 | 16 | 17 | 19 |
| 40 | stems/ha | 2211 | 2115 | 2138 | 2161 | 2137 | 2056 |
| | ba($m^2$/ha ) | 45.0 | 47.3 | 48.9 | 51.6 | 54.3 | 56.1 |
| | mean dbh | 16.1 | 16.9 | 17.1 | 17.4 | 18.0 | 18.6 |
| | vol($m^3$/ha) | 271 | 321 | 370 | 430 | 495 | 555 |
| | dom.height | 13 | 15 | 16 | 18 | 19 | 21 |
| 45 | stems/ha | 2127 | 2014 | 2016 | 2017 | 1975 | 1881 |
| | ba($m^2$/ha) | 48.2 | 50.2 | 51.6 | 54.0 | 56.4 | 58.1 |
| | mean dbhob | 17.0 | 17.8 | 18.1 | 17.4 | 18.5 | 19.1 |
| | vol($m^3$/ha) | 326 | 382 | 438 | 504 | 576 | 643 |
| | dom.height | 14 | 16 | 18 | 20 | 22 | 24 |
| 50 | stems/ha | 2055 | 1928 | 1913 | 1897 | 1840 | 1737 |
| | ba($m^2$/ha) | 50.8 | 52.6 | 53.7 | 55.8 | 58.0 | 59.5 |
| | mean dbh | 17.8 | 18.6 | 18.9 | 19.4 | 20.0 | 20.9 |
| | vol($m^3$/ha) | 380 | 443 | 504 | 577 | 655 | 728 |
| | dom.height | 16 | 18 | 20 | 22 | 24 | 26 |
| 55 | stems/ha | 1992 | 1854 | 1824 | 1794 | 1726 | 1616 |
| | ba($m^2$/ha ) | 53.0 | 54.4 | 55.3 | 57.1 | 59.1 | 60.3 |
| | mean dbh | 18.4 | 19.3 | 19.7 | 20.1 | 20.9 | 21.8 |
| | vol($m^3$/ha) | 433 | 502 | 568 | 646 | 730 | 808 |
| | dom.height | 17 | 20 | 22 | 24 | 26 | 28 |

APPENDIX 6. THE HOGARTH PLANTATIONS IN THE THUNDER BAY DISTRICT